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1973

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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TABLE OF CONTENTS

PERSONNEL

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J. G. Brooks, Physical Science Aid
D. A. Bucks, Agricultural Engineer
K. R. Cooley, Hydrologist
A. R. Dedrick, Agricultural Engineer (transferred to Phoenix, June)
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K. G. Mullins, Physical Science Technician (transferred January)
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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, transferred April)

J. B. Robinson, Soil Microbiologist (visiting scientist, departed March)
M. A. Seiler, Clerk-Stenographer
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W. R. Williamson, Hydrologic Technician (transferred to Phoenix, June)
M. F. Witcher, Clerk-Stenographer (transferred March)

TITLE: EVAPORATION OF WATER FROM SOIL

CRIS WORK UNIT: 5402-12260-002 CODE NO.: Ariz.-WCL-68-1

The objective and need for the research reported under this research outline appeared in the USWCL 1969 Annual Report. 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 manuscripts were prepared concerning soil-water flux patterns as a function of time and depth, and movement and accumulation of salt under diurnal evaporating conditions.

In 1973, four experiments were conducted. These experiments were designed to obtain data for a particular day after irrigation during which the most rapid drying of the soil surface occurred. Analysis of the 1971 data had indicated that the albedo (the ratio of reflected to incoming solar radiation) increased dramatically a few days after irrigation, and this albedo increase was correlated with the rapid drying of the surface few millimeters of soil.

The experiments were of basically the same design as the 1970 and 1971 experiments with the exception that soil-water contents, soil temperatures, evaporation, and meteorological parameters were obtained at twenty-minute intervals, and the water-content sample depth increments were changed to 0-0.2, 0-0.5, 1-2, 2-4, 4-6, 6-8, 8-10 cm. All soil samples were saved for future salt content analysis.

During 1973 analysis was completed on several aspects of the evaporation process. These were the comparison of calculated and measured soil-water fluxes, the calculation of soil heat flux, and the analysis of salt flux. In addition analysis was completed on the diurnal and seasonal aspects of water use by a bermudagrass lawn.

PART I. DIURNAL SOIL-WATER EVAPORATION: COMPARISON OF MEASURED AND CALCULATED SOIL-WATER FLUXES

A theory developed by Philip and DeVries has been used as a basis for predicting the movement of water in soil due to both water content and temperature gradients. The theory has been largely used in laboratory situations and has not been adequately tested under natural field conditions. A manuscript, abstracted below, has been prepared on this topic.

The theory of Philip and DeVries was used to predict soil water fluxes occurring near the soil surface under diurnal field conditions. The predicted values were compared with values obtained by measurements of soil-water content, soil temperature, and evaporation. Previously measured soil-water diffusivities and water vapor diffusivities were used in the theoretical calculations. The thermal vapor diffusivities were calculated using both the "simple" theory and the "complete" theory of Philip and DeVries. Comparison of measured and calculated fluxes indicated that the theory best predicts the measured values at intermediate water contents and that the "isothermal" theory is a better predictor at high and very low water contents.

PERSONNEL: R. D. Jackson

PART II. DIURNAL SOIL-WATER EVAPORATION: ESTIMATION OF LIQUID AND VAPOR PHASE FLUXES FROM CHLORIDE CONTENT MEASUREMENTS

Chloride fluxes for a bare soil undergoing drying were used to estimate the relative magnitudes of liquid and vapor water fluxes near the soil surface. The total water flux was obtained from soil water content and lysimetric measurements, and the chloride flux from chloride content in the same mass of soil. Both water and chloride fluxes were determined at various depths and times. The liquid water flux was calculated by assuming that the chloride moved only in the liquid phase. The vapor flux was taken as the difference between the total and liquid water fluxes. Reasonable estimates of the liquid flux were obtained when factors that affect the chloride distribution in the liquid phase in contact with the soil, such as anion exclusion, were included in the flux model.

PERSONNEL: F. S. Nakayama

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

A new technique for computing soil heat flux was developed which is based on measurements of only temperature and moisture content of the upper 20 cm of soil. The technique, named the null alignment method, is described in detail in a manuscript in preparation entitled "Soil Heat Flux Determination: A Null Alignment Method." Calorimetry is used to calculate an initial estimate of the soil heat flux utilizing an initial guess for the thermal conductivity at 20 cm. Then the temperature profiles for those times when zero temperature gradients exist in the upper 20 cm are used to force a "null alignment" of zero soil heat flux with zero temperature gradient by correcting the thermal conductivity at 20 cm. Then the corrected thermal conductivity at 20 cm is used to recalculate the soil heat flux for all time periods during the day. Soil heat fluxes computed with the null alignment technique for several days' data were very comparable to those measured by heat flux plates.

During the several soil drying experiments conducted during 1973, soil temperatures were measured every 20 min at depths of 0.1, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, - - - , 95, 10, 12, 14, - - - 30, 32, 48, 64, 96, and 128 cm. Concurrent gravimetric moisture samples were obtained at 0-.2, 0-.5, 0-1, 1-2, 2-4, 4-6, 6-8, 8-10 cm every 20 min and from 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm every four hours. From these data soil heat fluxes were determined using the null alignment method.

These soil heat fluxes, determined or measured using the null alignment method, are being used to test the theory of DeVries (1958, 1963) which seeks to predict the thermal conductivity and heat flux of a soil from the bulk density, quartz fraction of minerals, organic matter content, moisture content, moisture gradient, temperature, and temperature gradient. The details of this comparison test are described in more detail in the manuscript, "Diurnal soil-water evaporation: comparison of measured and calculated soil-heat flux," which is being prepared. The preliminary conclusions are that the calculated and measured values agree well at night. However, during the daytime hours the calculated heat flux was considerably less negative than measured for depths shallower than about 3 cm, although there was fair agreement below this depth.

PERSONNEL: B. A. Kimball

PART IV. DIURNAL AND SEASONAL SOIL WATER UPTAKE AND FLUX WITHIN A BERMUDAGRASS ROOT ZONE

Diurnal water movement within a bermudagrass root zone and the uptake of water by the roots was studied in a field plot. Details of the experiment are outlined in Annual Reports 1967 and 1968. A fast response tensiometer-pressure-transducer system was used to measure the hydraulic heads. The relations of pressure head to water content and to hydraulic conductivity were determined in situ. Diurnal water content and soil water flux profiles were derived using the established hydraulic properties. The fast response tensiometer system enabled the calculation of flux and water content changes over 2-hour intervals. Rewetting of drier soil from wetter regions below occurred regularly in the late afternoon. Diurnal water extraction rates, which were calculated for different depths and times during the growing season, yielded evapotranspiration rates that agreed favorably with rates measured on similar days in previous years using a lysimeter.

PERSONNEL: R. C. Rice

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

CRIS WORK UNIT: 5402-12260-002 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.

PROCEDURE:

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

RESULTS AND DISCUSSION:

Several plant species were tested, many of them in two separate experiments, to determine if the results could be duplicated. Since the numerous data are not fully analyzed, the results for only one species will serve as an example: black-eyed pea (<u>Vigna sinensis</u>).

<u>Data for 19 June 1973</u>. The plant was irrigated to "pot capacity," a value at which the soil matric potential (ψ_M) is -0.04 bar, and then was exposed to gradually increasing illumination (artificial "sunrise") over a 75-minute period by use of a programmer capable of repeating the same sequence on demand. This sunrise, although not as prolonged as in nature, nevertheless permits water absorption to be reasonably in balance with water loss and thus prevents the shock that might occur with the instant illumination common in many growth chambers.

All the lamps were on by 1240, which coincided with the attainment of the maximal transpiration rate of 225 g m^{-2} h^{-1}, a value which was maintained at essentially this high level for five half-hour periods (Figure 1). Not until three hours after the peak rate did transpiration decrease significantly, and then by only 13%. This kind of response attests to the constancy of the controlled environment in the transpiration-photosynthesis chamber.

It is noteworthy that the peak rate of photosynthesis was not attained until 1310, one-half hour after the maximum for transpiration. This delay cannot be attributed to insufficient stomatal opening, because, for all periods except the first half hour, leaf resistance (R_L) was low enough to indicate essentially complete stomatal opening, i.e., values less than 2 sec cm^{-1}. This disparity in time of peak rates of transpiration and photosynthesis implies the existence of a nonstomatal resistance to photosynthesis.

The measurements taken in the chamber permit the calculation of such a resistance, the so-called "mesophyll" resistance (R_M'). While R_L did not vary beyond a narrow range, 1.3 to 1.7 sec cm^{-1} for five half-hour periods, R_M' decreased from 21.0 sec cm^{-1} to 10.4 sec cm^{-1}, while the photosynthetic rate ranged from 9.2 to 15.5 mg dm^{-2} h^{-1}, respectively. Therefore, it appears that, at a given low value of R_L, R_M' was governing photosynthesis.

Leaf thickness, obtained by beta ray gauging, is a nondestructive method of monitoring changes in leaf water content. The data in Figure 1 show that leaf thickness did not decrease significantly, thus implying that the rate of water absorption was in balance with the transpiration rate. The lack of dehydration was confirmed by the values of relative leaf water content (RLWC), a measurement relating the actual leaf water content at a given time (obtained from the leaf thickness measurements) to the water content at full hydration (obtained by keeping the fully irrigated plant overnight in a tent where there was saturation vapor pressure). The RLWC decreased insignificantly during the first day, from 95.0% at the beginning of the test to 94.3% at 1310, then rising to 95.9% at 1540.

The time of maximum WUE, i.e., lowest TR, was 1310, when the TR was 100. Since beyond that time the rate of photosynthesis decreased somewhat more than transpiration, the TR rose slightly.

Data for 20 June 1973. A striking feature of the transpiration data is that the water loss at the time when the "sunrise" was finished agreed exactly with the loss rate at the end of the previous day, 195 g m^{-2} h^{-1}, at 0930 (Figure 2). Also in agreement were the R_L readings corresponding to this transpiration rate, 1.9 sec cm^{-1}, again being indicative of only a slight stomatal closure. However, beyond 0930 transpiration began to decrease steadily as R_L values gradually increased, the latter reaching 16.5 sec cm^{-1} at 1500, just before irrigation. Irrigation caused a drop in R_L to 10.5 sec cm^{-1} in the next half hour; then the lights were turned off.

At 1500 the transpiration rate had fallen to only 44.6 g m^{-2} h^{-1}, an 80% decrease from the peak rate on the previous day. At this time photosynthesis had fallen to 2.5 mg dm^{-2} h^{-1}, an 84% decrease from the peak rate on the previous day. On 20 June the photosynthetic rate reached its peak at 0900, one-half hour earlier than the time at which the maximum transpiration rate was attained. The decline in rate also started one-half hour earlier for photosynthesis than for transpiration. Again it appears that R_M' was strongly implicated in this decline, since the rise in R_L' from 1900 to 0930 was only from 2.6 sec cm^{-1} to 3.0 sec cm^{-1}, whereas the corresponding rise in R_M' was from 13.2 to 16.9 sec cm^{-1}. Beyond 0930 both R_L' and R_M' rose steadily, so that both resistances undoubtedly were effective in limiting photosynthesis.

Leaf thickness initially was 17.33 mg cm^{-2}, a value actually higher than that at the end of the previous day, possibly due to a small amount of leaf growth overnight. However, after full illumination occurred, at 0930, leaf thickness decreased steadily, reaching a minimum of 15.94 mg cm^{-2} at 1330. The corresponding RLWC values for the ranges of leaf thicknesses was from 99.5% to 90.6%, showing that progressive dehydration occurred due to the continued transpiration. The slight recovery which took place even before irrigation may not be significant. Irrigation back to the pot capacity brought about an immediate increase in leaf thickness; the corresponding rise in the RLWC was from 92.8 to 96.1% in a half hour.

Since both transpiration and photosynthesis were decreased similarly, the TR under drought was not greatly different from that when the plant had freely available water, i.e., about 110 instead of 100.

SUMMARY AND CONCLUSIONS:

On the basis of only one test it is tentatively concluded that black-eyed pea is not the kind of plant species that this research is seeking, in that its TR does not decrease under drought. This means that, although the amount of dry matter per unit of water transpired would not be significantly lower, the yield per acre would be considerably less. This statement assumes that short-term photosynthesis is directly related to the long-term accumulation of dry matter.

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

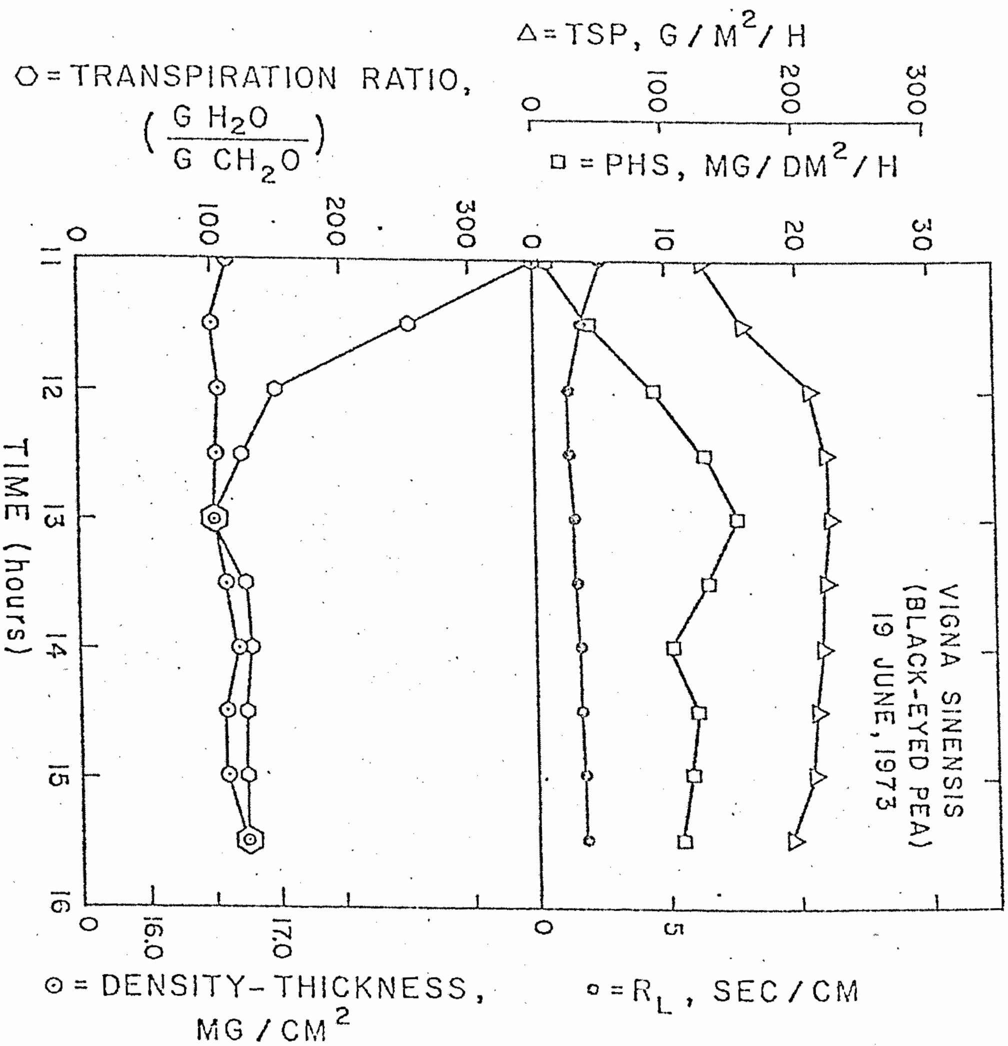


Figure 1. Hourly values of the rates of transpiration and photosynthesis, of leaf resistance (R_L), leaf density-thickness, and the transpiration ratio of a well-watered plant of <u>Vigna sinensis</u> in a controlled environment (19 June 1973).

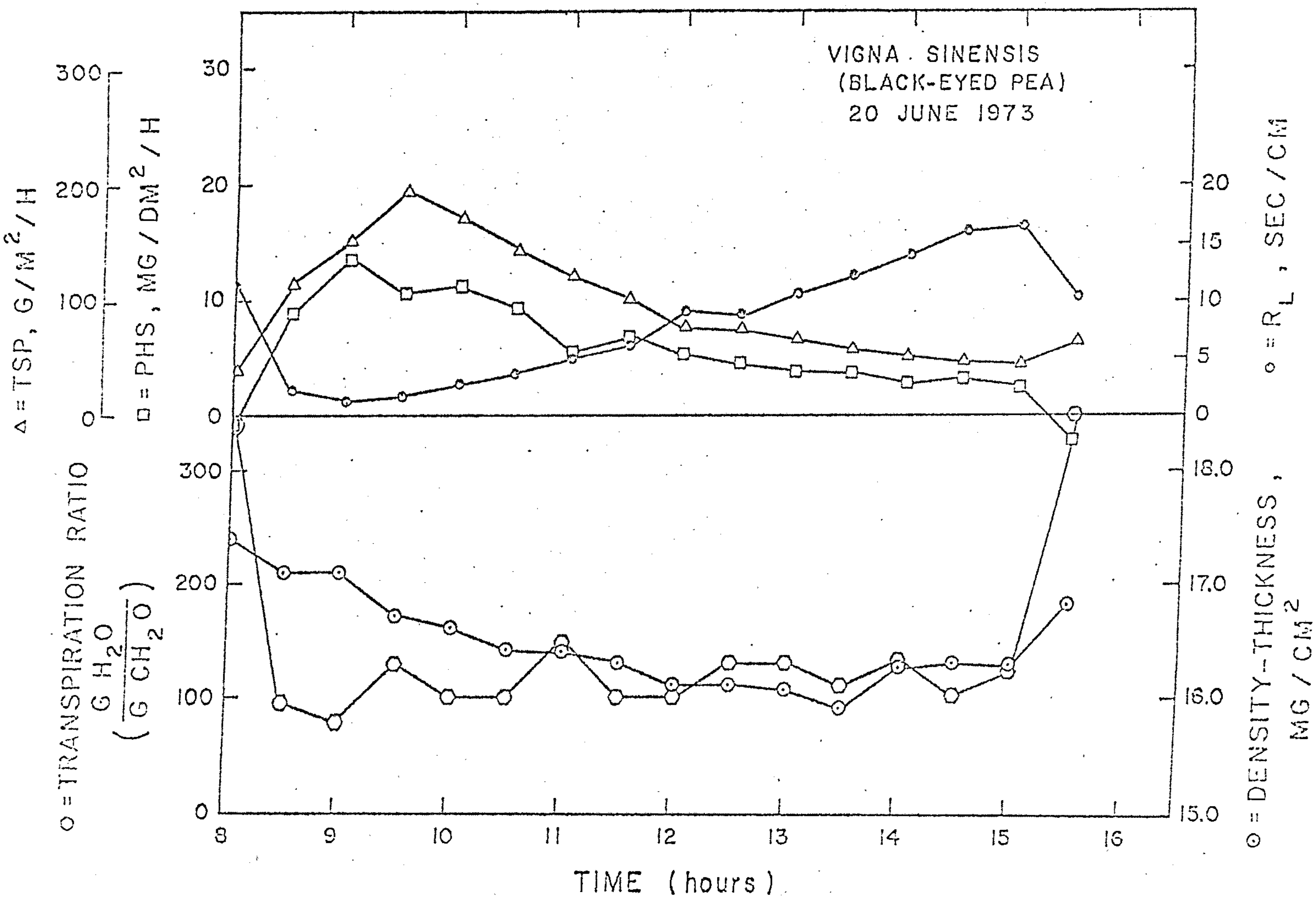


Figure 2. Hourly values of the rates of transpiration and photosynthesis, of leaf resistance, leaf density-thickness, and the transpiration ratio of a droughted plant of *Vigna sinensis* in a controlled environment (20 June 1973).

TITLE: HEAT AND LIGHT TRANSFER IN PONDS

CRIS WORK UNIT: 5402-12260-002 CODE NO.: Ariz.-WCL 71-3

Work under this outline was limited to one study developed from data acquired in the first year of the project's existance. It has been written up in manuscript form thusly:

Idso, S. B., and Foster, J. M. Light and temperature relations in a small desert pond as influenced by phytoplanktonic density variations. Water Resources Research. (In Press).

Measurements of incoming and reflected solar radiation, downwelling solar radiation in the water, and air temperature and water temperature at 4 different depths were recorded every half-hour over a 3-month period in a small man-made pond of reclaimed waste water at Phoenix, Arizona. At intervals of a few days, chlorophyll a and b values were also assayed to determine density variations in the pond's phytoplanktonic community. During this period, the extinction coefficient for solar radiation was found to be a linear function of both chlorophyll a and b concentrations, and the shape of the pond's midafternoon temperature profile was found to be highly correlated with this extinction coefficient. Water surface temperature increased during three distinct algal blooms to such a degree that the water-air vapor pressure difference increased by approximately 25% during the short periods of the blooms, indicating that phytoplanktonic density variations may exert a significant influence on evaporation.

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

TITLE: WATER VAPOR MOVEMENT THROUGH MULCHES UNDER FIELD CONDITIONS

CRIS WORK UNIT: 5402-12260-002 CODE NO.: Ariz.-WCL 71-5

The objective of this project has been accomplished, and it has recently been terminated. The results have been published in B. A. Kimball, "Water vapor movement through mulches under field conditions," Soil Science Society of America Proceedings 37(6): 813-818, 1973. Briefly, it was shown that under field conditions mass flow processes increase the loss of water vapor through granular mulches by 26% more than the loss due to molecular diffusion alone. This increase is significantly greater than has generally been presumed.

PERSONNEL: B. A. Kimball

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

CRIS WORK UNIT: 5402-12260-002 CODE NO.: Ariz.-WCL 71-11

INTRODUCTION:

The primary objectives and subsequent progress have been given in the 1971 and 1972 Annual Reports.

The modeling of solutions as a tool for predicting the precipitation of dissolved materials depends upon concepts of non-ideality of the chemical system. Two basic types of modeling used in general are (a) the ionic association model which assumes ionic interactions between cations and anions to form ion-pairs, and (b) the mean ionic activity model which does not account directly for ionic association. These two models were tested from exchange constant measurements of mixed salt-soil-water systems.

RESULTS AND DISCUSSION:

1. Sulfate Analysis. The development of a method for sulfate analysis in various types of waters using the nitrochromeazo indicator was completed (Rasnick and Nakayama, 2). The technique was shown to be rapid and still have the accuracy of the more time-consuming standard gravimetric procedures.

2. Solution Modeling. Similar exchange constant values were obtained for the soil-$NaCl$-$CaCl_2$ and the soil-Na_2SO_4-$CaSO_4$ mixtures where the interaction of cations and anions in solution were introduced to characterize the interactions of the exchange complex with the various ions in solution (Nakayama, 1). This finding supports the need for considering ion-pairing and further justifies the application of the ion-pair model for predicting the chemical composition of soil extracts, and irrigation and ground waters.

REFERENCES:

1. F. S. Nakayama. Evaluation of the sodium-calcium exchange constants in chloride- and sulfate-soil systems by the associated and non-associated models. Soil Sci. (in press) 1974.

2. B. A. Rasnick, and F. S. Nakayama. Nitrochromeazo titrimetric determination of sulfate in irrigation and other saline waters. Commun. in Soil Sci. and Plant Anal. 4(3):171-174. 1973.

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

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

CRIS WORK UNIT: 5402-12260-002 CODE NO.: Ariz.-WCL 72-4

Significant errors in measuring the bulk density and water content of soils can result from a procedure commonly used with gamma-ray transmission equipment. The detector probe can be exposed directly to the unattenuated gamma-ray source when moving from a standard absorber to the soil. Under this high-exposure condition, 20 to 30 minutes may be required before the system will stabilize and reliable count rates can be taken. To avoid this difficulty, it was found that under our conditions it was desirable to take a standard count rate in the soil pedon where the bulk density remained constant, thus eliminating the exposure of the detector to the unattenuated gamma-ray source.

Using this technique bulk density in a soil pedon was measured with a gamma-ray transmission technique utilizing ^{137}Cs and ^{241}Am. Both gamma-ray sources could not be used simultaneously for bulk density determinations in a system where the sources were uncollimated and the detector was not shielded. By alternating sources for each scan down the soil profile, it was shown that bulk density decreased in the top 6 cm of soil about 30 minutes after water was ponded on the soil surface. As soon as the water drained from the surface, bulk density values approached preirrigation levels. Changes in height of the soil surface upon irrigation corresponded with changes in bulk density.

Manuscripts cited below elaborate on the two preceding subject matters:

(1) Reginato, Robert J. Count rate instability in gamma-ray transmission equipment. Soil Sci. Soc. Amer. Proc. January-February 1974.

(2) Reginato, Robert J. Gamma radiation measurement of bulk density changes in a soil pedon following irrigation. Soil Sci. Soc. Amer. Proc. January-February 1974.

PERSONNEL: Robert J. Reginato

TITLE: GRAVEL BED COOLERS FOR GREENHOUSES

CRIS WORK UNIT: 5402-12260-002 CODE NO.: Ariz.-WCL 72-5

This project was initiated to design, test, and evaluate evaporative coolers made from gravel beds for the cooling of sealed greenhouses. Near the beginning of last year laboratory apparatus was constructed for measuring heat transfer coefficients under various flow conditions for commercial grades of gravel. Two preliminary tests indicated that the apparatus worked well and was giving accurate heat transfer coefficients as well as accurate pressure head loss data.

However, then an event occurred which caused the focus of attention to move completely away from using gravel beds. In a regular staff review conference, John Replogle suggested that water could be used to convey the "coldness" from the gravel to the greenhouse using a continuous flow system instead of the alternate switching system originally planned. Subsequent discussions and designs led to vastly more simple system for cooling a sealed greenhouse.

The newer, simplified cooling system is shown schematically in Fig. 1. Basically, it will consist of conventional fan-pad evaporative coolers, but they will be utilized in a new way. Outside air will be drawn through the upper "outside" pad. Some water will evaporate into this air, thus cooling the remaining water flowing down the pad. This cool water will be collected at the bottom of the outside pad and piped inside the greenhouse to the top of the "inside" pad. It then will trickle down the inside pad picking up heat from the hot greenhouse air which will be circulating through the pad. As the water will warm, the greenhouse air will cool. At the bottom of the inside pad the now warm water will be pumped to the top of the outside pad to again be cooled and repeat the cycle.

The outside air which will be drawn through the outside pad will be blown through an attic formed by stretching a sheet of transparent plastic across the greenhouse from eave to eave. This feature will lower the sensible heat load on the greenhouse, and thus some of the "coolness" and the exhaust air can be utilized which would otherwide be lost.

Calculations have been made using the procedure described by Beall and Samuels (S. E. Beall and G. Samuels. The use of warm water for heating and cooling plant and animal enclosures, Oak Ridge National Laboratory Report, ORNL-T-M-3381) to determine the size of pads and flow rates of air and water required. For a 14' × 21' prototype greenhouse having wet pad areas of 14' × 3' with design conditions of 108F dry bulb and 77F wet bulb temp of outside air and a heat load of 221 BTU/hr/ft^2, the results indicate that flow rates of about 7000 cfm for air inside the greenhouse and through the attic and of about 21.3 gpm for water through the pads will give a temperature rise about 16F above outside wet bulb temp for the inside greenhouse air as it flows through the house. A summary of the design calculations is shown in Fig. 2.

Figure 3 shows how the actual propotype greenhouse will appear. The upper wet pad will instead be two conventional box type evaporative coolers having a pad area somewhat larger than 14' × 3'. The inside air will be circulated around the side of the greenhouse through the large air duct. The inside pad is a 14' × 40" wet wall at the outlet of the duct. The greenhouse is now about half constructed. The frame is erected and the walls and roof of fiberglass have been installed. It is hoped that construction and instrumentation is completed before hot weather arrives so that a thorough test can be achieved this summer.

Since the focus of this project has turned away from gravel beds for coolers, this project will be terminated this year. A new project will be started having a more descriptive title with the objectives to study greenhouse cooling and heating in general, as well as CO_2 fertilization.

SUMMARY:

A recent design innovation caused attention to a shift from gravel bed coolers to a more conventional dual fan-pad system for cooling a sealed greenhouse. One of the pads will be outside the greenhouse and will provide a source of cool water as relatively dry outside air is blown through it. This cool water will be piped inside to the other pad. The greenhouse air will be circulated through this inside pad and will be cooled by heat exchange with the cool water. After being warmed by passing through the inside pad, the water will be pumped to the outside pad to repeat the cycle. Construction is progressing on a prototype greenhouse, and it is anticipated that a thorough test of the cooling system can be obtained this summer.

PERSONNEL: B. A. Kimball, W. R. Williamson

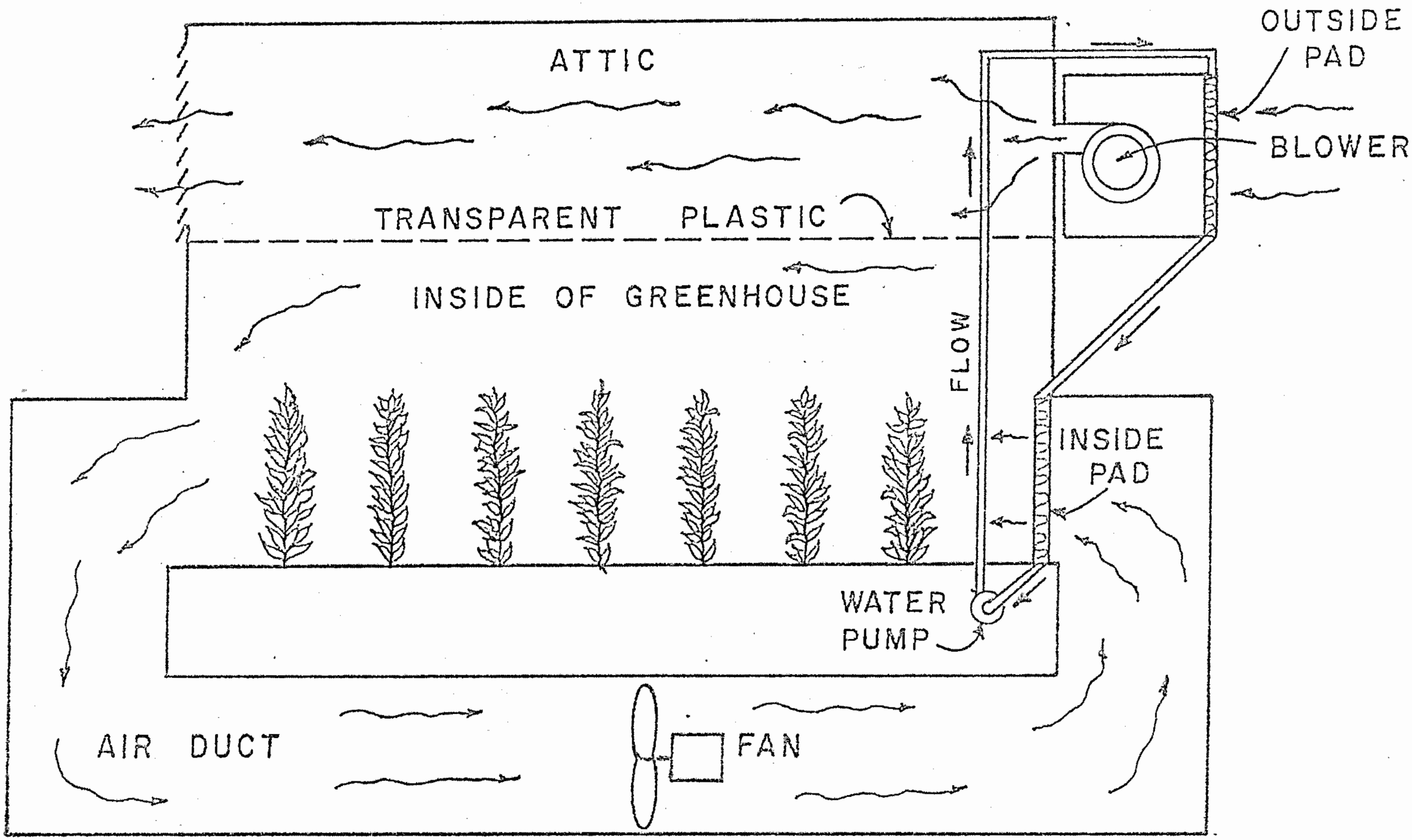


Figure 1. Schematic diagram of dual fan-pad evaporative cooling system for a sealed greenhouse.

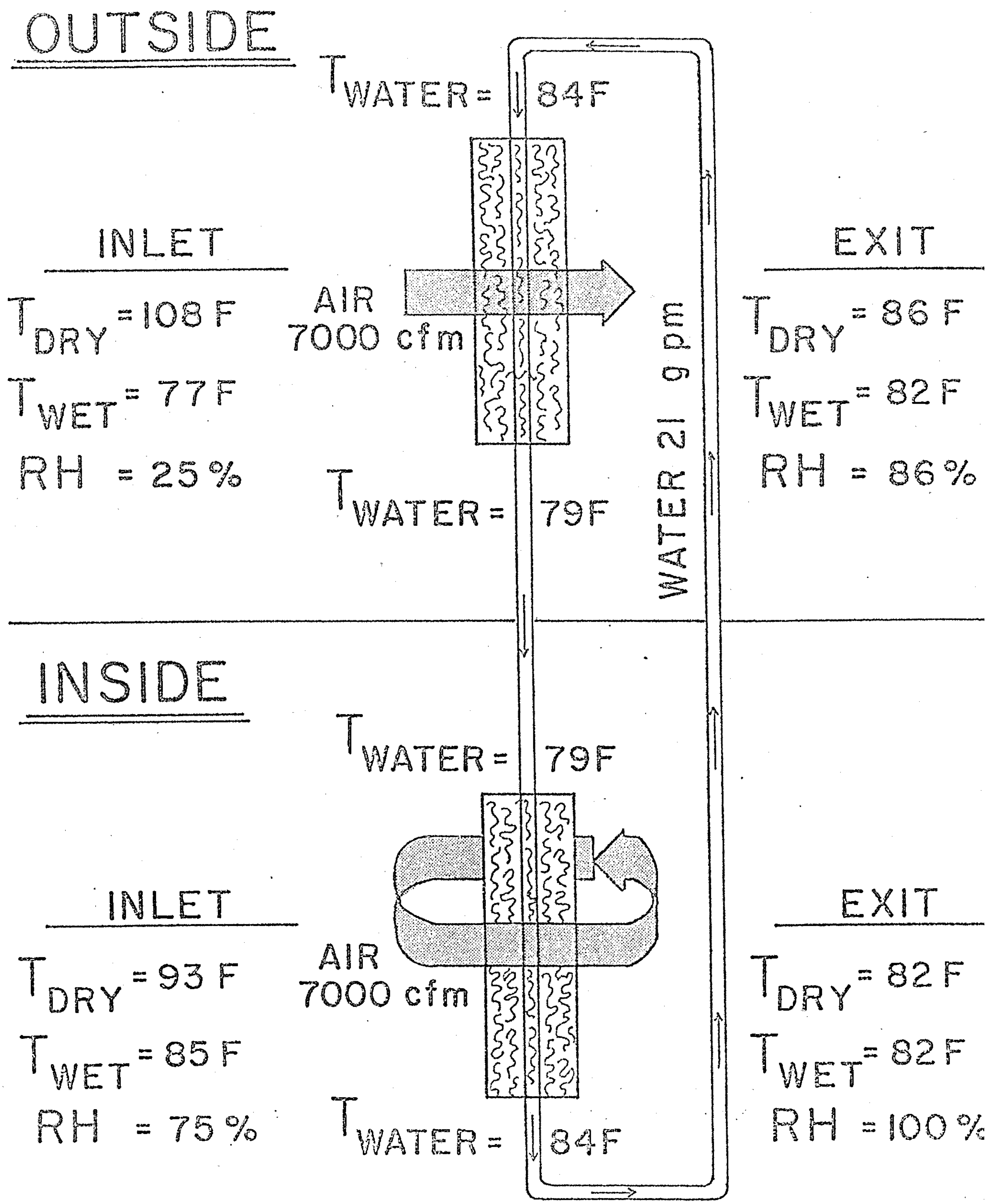


Figure 2. Summary of design operating conditions for dual fan-pad evaporative cooling system.

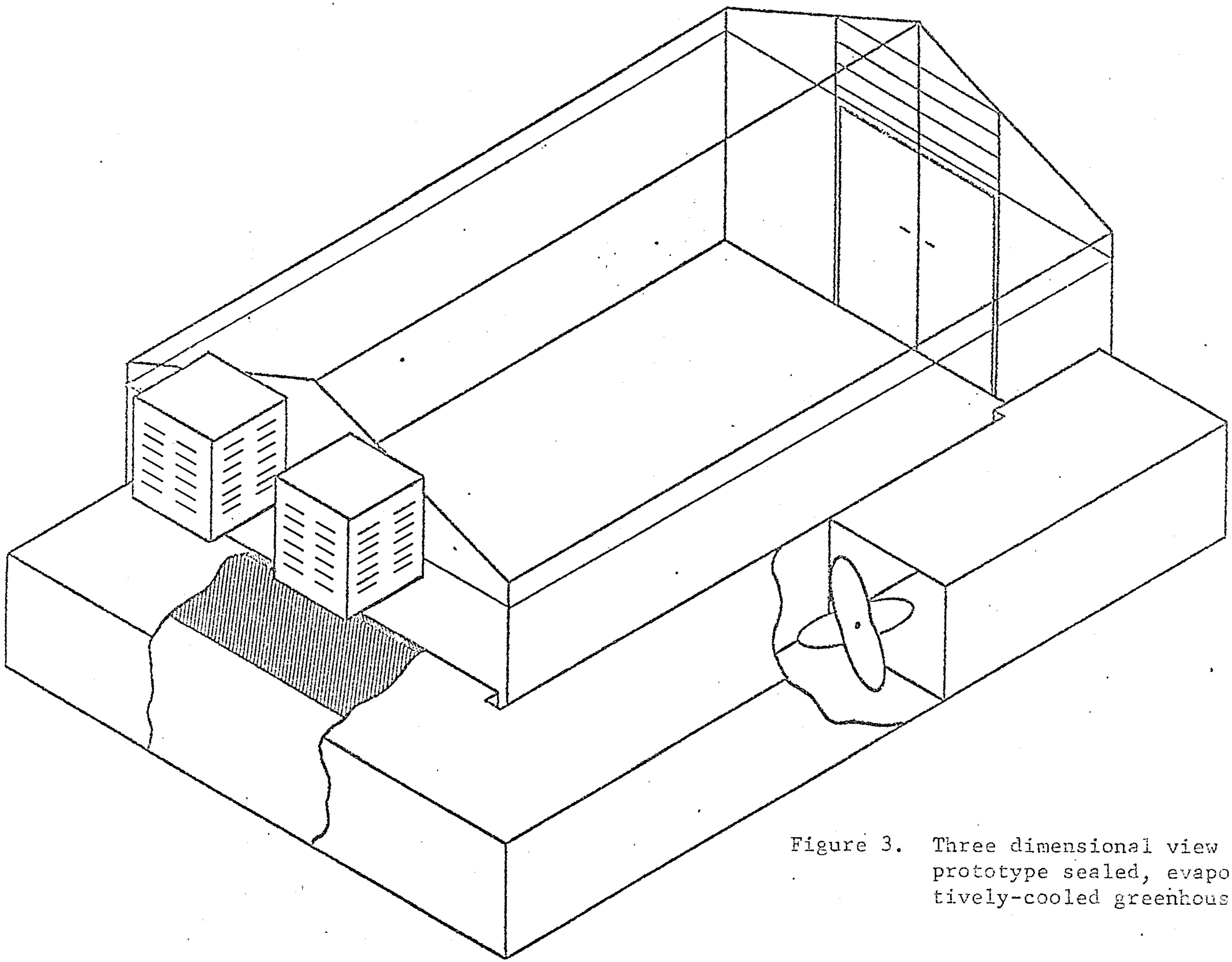


Figure 3. Three dimensional view of prototype sealed, evaporatively-cooled greenhouse.

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

CRIS WORK UNIT: 5402-12260-002 CODE NO.: Ariz.-WCL 72-6

Work under this outline this year consisted of two specific studies of atmospheric radiation fluxes and the development of two review papers. These are reported on in more detail below. In addition, much field work was done in connection with a study of the evaporation process itself. Analyses are incomplete at this time, however, and so they will not be reported until next year.

Idso, S. B. On the use of equations to estimate atmospheric thermal radiation. Archiv. für Meteorol., Geophys. und Bioktim. (In Press).

Four of the most commonly used empirical equations relating atmospheric thermal radiation to screen-level vapor pressure and/or air temperature were contrasted. The successes and failures of those equations that are based only on air temperature were shown to be dependent upon the degree of correlation between surface vapor pressure and air temperature via a modified "opacity effect." Several considerations were listed for determining whether to use an equation based only on air temperature or one based on both air temperature and vapor pressure. The equations were then evaluated relative to each other in each of these two groups. Finally, some new ideas were presented relative to the problems encountered with estimating atmospheric thermal radiation when clouds are present.

Idso, S. B. Low-level aerosol effects on earth's surface energy balance. Naturwissenschaften. (Submitted for Publication)

The introduction of a small amount of dust into the atmosphere on a typical cloudless day at Phoenix, Arizona, increased the downward atmospheric thermal radiation by about 10%. The total transmission of solar radiation, however, was unaffected. Thus, if man ever begins to increase the background aerosol content of the atmosphere, this effect may tend to warm the earth - rather than cool it, as has often been previously postulated.

Idso, S. B. The calibration and use of net radiometers. Advances in Agronomy. (In Press).

This review paper discusses practical aspects of net radiometry, such as calibration techniques, basic consideration of data acquisition, and methods of modifying net radiometers for a variety of different applications in agronomic and soils research.

Idso, S. B. Climatic effects of increased industrial activity upon the world's established agro-ecosystems. Agro-Ecosystems. (Submitted for Publication).

The major effects of human industrial activity upon the global climate were considered. It was indicated that the direct production of heat plus the increase in atmospheric CO_2 from the burning of fossil fuels have both long been recognized as having a warming influence upon the global climate. New evidence was then cited for believing that the addition of aerosols to the atmosphere by man also tends to warm the earth. Thus, the potential effects of a mean global warming trend upon other climatic elements and some of the earth's established agro-ecosystems were investigated. Examples of both direct and indirect types of effects were given, plus some recommendations for contemporary research required to meet the challenge of future climatic change.

PERSONNEL: Sherwood B. Idso and J. M. Pritchard

TITLE: GROWTH AND YIELD OF JOJOBA (*Simmondsia chinensis* (Link) Schneider) ON RUNOFF-COLLECTING MICRO-CATCHMENTS

CRIS WORK UNIT: 5402-12260-002 CODE NO.: USWCL 73-4

INTRODUCTION:

The jojoba is indigenous to an arid environment, occupying about 40,000 ha of the Sonoran Desert of the United States and Mexico. There is a small stand of jojoba 50 km east of Phoenix, at Usery Pass. Jojoba currently is receiving attention because its seed contains a valuable wax which makes an excellent substitute for the now rare sperm whale oil. It is suspected that the Usery Pass area, with an annual precipitation of about 250 mm, is marginal for the growth of jojoba, since this species generally flourishes where the annual precipitation is 380 to 450 mm.

This situation presented an opportunity to use water harvesting for attempting to improve the seed yield and growth of jojoba.

PROCEDURE:

Thirty plots, each with a female jojoba bush from the native stand, have been established within a fenced area of about 1 ha at an elevation of 610 m. The objective is to improve seed yields and plant growth by augmenting the natural rainfall by water harvesting. There are three treatments: T_o, a control, with minimal disturbance to the natural vegetation; T_1, a cleared, smoothed, and rolled treatment; and T_2, treatment T_1 plus a spray application of a water repellant to further increase rainfall runoff. Treatments T_1 and T_2 have a 20-m^2 collecting area supplying a plant area of 4 m^2, as shown in the drawing (Figure 1).

Three of the ten replications of each treatment have water-content-monitoring neutron meter access tubes installed near the plant to a depth of 140 cm. The native plants range in size from 0.5 to 1.6 m. The soil water content is measured periodically to determine the effectiveness of the microcatchments in collecting and storing water near the plant. In addition, measurements of the

Annual Report of the U.S. Water Conservation Laboratory

relative leaf water content (RLWC) will establish the effect of any differential in water storage on leaf hydration. The increase in plant volume over the long term will be followed by measuring periodically the length, width, and height of each bush. Annual seed yield will be determined by monitoring both the number and size of fruits per plant and per treatment.

RESULTS AND DISCUSSION:

The initial values of the RLWC were taken after a 115-day drought. On the sampling date, 8 November 1973, there were no significant differences in RLWC among the means of the three treatments (10 replications each), the values encompassing the range of 75.7% ± 1.2%. These low values (100% being a fully hydrated leaf) are consistent with the extreme drought that the plants had been enduring, which resulted in a soil water content of only 5% by volume (Figure 2), a base level common to all three treatments and throughout the profile from depths of 20 to 140 cm.

After rainfall of 29.9 mm in November 1973, and 41.2 mm in January 1974, the RLWC on 11 January had increased to a range of 85.8% ± 1.4%. Again there were no significant differences in RLWC among the means from the three treatments on the day of sampling. However, when the data from 30 plots sampled on 11 January were pooled and compared with the analogous value for 8 November, the difference between means was statistically significant at the 0.01 level (The mean value of RLWC on 11 January was 85.6% as compared to 75.4% on 8 November). In summary, a total rainfall of 71.1 mm brought about a mean increase of 10.2% in the RLWC, but on a given date no significant differences in RLWC could be attributed to water harvesting treatment.

Figure 2 shows that rainfall resulted in an effective storage of soil water at the 20-cm depth of the profile, regardless of treatment. However, at depths of 40 and 60 cm or more, storage occurred according to the following order of treatment: $T_0 < T_1 < T_2$. This kind of result is what was hypothesized to occur because of water harvesting, and over the long term could be expected to bring about a significantly higher RLWC in treatments T_1 and T_2 than in T_0, provided that actively absorbing roots are present in the deeper levels of the soil. Storage of more water may promote growth and fruiting and thus lead to greater seed yields than in the controls.

SUMMARY AND CONCLUSIONS:

Treatments T_1 and T_2 show promise of enhancing soil water storage as compared to the control treatment (T_0). The cumulative effect of such storage should lead to better leaf hydration, i.e., a higher RLWC, and ultimately to more growth, flowering, and finally to greater seed yield. However, several seasons may be necessary to realize such an effect. Also, it must be kept in mind that the whole experiment is predicated on the occurrence of reasonably typical amounts and distribution of rainfall.

PERSONNEL: <u>W. L. Ehrler</u>, S. T. Mitchell, and D. H. Fink

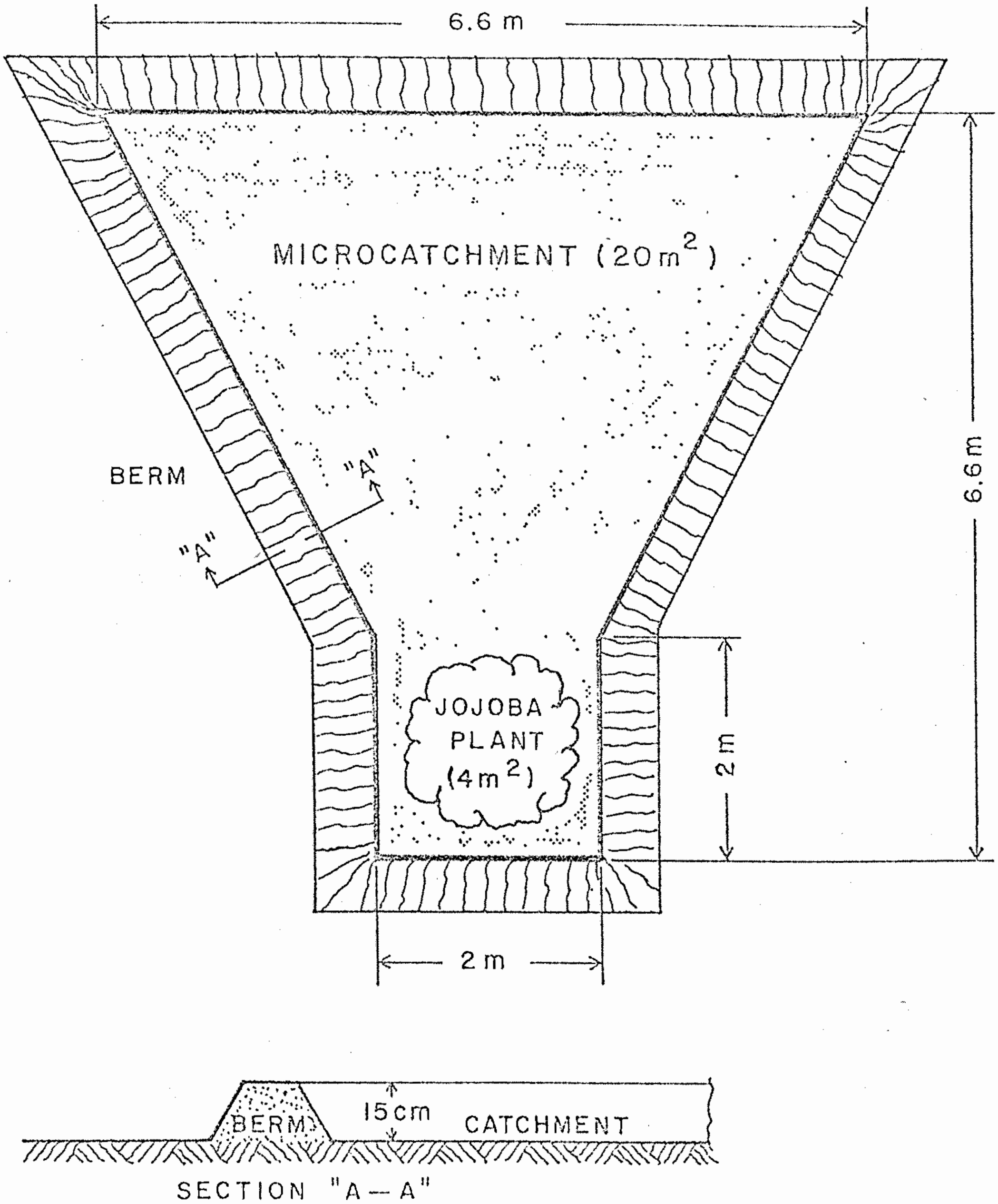


Figure 1. A plot diagram of the jojoba microcatchment and receiving area.

WATER STORAGE IN JOJOBA PLOTS AS AFFECTED BY TREATMENT OF MICROCATCHMENTS

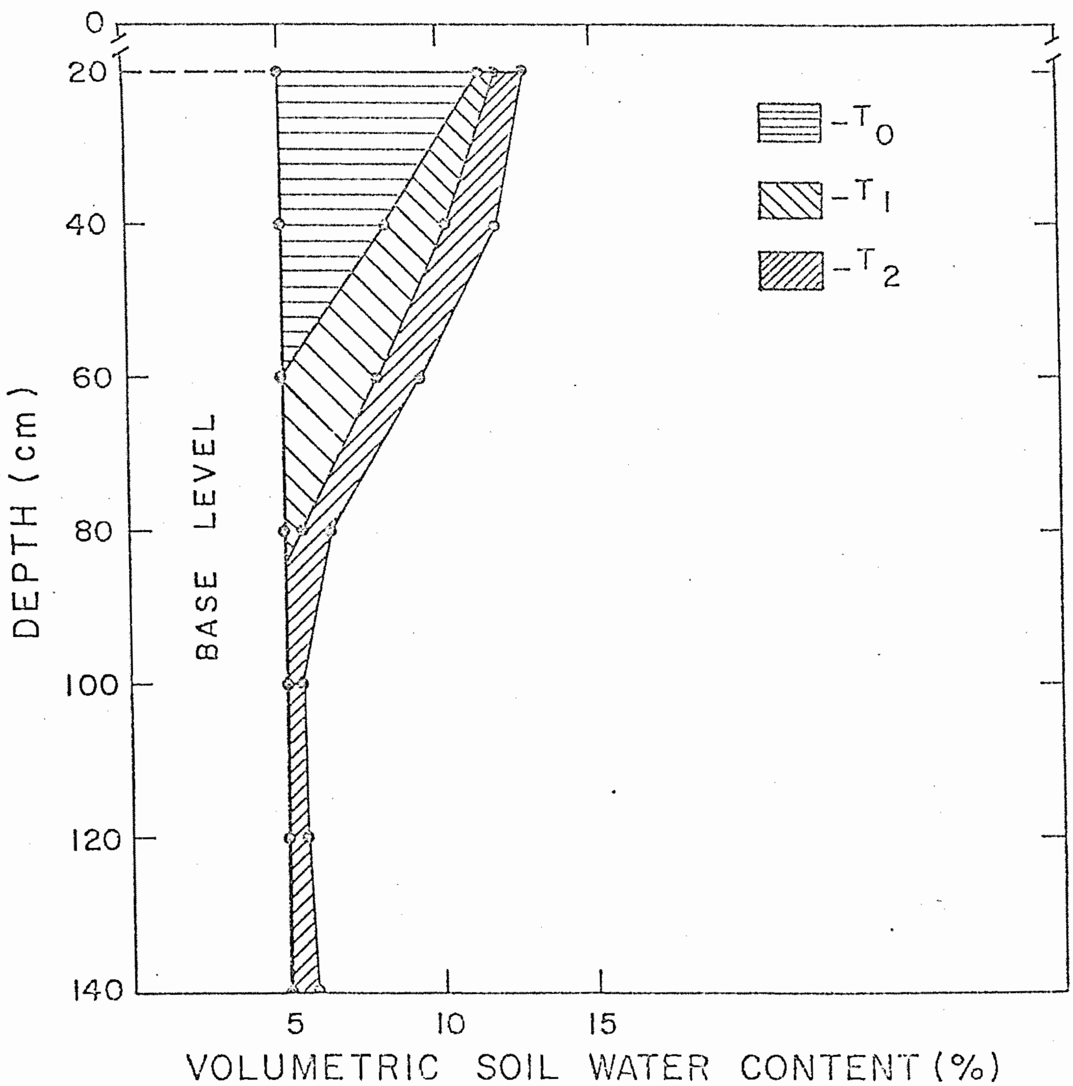


Figure 2. The volumetric soil water content by depth in the jojoba receiving area as affected by three microcatchment treatments, as compared to a common base level before significant rainfall.

TITLE: WASTEWATER RENOVATION BY SPREADING TREATED SEWAGE FOR GROUNDWATER RECHARGE

CRIS WORK UNIT: 5402-12260-003 CODE NO.: Ariz.-WCL 67-4

INTRODUCTION:

The year of 1973 was not a good year for the Flushing Meadows Project. On 1 April, Mr. M. S. Riggs, an employee of the Salt River Project who was stationed at the U. S. Water Conservation Laboratory to perform the chemical analyses of the effluent and renovated water samples, was called back to the Salt River Project. The essential analyses, such as nitrogen and phosphorus, were then performed by Mr. E. D. Escarcega, in addition to his regular duties. Mr. Escarcega left himself on 7 January 1974.

From about 1 March until 10 June, the Salt River was flowing. Sediment-laden water flowed through the effluent channel, so that the basins could not be inundated. The access road to the Flushing Meadows Project was flooded making it impassable to cars. After the flow, extensive repair to the effluent channel, the access road, and the approach to the bridge was required. The cooperation of the Salt River Project in this and other matters of the project is gratefully acknowledged.

The Flushing Meadows Project was not flooded. However, vandalism reached its peak in 1973. Many water-stage recorders were damaged or taken away. For this reason, infiltration rates could not be measured for basins 2 and 6 from 1 June until 4 September.

The operation of the basins in the first part of 1973 was a continuation of the 1972 studies which were aimed at lowering the ammonium content of the renovated water and "rejuvenating" the nitrogen-removal capacity of the soils beneath the basins. No crops were planted in 1973. After the flow in the Salt River had ceased, the boards at the outflow ends of basins 5 and 6 were removed to create a minimum water depth (about 2 inches) in the basins. This was done to study the effect of reduced infiltration rate on

Annual Report of the U.S. Water Conservation Laboratory

the nitrogen removal from the effluent water as it seeps through the soil. Laboratory studies on columns (see Annual Report by J. C. Lance) indicated that such reduced infiltration could double or almost triple the amount of nitrogen removed by denitrification.

Contact was made with Dr. J. L. Melnick of the Virology Department at Baylor College of Medicine, Houston, Texas, to determine the possibility of a cooperative project on concentrating renovated water for virus assay. A contract was entered into and in 1974 the Baylor group will come to Phoenix several times to concentrate renovated water and analyze the samples at Houston for number and types of viruses.

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. <u>Recharge Basin Management</u>.

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 in 1973 was as follows:

Basin 1. Bare soil with a continuous cover of granular sludge and dead algae, decreasing in thickness as the quality of the effluent improved after the spring.

Basin 2. Gravel layer, with sludge between gravel particles.

Basin 3. Sudangrass straw from last year's crop, starting as about a 1-foot thick layer early in the year, decreasing to a 2-inch layer later in the year. Also, bermudagrass grew in from the sides and covered 50% of the basin in the fall.

Basin 4. Same as 3.

Basin 5. Bare soil with bermudagrass straw and a sludge build-up in the spring, with a stand of bermudagrass, sprangle-top, and barnyard grass developing as the year progressed.

Basin 6. Same as 5.

In January, February, and March the water depth in the basins was 12 inches for basins 1, 2, 5, and 6, and 6 inches for basins 3 and 4. After 1 June, the water depth was 12 inches in basins 1 and 2, 6 inches in basins 3 and 4, and about 2 inches in basins 5 and 6.

Flooding and drying periods of about 2 weeks each were employed throughout the year. In June, July, and August, basins 3, 4, 5, and 6 received a small "shot" of effluent (about 4 inches) during drying. This was to determine if nitrogen removal could be increased by pushing nitrates down to lower zones where conditions might be more favorable for denitrification. The short floodings during drying periods were replaced by sprinkling with a low-head sprinkling system after the middle of September, when about 1 inch of effluent was applied once or several times during drying.

2. <u>Infiltration Rates.</u>

The infiltration rates (Figure 2) for January, February, and March were rather low, except for basin 2. This is the first time that the gravel basin has had higher infiltration rates than the other basins (see previous annual reports). The long, forced dry period from March to June resulted in considerable infiltration recovery (see basins 1 and 4 in Figure 2). For basins 5 and 6, considerable recovery must also have taken place, considering that the depth after the dry period was only about 2 inches and that the infiltration rate at this shallow depth was about the same as at the 12-inch depths in the first three months of the year.

After June, basin 1 exhibited the typical decline and recovery patterns in infiltration rate. Sprinkling during drying probably reduced the recovery in infiltration rate towards the end of the year. Basin 2 showed a general decline in infiltration, whereas the infiltration rates for basins 3, 4, 5, and 6 were about constant in the June-December period. The effluent was mostly clear and relatively free from suspended solids after the long spring dry up.

The accumulated infiltration in 1973 was highest for basins 2 and 4, and averaged 210 feet for all basins (Figure 3). Considering that the basins were not flooded for about one-fourth of the year and that shallower depths were used, accumulated infiltrations of over 300 ft/year would undoubtedly have been obtained if the basins had been operated for 12 months at their normal depth of 1 foot.

The permanent effluent pond was filled again, after a breakdown of the pump, and the seepage was periodically determined. As in previous years, the seepage remained in the range of 0.2-0.4 ft/day (Figure 4). This is very low seepage, considering that the depth of the pond was 4 to 5 ft. Thus, continuous flooding with sewage effluent as occurs in the effluent channel itself, will lead to very small infiltration rates.

II. WATER QUALITY STUDIES

1. Sampling and Analytical Techniques.

Sampling schedules, the sampling of effluent and renovated water, and analytical techniques are the same as described in previous annual reports.

2. Total Organic Carbon.

The total organic carbon content of the secondary effluent was generally in the 10 to 15 mg/liter range for the early part of the year (Figure 5). In August, the effluent was of very good quality and had a TOC content of about 6 mg/liter. The TOC content of the renovated water was generally below 5 mg/liter (Figure 5).

3. Nitrogen.

The total-N content of the effluent was between 20 and 40 mg/liter with an average of about 30 mg/liter. The N-content was highest in January and February (Figure 6). The increasing trend in the NH_4-N concentration of the renovated water from ECW, which started in December 1972 after a gradual decline of the NH_4-N content in 1972, continued in January and February of 1973 (Figure 6). After the long dry up from March to June, a considerable NO_3-peak was observed in ECW water after flooding was resumed. This was probably due to nitrification of adsorbed NH_4 and organic N in the soil during the long drying. Thereafter, the NO_3-peaks were considerably smaller. The NH_4-N content also declined from June to December. The N removal for the ECW water was quite good. Whether this is due to the lower infiltration rates (caused by the 6-inch water depth in the basins), to the water application during drying, or to the remnants of the sudangrass crop of 1972, or to a combination of these factors, is difficult to say.

The numbers below the NO_3-peaks in the renovated water indicate the percentage nitrogen that was removed for each flooding cycle. This percentage was obtained by multiplying total-N levels in effluent and renovated water by the infiltration rate during flooding, assuming vertically downward parallel flow (piston flow), and calculating the percentage N removal. The infiltration rates were taken as the average of the infiltration rates for basins 3 and 4 during the particular flooding period.

There are two sources of errors in this procedure, which have opposite effects on the calculated percentage N removal. The first source of error is that the NO_3-peak may not always be accurately characterized because the daily grab-sampling failed to include the peak NO_3-concentration. Sometimes these peaks occurred on week-ends. In general, however, flooding periods were scheduled to avoid the occurrence of NO_3-peaks on week-ends. The second source of error is that divergence of the flow causes the fluxes in the aquifer at the intake of ECW to be less than the infiltration rates. This causes the observed NO_3-peak in the renovated water to be broader than it would be if true, parallel and vertically downward piston flow had occurred.

The weighted mean of the nitrogen removal percentages was 21% for 1973. If the high NO_3-peak of June (which yielded a negative N removal) is excluded, the average N removal was 38%.

The low water depth in basins 5 and 6 and resulting lower infiltration rates were apparently quite effective in stimulating denitrification, as indicated by the average nitrogen removal of 74% after June (Figure 7). This corresponds to a removal of 8153 kg N/ha during the 7-month period, or an annual nitrogen removal rate of 13,977 kg/ha. This is much more than the 9,000 kg of N removed per ha on the basis of an annual infiltration of 100 m and a nitrogen removal of 30%.

The NO_3-peaks for the renovated water from well 5-6 were essentially non-existent in September, November, and December. Also the NH_4-N concentration decreased during the June-December period, indicating that the amount of ammonium adsorbed in the soil during flooding did not exceed the amount of adsorbed ammonium that could be nitrified during drying.

The nitrogen removal for the renovated water from well 1-2 was generally between 30 and 40% and in the 40 to 50% range for the last three flooding periods of the year (Figure 8). Thus, the sprinkling between flooding periods may have been effective in increasing denitrification. It is difficult to conclude, however, whether this was due to the movement of nitrate to lower zones, or to reduced infiltration rates during flooding because of less infiltration recovery during drying when sprinkling was used.

The procedure of calculating the N removal by means of the piston-flow approach was also applied to sequences of long flooding and drying periods in previous years. Short, frequent flooding cycles were not included in this calculation, because the predominantly aerobic conditions yielded essentially complete nitrification of the nitrogen in the effluent without significant nitrogen removal. The results (Table 1) show that the weighted mean removal percentage for all long flooding cycles was 30%, which agrees well with previous predictions based on the average total-N concentrations of the renovated water from outlying wells, and with the results of laboratory studies on soil columns.

The N removal percentage appeared to decrease with increasing NH_4-N content of the renovated water. This is demonstrated in Figure 9, which shows that when the NH_4-N content of the renovated water went up, the N-removal percentage went down, and vice versa. This shows the importance of avoiding NH_4-increases in the renovated water, as can be acomplished by selecting flooding and drying cycles so that not more NH_4 is adsorbed in the soil during flooding than can be nitrified during drying. A plot of the percentage nitrogen removal versus the NH_4-N content of the renovated water is shown in Figure 10. Although there is considerable scatter, the downward trend of the relation as indicated by the best-fitting straight line is unmistakable.

4. Phosphates.

The PO_4-P concentration of the effluent for the period July-December was about 9 mg/liter (Figure 11). The PO_4-P concentrations in the renovated water of ECW, well 1-2, and well 7 were not much different and fluctuated around 4 mg/liter. The PO_4-P level of the renovated water from well 1 was much lower, as was that of well 5-6. The intake of well 5-6 is in relatively fine-textured material which may explain the increased phosphate removal for this well. Well 1 is at the same distance from the basins as well 7 (Figure 1). However, well 1 is also in less permeable material, which probably explains the lower PO_4-P concentrations in the renovated water.

5. Dissolved Salts.

The total dissolved solids content of the secondary effluent was about 1,000 mg/liter, as in previous years. The total salt content of the renovated water from ECW was also about 1,000 ppm except for the period June 11 until June 18, when salt contents of between 1,400 and 1,700 mg/liter were observed. This could have been due to the long drying period previous to June, causing salt build-up in the upper soil layers, which was leached out when flooding was resumed in June. A similar effect was noted for the total salt content of the renovated water from well 1-2. The salt content of the renovated water of well 5-6 increased to about 1,400 ppm in the middle of June. Wells 1 and 7 yielded water with salt concentrations of about 1,000 ppm, and WCW yielded water with salt concentrations of 3,000 to 4,000 ppm, which must have been native groundwater.

6. pH.

The pH of the renovated water generally was between 6.5 and 7.0. The pH of the effluent was not measured, but it was usually around 8 in previous years.

7. Metals.

Acidified samples of secondary effluent and renovated water from various wells, taken in the period September 1972 to February 1973, were shipped to Dr. J. V. Lagerwerff of the Agricultural Research Service in Beltsville for Hg-analysis. The results (Table 2) show that the average mercury content of the effluent is around 2.1 ppb, whereas the average mercury content from the various wells ranges between 1.0 and 1.4 ppb.

8. Viruses.

Frozen samples of raw sewage, secondary effluent, and renovated water from various wells were sent to Dr. Hillel I. Shuval of the Environmental Health Laboratory, Hebrew University, Jerusalem, Israel, for virus assay. The generous offer of Dr. Hillel to do this work is gratefully acknowledged. The results (Table 3) show that virus was present in the raw sewage and to a lesser extent in the secondary effluent, but that the renovated water was free from viruses. This applies to 4-liter samples. To obtain a better picture of the virus level in the renovated water, much larger volumes must be analyzed. This requires concentration of the viruses from large volumes into small volumes of water. This will be done in 1974 by the Virology Department of Baylor College of Medicine, Houston, Texas, under contract with the U. S. Water Conservation Laboratory.

9. Biostimulation of Renovated Water in Impoundments.

The east lined pond and the west lined pond were pumped out on the 21st of August, cleaned and filled with renovated water from the East well on 24 August. The ponds were then stocked with about 3,000 top minnows (Poeciliopsis occidentalis) and 1,000 blue-gill (Lepomis macrochirus), equally distributed over the two ponds, on 4 September 1973. Renovated water from the East Well is continuously applied to the ponds at such a rate that it replaces the volume of the west lined pond in 32 days and the volume of the east lined pond in 12 days. Nitrogen and phosphorus concentrations in the ponds are shown in Table 4. Secchi disk readings are shown in Figure 12. The nitrogen and phosphorus levels are rather stable. The Secchi disk readings show minor fluctuations. The type fish were selected so as to produce a large population of relatively small fish, which might take advantage of the large primary productivity of the fairly eutrophic renovated sewage effluent waters, while avoiding excessive algal blooms.

III. FUTURE PROJECTS

In 1973 the application of the City of Phoenix for a grant from the Environmental Protection Agency to partially finance the 23rd Avenue Recharge and Renovation Project, was approved. Detailed plans for this 40-acre high-rate infiltration system were prepared by Dibble and Associates, consulting engineers, and approved by various local and federal agencies. Construction is expected to start in the spring of 1974 with completion scheduled for the summer.

In April 1973, the University Project Committee for the Rio Salado Project completed its report on the general plan for the University Project. Basically, this project consists of a 2-mile long combination of lagoon and rowing course with a total surface area of approximately 140 acres in the Salt River bed north of the Arizona State University campus, and a lake of about 10 acres north of the Tempe Beach Park. Water would be supplied by a well or various wells in the Salt River bed. These wells would pump a mixture of native groundwater and renovated sewage water that infiltrated as secondary effluent from the effluent channel below the Mesa Sewage Treatment Plant. Architectural renditions of this project have been prepared and detailed engineering planning is under way.

SUMMARY AND CONCLUSIONS:

Lower water depths and small effluent applications during drying were used for the infiltration basins of the Flushing Meadows Project in an effort to increase nitrogen removal by denitrification. The highest N removal was 74%, which was obtained for the basins with the shallowest water depth (about 2 inches). The infiltration rate for these basins was 20 ft/month and the nitrogen removal was 8153 kg/ha for a 7-month period. The average N removal when sequences of long flooding and drying periods were used was 30% for the life of the project, using water depths of 1 ft. This is considerably less than the N removal obtained with a water depth of 2 inches.

The average accumulated infiltration for the 6 basins was 210 ft in 1973. This amount infiltrated in 9 months, since no water could be applied to the basins in March, April, and May due to flow in the Salt River and inaccessibility of the project.

The Total Organic Carbon content of the renovated water was generally between 0 and 5 mg/liter. The PO_4-P concentration was about 9 mg/liter for the effluent and 1 to 5 mg/liter for the renovated water, depending on the location of the well. The Hg content of the effluent averaged 2.1 ppb, and that of the renovated water varied from 1.0 to 1.4 ppb. The suggested maximum Hg concentration for drinking water is 5 ppb. Preliminary virus assays showed that the renovated water is free from virus. The raw sewage contained 62 PFU/liter, and the secondary effluent 4 PFU/liter.

Detailed plans for the 40-acre infiltration system below the 23rd Avenue Sewage Treatment Plant in Phoenix have been prepared, following the approval of an EPA grant for this project. The project will renovate about 15 mgd of secondary effluent and is scheduled for completion at about August 1974.

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

Table 1. Nitrogen removal percentage for ECW water.

Flooding cycle as characterized by occurrence of NO_3-peak in renovated water	Percentage removal of total nitrogen
Oct 68	67
Dec 68	50
Jan 69	
Feb 69	
Mar 69	
Oct 69	
Nov 69	21
Dec 69	38
Feb 70	38
Mar 70	53
Apr 70	-25
May 70	- 9
Jun 70	22
Jul 70	22
Aug 70	9
Sept 70	30
Nov 70	64
Dec 70	49
Mar 71	-22
Apr 71	40
May 71	30
Jun 71	41
Jul 71	24
Aug 71	28
Oct 71	33
Nov 71	57

Table 2. Results of Hg-analyses for sewage effluent and renovated water from various wells.

Sample	Date collected	ppb Hg in acidified solutions	
		Undigested (inorganic)	Digested (total)
Effluent	27 Sept 72	0.2	1.8
"	20 Dec 72	0.2	3.2
"	22 Feb 73	0.5	1.4
Well #1	27 Sept 72	0.0*	1.7
"	20 Dec 72	0.1	1.1
"	17 Jan 73	0.4	1.3
"	22 Feb 73	0.0	0.7
Well #7	27 Sept 72	0.2	1.1
"	20 Dec 73	0.0	1.5
"	17 Jan 73	0.1	1.8
"	22 Feb 73	0.2	1.4
Well #8	27 Sept 72	0.0	1.0
ECW	27 Sept 72	0.0	1.2
"	20 Dec 72	0.0	1.0
"	17 Jan 73	0.1	0.8
"	22 Feb 73	0.0	2.1
East Well	22 Feb 73	0.1	1.3

*0.0 means lower than the detection limit of 0.05 ppb.

Table 3. Virus concentrations (in PFU per volume of sample tested) in sewage and renovated water.

Sample	$AL(OH)_3$ method	Phase separation method
Raw sewage	----	62 PFU/liter
Secondary effluent	3 PFU/liter	4 PFU/liter
ECW	0 PFU/2.2 liters	0 PFU/liter
Well 1	0 PFU/2.3 liters	0 PFU/2 liters
Well 7	0 PFU/3 liters	0 PFU/2 liters

Table 4. Nitrogen and phosphorus concentrations in ELP and WLP.

Date	East lined pond			West lined pond		
	NO_3-N	NH_4-N	PO_4-P	NO_3-N	NH_4-N	PO_4-P
9-10	11	3.6	3.6	11	2.7	3.7
9-24	6.0	0.2	0.7	6	0.2	1
10-11	6	0.4	1.8	7.1	0.8	2.6
10-16	5.6	0.3	1.2	6.6	0.9	3.6
10-30	5.5	0.5		6.2	1.5	
11-6	7.6	0.9	2	8.7	1.6	4.5
11-26	9.6	0.8		10.3	1.6	
12-4	11.0	1.2	2.4	11.4	1.2	3.8
12-14	10.2	1.1	2.1	10.5	2.5	4.1

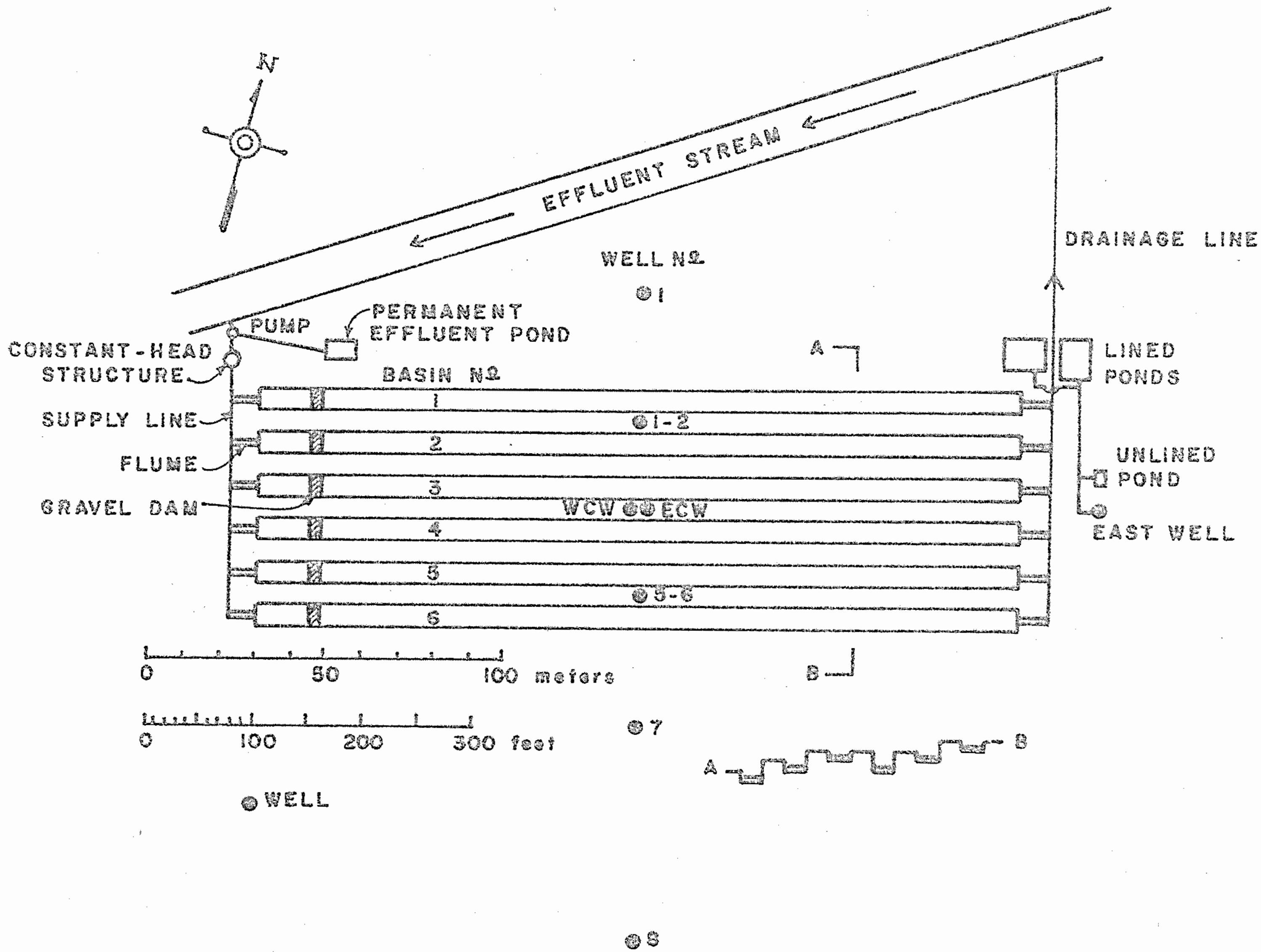


Figure 1. Schematic of Flushing Meadows Project.

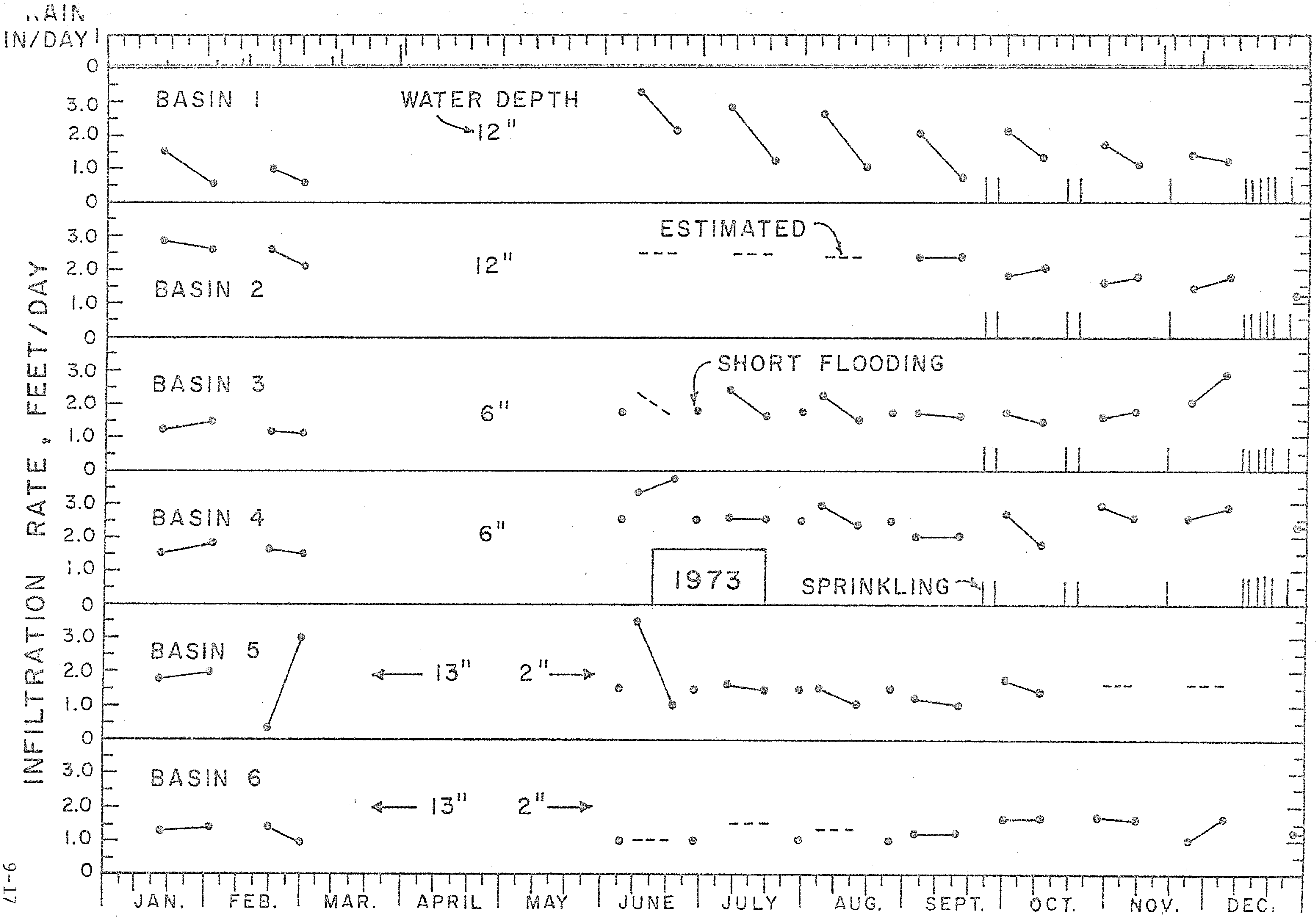


Figure 2. Infiltration rates in recharge basins and rainfall.

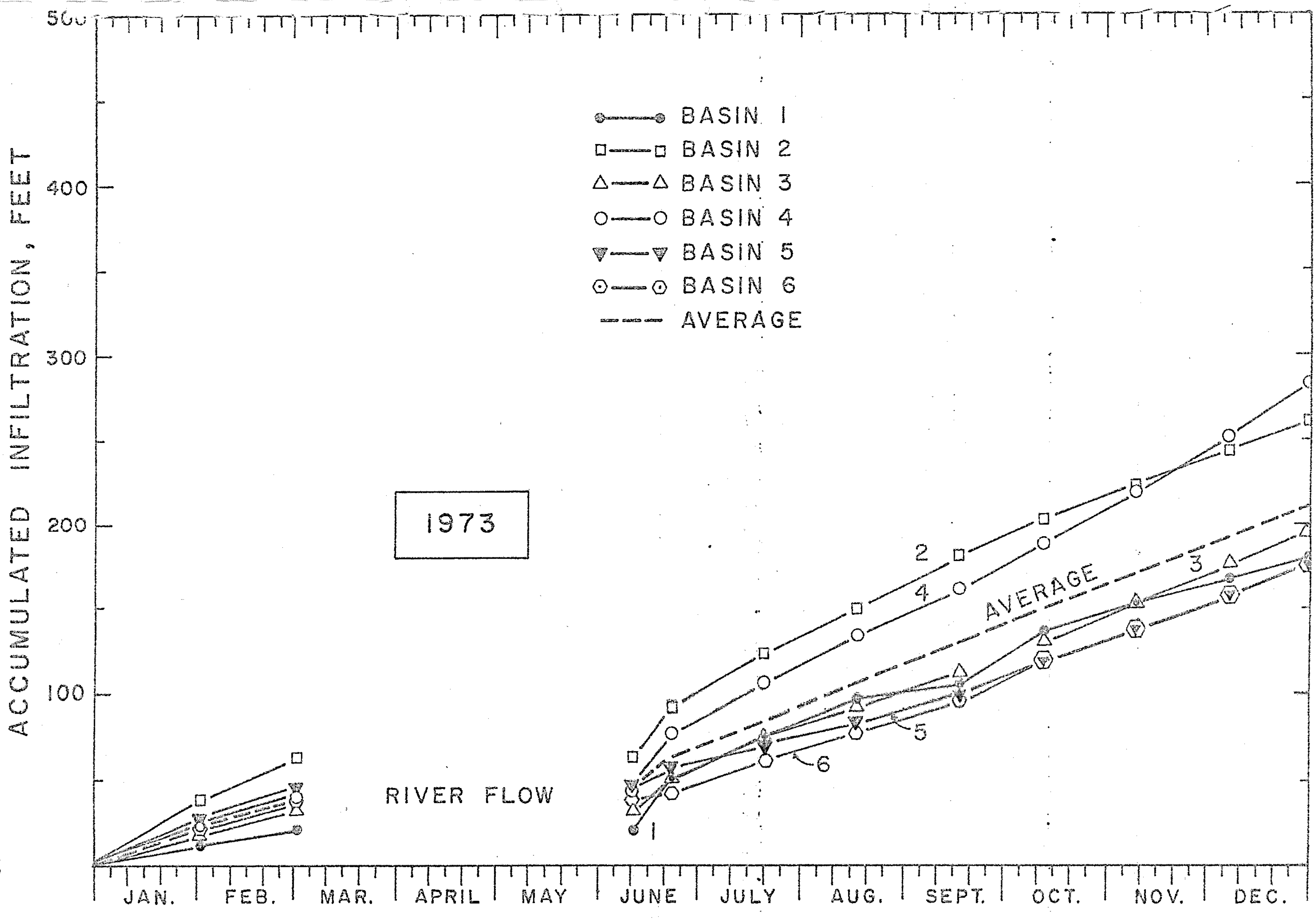


Figure 3. Accumulated infiltration in recharge basins.

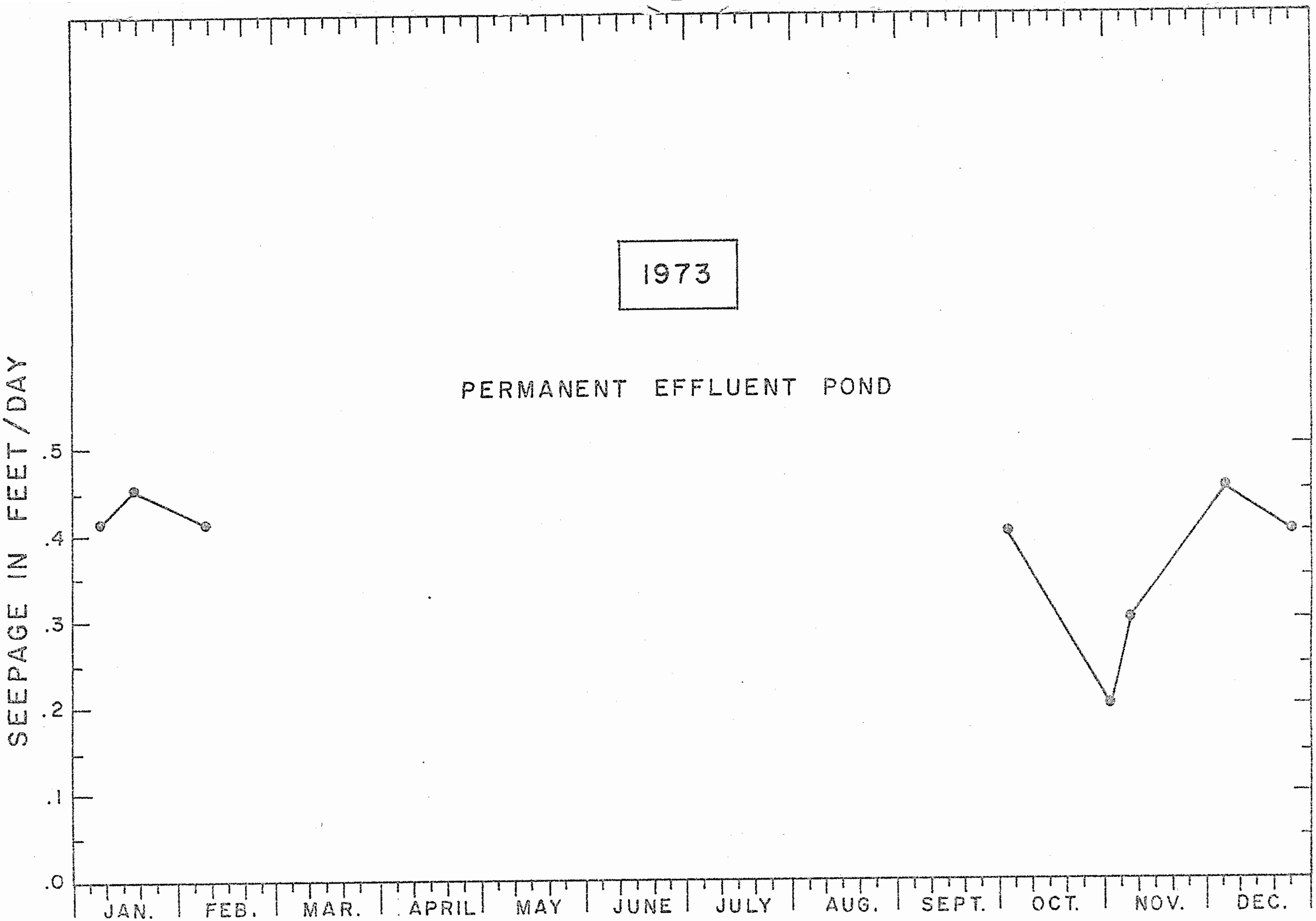
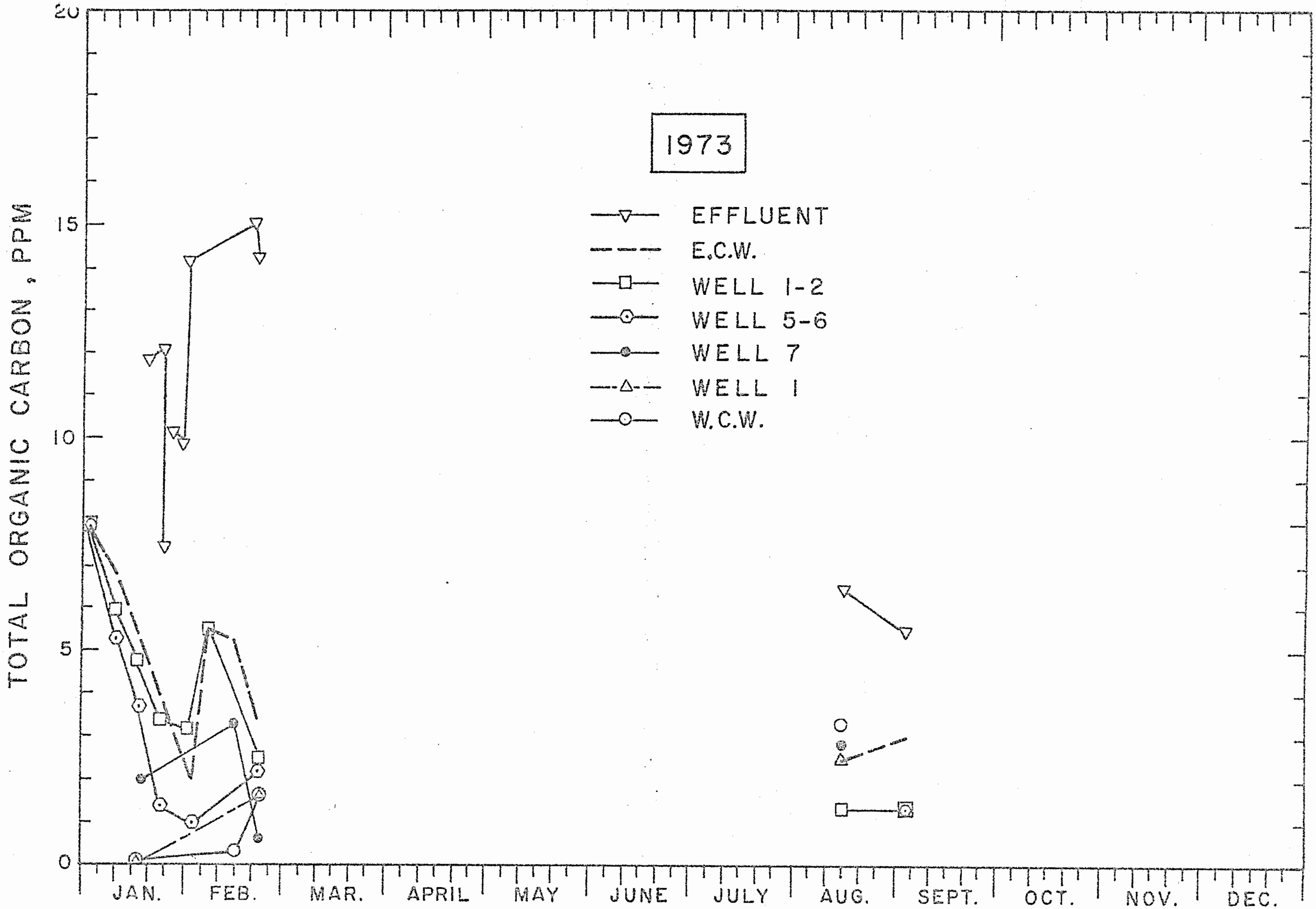


Figure 4. Seepage rate in permanent effluent pond.



Annual Report of the U.S. Water Conservation Laboratory

Figure 5. TOC of effluent and renovated water.

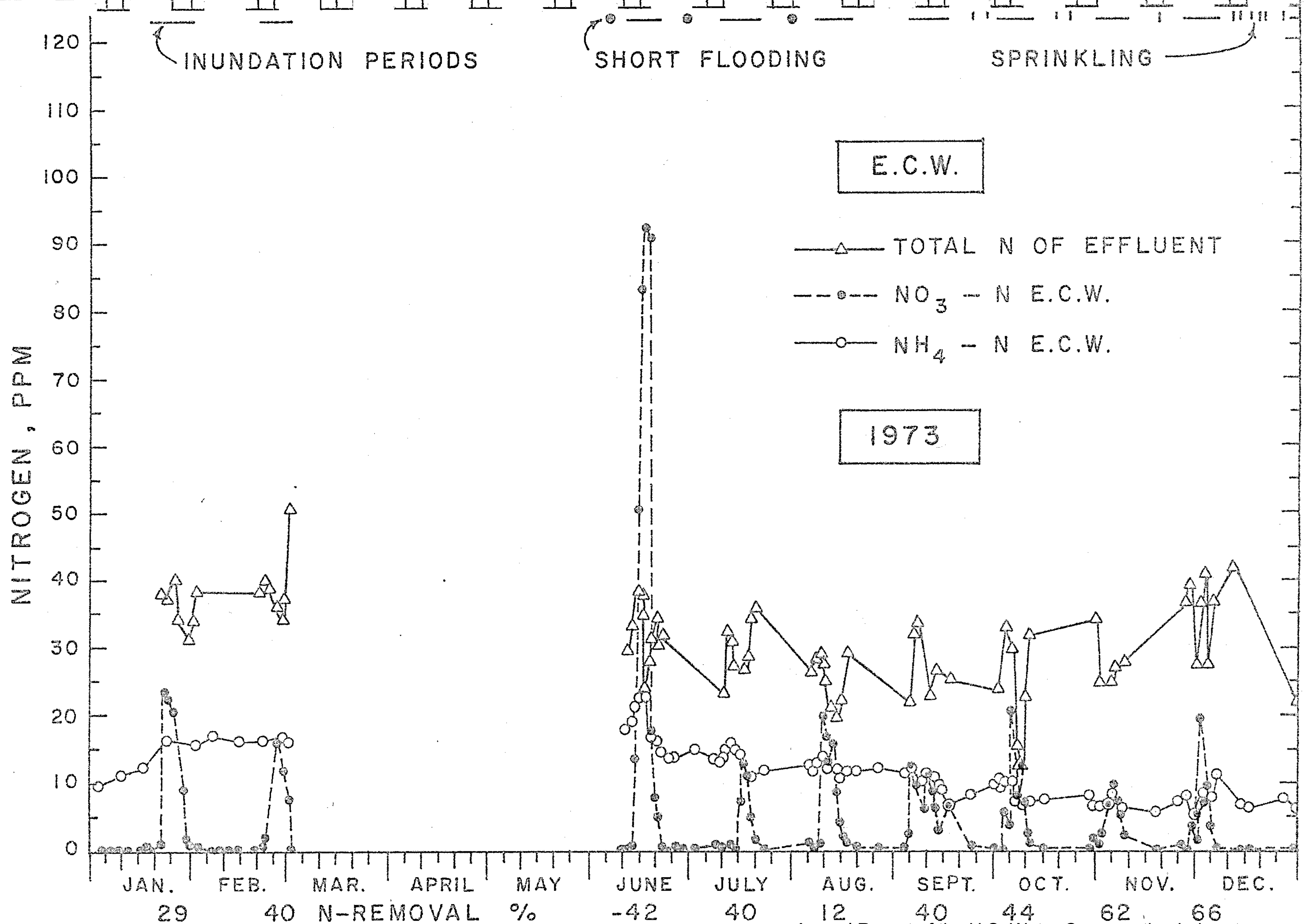
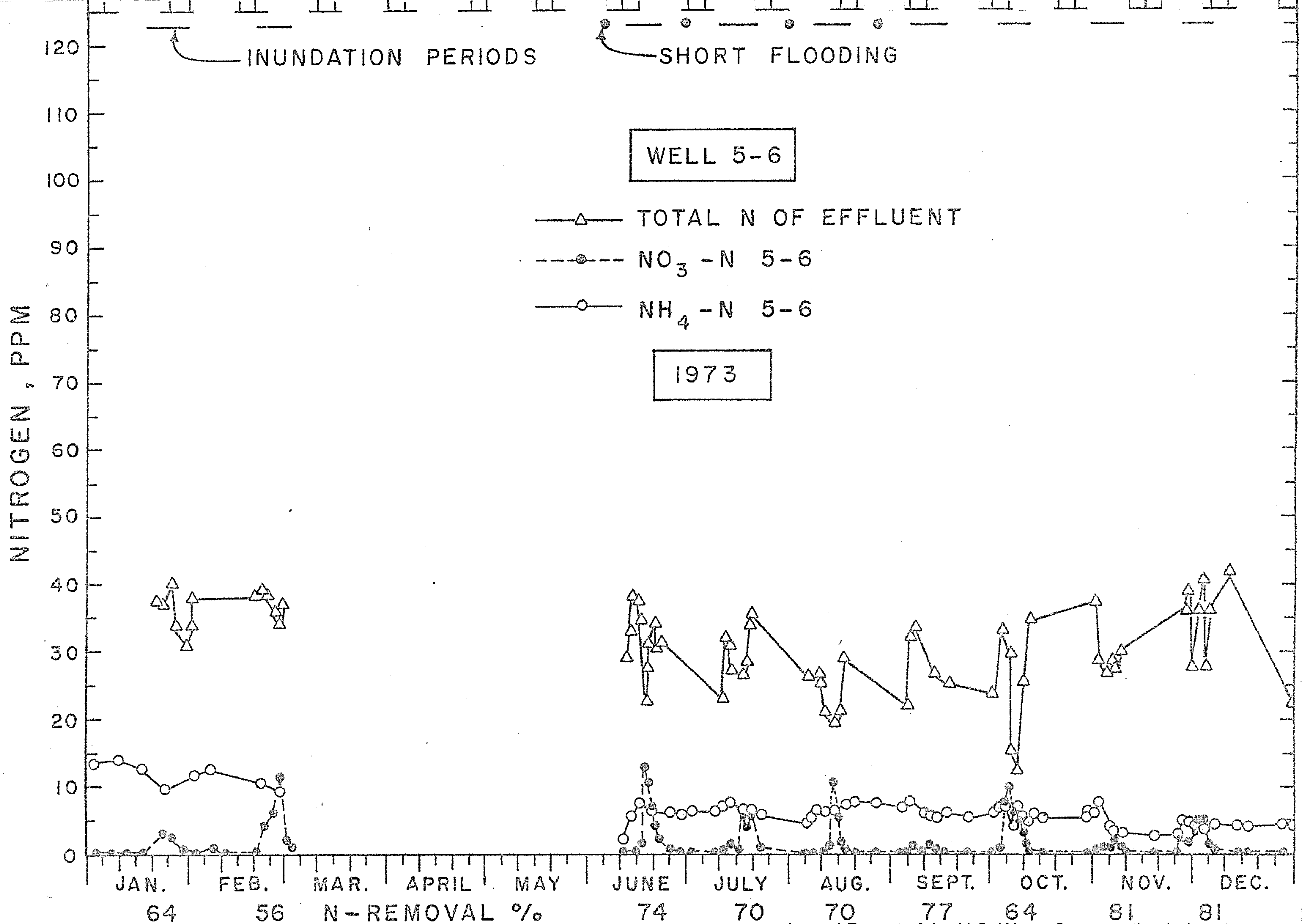
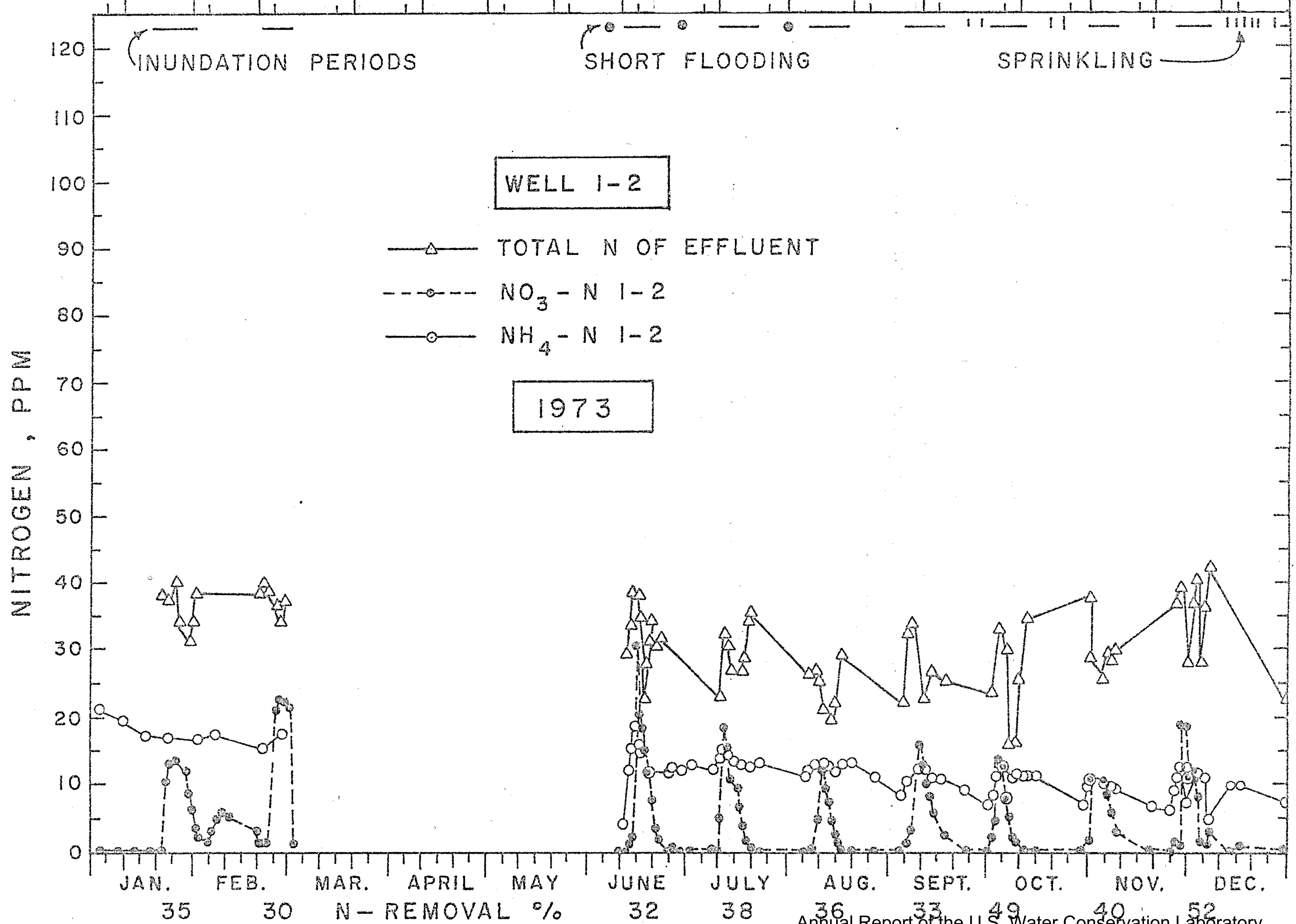


Figure 6. Total nitrogen in effluent and nitrate-N and ammonium-N in renovated water from ECW.



Annual Report of the U.S. Water Conservation Laboratory

Figure 7. Total nitrogen in effluent and nitrate-N and ammonium-N in renovated water from well 5-6.



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 1-2.

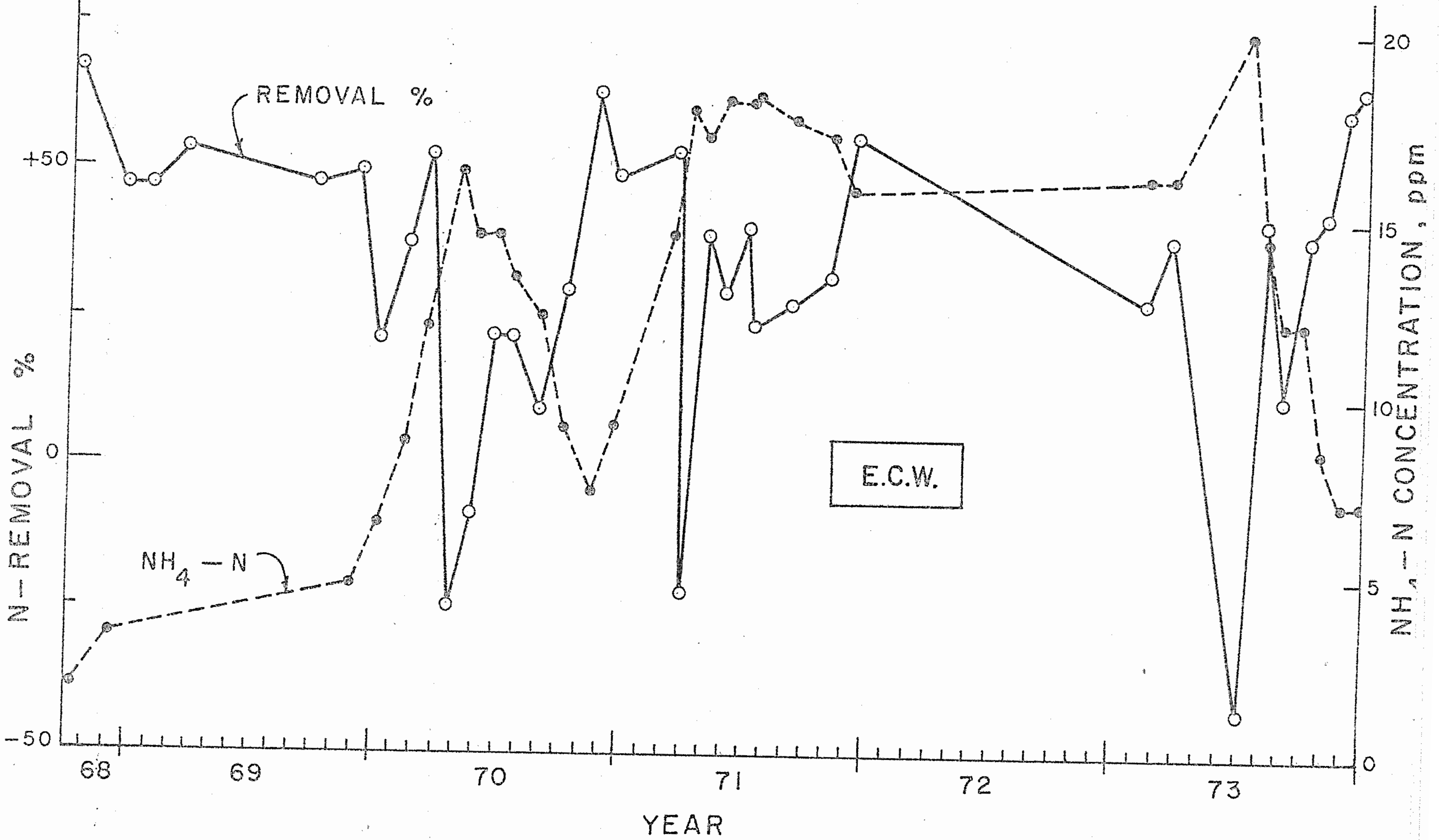


Figure 9. Nitrogen removal and NH_4-N in renovated water for ECW.

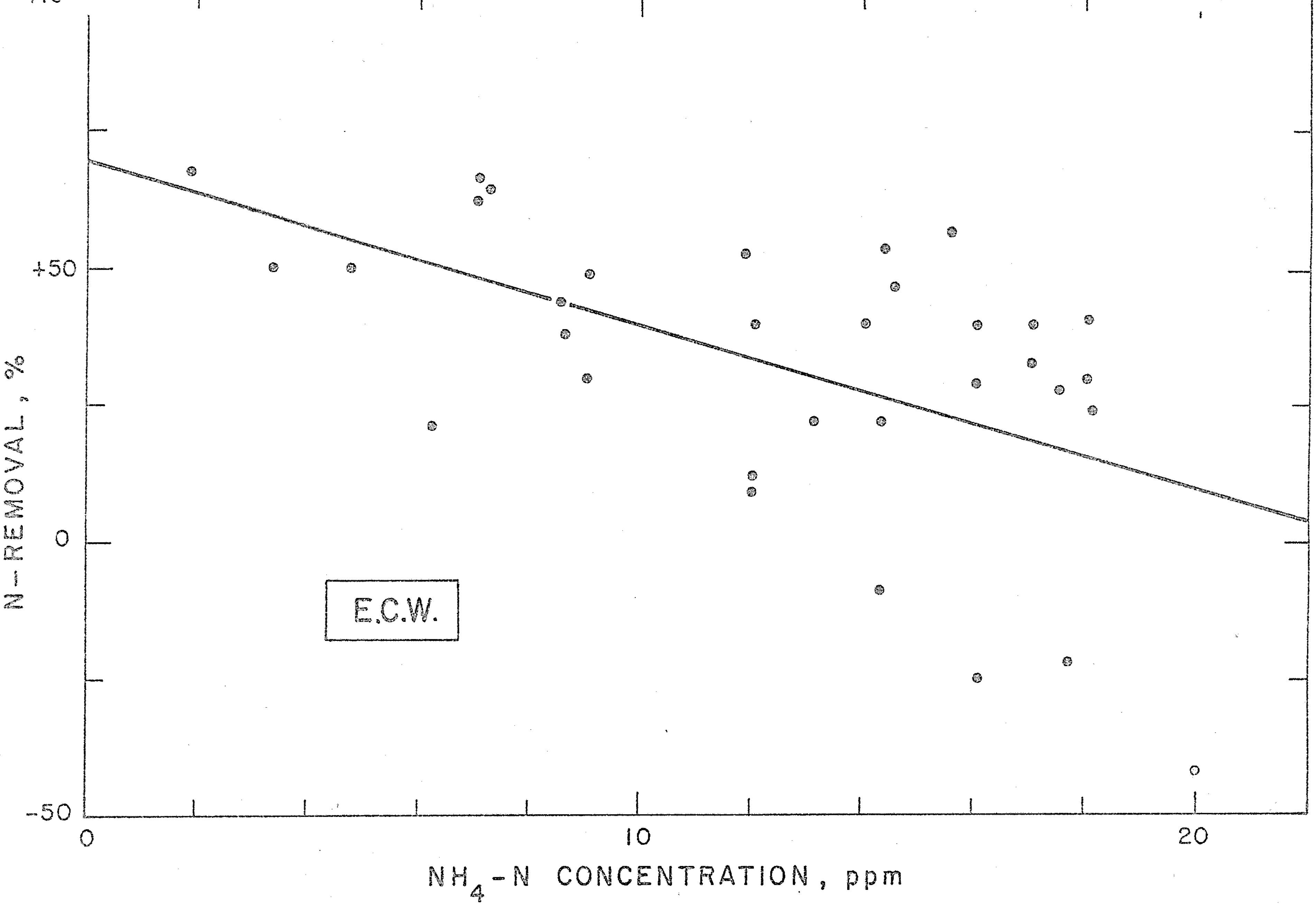


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Figure 10. Nitrogen removal in relation to NH_4-N concentration for renovated water from ECW.

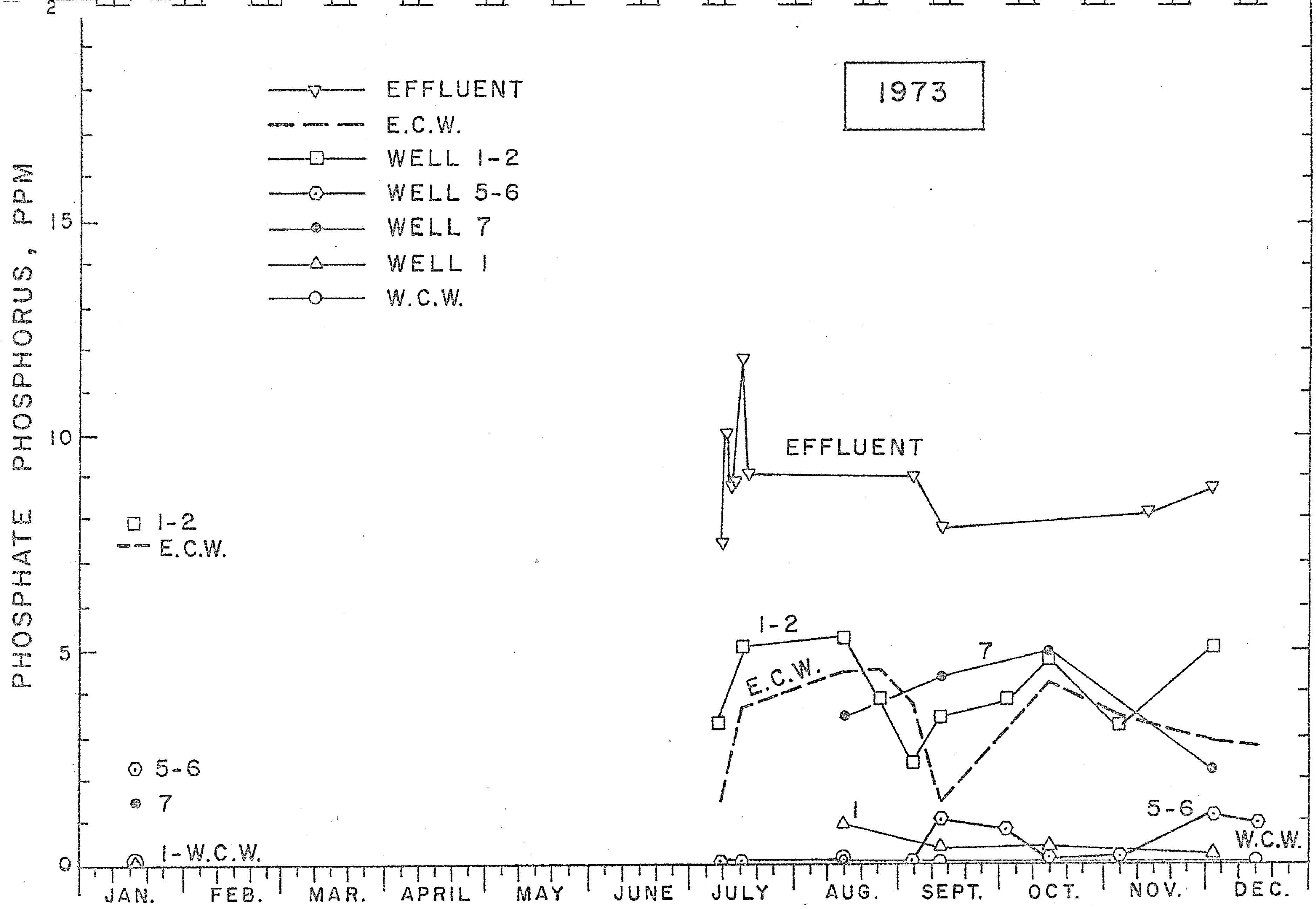

Figure 11. Phosphate concentrations in effluent and renovated water.

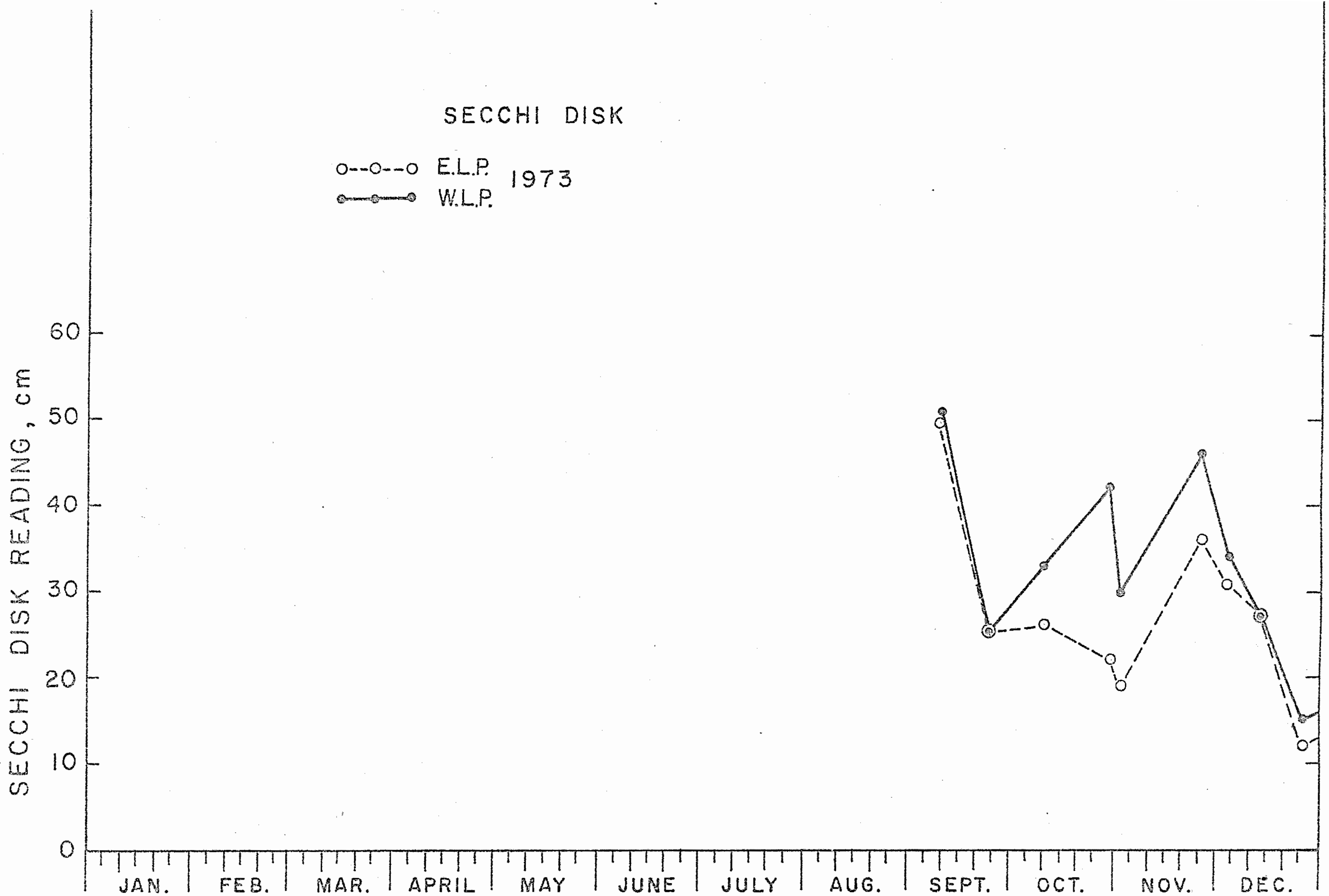

Figure 12. Secchi disk readings in lined ponds.

TITLE: PREDICTING REDUCTION IN WATER LOSSES FROM OPEN CHANNELS BY PHREATOPHYTE CONTROL

CRIS WORK UNIT: 5402-12260-003

A procedure was developed to calculate seepage from a stream due to uptake of groundwater by vegetation or evaporation in the floodplain. The calculation is based on the relation between evapotranspiration rate and water table depth. If such relations are known for certain phreatophytes and for the floodplain condition after phreatophytes have been removed, the reduction in seepage losses from the stream can be computed. The numerical calculation process was simplified by replacing the curves relating evapotranspiration rate and water table depth, which are generally sigmoid, by stepfunctions of the same area. These stepfunctions gave the same seepage as the incremental procedure in several comparisons.

Application of the procedure to a hypothetical stream and floodplain showed that replacing a deep-rooted vegetation by bare soil or shallow-rooted vegetation causes a rise of the water table in the floodplain. The percentage reduction in seepage losses from the stream was only significant if the depth from which groundwater can be removed by evaporation was much smaller after removal than before. The amount of water saved by phreatophyte control increased with increasing elevation of the floodplain above the water level in the stream.

A detailed discussion of the procedure and its application appears in a manuscript of the same title as above. The manuscript will be submitted for publication in Water Resources Research.

PERSONNEL: H. Bouwer

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

CRIS WORK UNIT: 5402-12260-003 CODE NO.: Ariz.-WCL 68-3

PART I. CHEMICAL AND BIOLOGICAL PROCESSES DURING RENOVATION

INTRODUCTION:

Experiments on renovation of secondary sewage effluent by soil columns in 1973 concentrated on methods to remove most of the nitrogen from sewage water by denitrification with little or no addition of an external energy source. The primary experimental areas were

(1) tracer studies to determine how reduction in infiltration rate stimulated denitrification;

(2) additions of organic carbon (dextrose) to soil columns only during the beginning of the flooding period in an attempt to provide carbon for denitrification of the nitrate peak leached from the soil during that segment of the flooding cycle;

(3) experiments with vegetated soil columns to determine if denitrification is stimulated significantly by plants during high-rate land filtration.

PROCEDURE:

Laboratory Columns. The eight soil columns packed in 1972 were used again in 1973. Two columns with low infiltration rates were repacked in August. The columns were flooded with secondary sewage effluent on schedules of 9 days flooded alternated with 5 days dry.

A pulse of KCl was added to 4 columns as a tracer to study the effect of infiltration rate or flux on the movement of nitrate through the soil. The total salt concentration of the first 1,500 ml of sewage water infiltrated into the soil was increased from approximately 1,000 ppm to 3,000 ppm by the addition of 40.2 mm KCl. The salt concentration in the water collected from the bottom of the soil columns was monitored with a Wheatstone bridge. This water was also analyzed for NO_2^-, NO_3^-, and NH_4^+.

Another experiment was conducted to determine if wetting the columns with small quantities of sewage during part of the dry period would stimulate denitrification. About an inch of water was added to each column on two different days during the dry period.

Experiments were then conducted to determine if a pulse of carbon added at the beginning of the flooding period would stimulate denitrification. Enough dextrose to increase the organic C content by 100 ppm was added to the first 2 liters of sewage infiltrated into columns 4 and 8 on August 21. This procedure was repeated on the first day of each flooding cycle until October when carbon was added to the first 4 liters of sewage infiltrated into columns 4 and 8, and the first 2 liters entering column 7. These additions were continued for the remainder of the year. Dextrose was also added to 4 liters of sewage infiltrated into columns 5 and 6 beginning on November 13.

Outside Columns. Nine other columns were constructed in December 1972 and enclosed in a special shelter to study the effect of plant growth on nitrogen removal. These consist of 6-inch diameter PVC pipes packed with material taken from the Flushing Meadows recharge basins. The pipes were placed in an insulated building with the top of the pipes protruding through the roof. The soil was packed in the columns to the level of the roof so that the soil surface was exposed to the atmosphere and plants could be grown in the columns.

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 building 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. The barley was clipped to a 10-cm height. The plant material removed from the columns was weighed, oven-dried at 105 C, and weighed again, while the other clippings were weighed, chopped, and returned to the columns. The barley was clipped on February 18, March 15, and May 3.

The columns were emptied and repacked in June, and planted to common bermudagrass on July 6. Bermudagrass sprigs were planted about an inch apart in the columns. The same three treatments of bare soil, vegetated with clippings removed, and vegetated with clippings returned to the soil surface were used. The grass was clipped on August 3 and at 2-week intervals during each dry period for the remainder of the year. The clippings were weighed and returned to the soil or dried as described above for the barley.

The sewage water and water drained from the columns was sampled daily and analyzed for NO_2, NO_3, and NH_4^+. Oxidation-reduction electrodes were installed at the 2, 20, and 40 cm depths and monitored daily.

RESULTS AND DISCUSSION:

Tracer Study. A plot of infiltration vs. percent nitrogen removal on a log-log basis showed that nitrogen removal increased exponentially as infiltration rate decreased (Figure 1). We hypothesized that a change in infiltration rate affected nitrogen removal by changing the flow characteristics of the system. Nitrate formed in the soil during the dry period was leached from the soil in a narrow concentrated band when the infiltration rate was high. A decrease in infiltration rate caused the nitrate to be leached in a more diffuse wave and allowed considerable mixing of the nitrate with the infiltrating sewage water. Thus, mixing the sewage water with nitrate provided a more favorable C to NO_3-N ratio for denitrification than that obtained when nitrate was leached in a concentrated band. An increase in the detention time within the soil might have also increased denitrification. The nitrate concentration of water collected from soil columns with a low infiltration rate (15 cm/day) was consistently around 5 ppm with little evidence of a nitrate peak, whereas the water from columns with an infiltration rate of 50 cm/day had a peak nitrate concentration of 70-80 ppm (Figure 2A). The NH_4-N concentration was < 1 ppm in both cases. The sewage water contained on the average 30 ppm NH_4-N and 1 ppm each of NO_3-N and organic-N.

We tested the hypothesis by adding a pulse of KCl to the sewage water at the beginning of a flooding period and by monitoring the salt concentration of the water collected from the columns. The total salt concentration of the first 1,500 ml of sewage water infiltrated into the soil was increased from approximately 900 ppm to 3,000 ppm by the addition of KCl. The salt concentration measured with a Wheatstone bridge indicated that a concentrated salt peak passed through a soil column with an infiltration rate of 23 cm/day (Figure 2B). Much more dispersion or mixing occurred in a column with an infiltration rate of 14 cm/day. No concentrated salt peak was observed with the slow infiltration rate, and some increase in salt concentration was measured in water collected throughout the 9-day flooding period and draining from the columns during a 5-day dry period. These data supported our hypothesis that the decreased infiltration rate resulted in more mixing of the nitrate with the incoming sewage water.

Flooding at an infiltration rate of 15 cm/day on a schedule and a soil similar to the one used with the columns would result in 80% N removal during an annual application of 38 m of sewage water. The infiltration rate can be varied in the field by adjusting the water depth in infiltration basins. The optimum infiltration rate could vary with the soil used.

Wetting Soil Columns During Part of the Dry Period. Gilbert et al. (1) suggested that on the basis of field data it might be possible to stimulate denitrification by adding enough sewage during the dry period to saturate the upper few inches of soil but not enough to leach the nitrate to lower depths away from organic material trapped near the surface. Addition of small volumes of sewage during the dry period did not appear to stimulate denitrification (Table 1). This was probably due to the fact that little carbon was available near the surface of the soil during the dry period. The suspended material in the sewage settled out in the jug before the water was siphoned into the columns. These brief experiments were not a thorough test of this procedure, but they do indicate that carbon would have to be supplied in the field from suspended solids collected near the surface or algae growth for denitrification to be stimulated.

Organic Carbon Additions. The addition of dextrose at the beginning of the flooding period stimulated denitrification but did not result in complete denitrification (Table 2). The addition of 100 ppm dextrose to the first 2 to 4 liters of sewage infiltrated increased N removal by 15-20% at each infiltration rate. However, all of the increased N removal at the highest infiltration rate may not be due to added carbon because the infiltration rate declined somewhat with added carbon. The infiltration rates did not change when carbon was added to the other two columns. There may be at least two possible explanations why denitrification was not complete. Although enough carbon was added for essentially complete denitrification, some carbon might have been removed by other microorganisms before denitrifiers could utilize it. It is also possible that the population of denitrifiers was not large enough to reduce the high concentration of NO_3 passing through the soil in a short period of time. The population of denitrifiers probably could be increased by applying carbon throughout the flooding cycle but not by applying it in pulses. An increase in the concentration of carbon added should show whether the limiting factor is the carbon concentration or the population of denitrifiers.

Phosphate Removal. A relatively small number of analyses indicated a relationship between infiltration rate and phosphate removal as was noted last year (Figure 3). This relationship will be investigated thoroughly during next year.

Vegetated Columns. The barley planted in freshly packed columns did not appear to affect nitrogen removal during the first three months (Table 3). However, the % nitrogen removal declined from 84% to 72% in the bare soil columns after 3 months. This was probably due to depletion of some organic matter which was present when the columns were packed with soil from field recharge basins. After the columns were well established, the vegetated columns removed 85% of the nitrogen, or 12% more nitrogen than the bare ones. Returning the clippings to the soil surface did not affect nitrogen removal. The high nitrogen removal in the vegetated columns was probably maintined by the addition of some carbon from dead roots and root exudates.

The barley grew quite well under mostly flooded conditions, e.g., 9 days flooded alternated with 5 day dry periods. The total production for 4 months' growth for columns where clippings were removed was 2 to 4 kg/m^2 or 24 metric tons/ha (Table 4). Although these yields cannot be extrapolated to field conditions, they indicate that vegetative growth was not inhibited and that it may be possible to harvest a crop from a high-rate land disposal field. Returning the clippings to the soil surface definitely inhibited plant growth. The forage production by the two groups of columns was about the same until vegetation was added back to one group from the first harvest. The yield was reduced by more than 50% after the first clippings were returned, and the plants died about a month earlier in the spring than where clippings were removed.

The increase in N-removal by the columns planted to barley occurred at relatively low infiltration rates (12-15 cm/day). The question still remained as to whether vegetation could increase N-removal when very heavy N loads were applied. The columns were re-packed at lower bulk densities after the barley died, and infiltration rates of 20-30 cm/day were obtained (Table 5). The % N-removal was again about the same for vegetated and bare soil columns for about 3 months after bermudagrass was planted in 6 columns (Table 6). The vegetated columns then removed about 9% more nitrogen on the average than bare soil columns. The return of the clippings to the soil surface did not appear to affect N removal. Denitrification must have been stimulated by the plants because the increase in N removal was considerably more than could have been incorporated in plant tissue. The growth of bermudagrass was not affected by returning the clippings to the soil surface. Plant growth was again quite vigorous, but the yield of 1.2 kg/m^2 of dry matter was only about half that obtained from the barley (Table 7). More data on nitrogen removal and yield will be obtained from these columns.

PART II. REDOX POTENTIAL MEASUREMENTS

INTRODUCTION:

Redox potential measurements were continued in both vegetated and nonvegetated soil columns during 1973.

PROCEDURE:

Nine soil columns packed with Flushing Meadows loamy sand were intermittently flooded with secondary sewage effluent. Three of the columns were bare and six were planted with barley (Hordeum vulgare). The vegetated columns were clipped periodically and for three of the columns the clippings were removed. Redox potentials were measured at four depths in the columns using a single reference calomel electrode and a newly developed salt bridge between columns. Redox potential measurements were also made in columns where a pulse of carbon was added to the sewage at the beginning of the flooding period. All columns were fitted with redox probes at 2, 20, and 40 cm depths, and columns exposed to sunlight also had redox probes in the head of water above the soil surface.

RESULTS AND DISCUSSION:

The vegetated columns had lower redox potentials (-200 to -300 mv) near the surface (2 cm) during flooding than the bare columns (0 to 100 mv) (Figure 4). This suggests the availability of more carbon near the surface for denitrification in vegetated columns. The vegetated columns did remove more nitrogen than bare columns. The columns from which the barley clippings were removed had higher redox potentials (500 to 600 mv) near the surface during the dry period than columns with clippings returned to the surface (400 to 500 mv). This suggests the possibility of more denitrification near the surface during the dry period in columns with clippings returned. However, no differences were measured in overall N removal between the two sets of vegetated columns. The N removal in these columns was consistently above 80%, even though the redox potential was not poised in the 200-300 mv range except in the columns where vegetation was returned.

The redox potential in the water above the soil fluctuated in a diurnal pattern (Figure 5). This was due to oxygen production by algae growing in the water during the day and oxygen utilization by algae and decomposing organic matter during the night. The drop in redox potential during the night was much more pronounced in the columns where clippings were returned. The redox fluctuations suggest that nitrate could be formed by oxidation of ammonium during the day and denitrified during the night or after infiltration into the soil. However, overall nitrogen removal by these columns was not much different than nitrogen removal in columns in the laboratory where algae did not grow.

Measurements at frequent intervals showed that the redox potential changed abruptly after 2 hours of drainage at the 2 and 8 cm depths, after 4 hours at the 40 cm depth, and after 6 hours at the 60 cm depth (Figures 6 and 7).

A method was devised to connect the columns with a salt bridge so the calomel electrode would not have to be transferred from one column to another. A piece of 15-bar ceramic was cut and placed in a tube and inserted into each column (Figure 8). The tubes were connected by Tygon tubing filled with a saturated KCl solution which was also connected to a reservoir of saturated KCl. The calomel electrode was suspended in the reservoir. Readings could then be taken without moving the calomel electrode, and an automatic switchbox scanned the probes of each column at a preset rate. This resulted in successful automatic, time-continuous measurements of soil redox potentials. Measurements were made to compare the old method where the calomel electrode was moved from one column to another with the salt bridge method (Figure 9). The two methods measured the same change in redox potentials (e.g., the slope is 1.0), but the salt bridge technique gives a slightly higher reading (e.g., the intercept was 11.1 mv). The amount of KCl solution added to the soil columns was minute.

The addition of carbon in a pulse at the beginning of the flooding period lowered the redox potential, but the 2-cm probe was the only one to register much change (Figure 10). This suggests that most of the increase in microbial activity occurred near the surface.

SUMMARY AND CONCLUSIONS:

Experiments with soil columns during 1973 concentrated on methods to remove most of the nitrogen from sewage by denitrification with little or no addition of an external energy source.

Nitrogen removal was shown to increase exponentially as infiltration rate decreased, with 80% removal occurring at 15 cm/day infiltration. Tracer experiments conducted by adding a pulse of KCl to the first 1,500 ml of sewage water infiltrated at the beginning of the flooding period showed that reducing the infiltration rate resulted in more mixing of the nitrate from the soil with the incoming sewage water. No concentrated salt peak occurred with the low infiltration rates, indicating that these rates provided a more favorable C to NO_3-N ratio for denitrification than high infiltration rates which result in leaching a concentrated nitrate peak. Eighty percent removal could be obtained during an annual application of 38 m of sewage water.

Addition of small volumes of sewage during the dry period to increase the soil moisture content near the surface did not increase nitrogen removal. This indicates that carbon would have to be supplied from suspended solids or algae growth for this method to increase N removal. The addition of 100 ppm dextrose to the first 2 to 4 liters of sewage water infiltrated into soil columns increased N removal by 15-20%. Additional experiments are needed to determine if more carbon is needed or if the population of denitrifiers limits N removal under these conditions.

Growing barley or bermudagrass in soil columns increased N removal by 9-10% after the plants became well established. This could result in an increase in N removal of 2,000 kg/ha. The return of clippings to the soil surface has not increased N removal. Plant growth was quite vigorous with dry matter yields of 4 kg/m^2 for barley and 1.2 kg/m^2 for common bermudagrass. This suggests that vegetative growth was not inhibited by flooding for 9 out of every 14 days, and it may be possible to produce a crop under these conditions. Returning the clippings to the soil surface inhibited the growth of barley but did not affect the bermudagrass.

REFERENCES:

1. R. G. Gilbert, J. B. Robinson, and J. B. Miller. The microbiology and nitrogen transformations of a soil recharge basin used for wastewater renovation. Proc. Internatl. Conf. on Land for Waste Management, Ottawa, Canada, October 1973.

2. J. C. Lance and F. D. Whisler. Nitrogen removal during land filtration of sewage water. Proc. Internatl. Conf. on Land for Waste Management, Ottawa, Canada, October 1973.

3. R. S. Linebarger, F. D. Whisler, and J. C. Lance. A new technique for rapid and continuous measurement of redox potentials. Jour. Environ. Qual. (in review)

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

Table 1. The effect of sewage water additions to columns during 2 days of the dry period on nitrogen removal1/

Treatment	COLUMN NUMBER			
	1	4	7	8
	% nitrogen removal			
Water added2/ during dry period	60.5	26.1	60.2	33.3
No water3/ added	62.3	23.9	63.3	31.4

1/ Columns flooded with sewage on schedules of 9 days flooded alternated with 5 days dry.

2/ Average of 2 cycles June 12 - July 10.

3/ Average of 2 cycles July 24 - August 21.

Table 2. The effect of additions of carbon to sewage water during the first 2-3 days of a 9-day flooding period on N-removal

Column	% N-removal		Infiltration rate (cm/day)	
	Added C	No C	Added C	No C
1	34.5	20.4	26.4	33.7
2	53.9	33.3	22.6	23.0
3	79.0	60.9	13.9	14.6

Table 3. Effect of barley on nitrogen removal by soil columns

Period	% NITROGEN REMOVAL		
	Bare soil	Clippings removed	Clippings returned
JAN 3 to MAR 6	84	85	85
APR 3 to MAY 15	72	85	84

Table 4. The yield of barley forage grown in soil columns flooded with sewage water on schedules of 9 days flooded alternated with 5 days dry

	OVEN DRY WEIGHT	
Harvest date 1/	Clippings removed	Clippings returned 2/
	g/column	g/column
15 February	26	26
16 March	14	4
3 May	3	1
Total	43	31
Total in kg/m^2	2.4	1.7

1/ Planting date was December 5, 1972.

2/ Calculated from green wet by assuming % moisture was the same as where clippings were removed and dried.

Table 5. The infiltration rates of vegetated and bare soil columns flooded with sewage effluent

Date	INFILTRATION RATE		
	Clippings removed	Clippings returned	Bare
1973	cm/day	cm/day	cm/day
8/7 - 8/21	24.7	25.1	26.0
8/21 - 9/4	25.4	26.0	26.5
9/4 - 9/18	24.6	25.2	26.2
9/18 - 10/2	24.6	24.9	26.0
10/2 - 10/16	22.7	24.0	23.6
10/16 - 10/30	22.4	23.4	23.4
10/30 - 11/13	21.1	22.5	22.8
11/13 - 11/27	22.5	23.2	22.6
11/27 - 12/11	22.7	25.7	22.6
12/11 - 12/26	22.7	23.1	22.5

Table 6. The effect of common bermudagrass on nitrogen removal by soil columns

Period	% NITROGEN REMOVAL		
	Clippings removed	Clippings returned	Bare soil
AUG 7 to OCT 30	47.7	48.9	44.6
OCT 30 to DEC 11	52.9	50.5	42.1

Table 7. The yield of bermudagrass forage grown in soil columns flooded with sewage water on a schedule of 9 days flooded alternated with 5 days dry

Date	CLIPPINGS REMOVED			CLIPPINGS RETURNED			Total
	Column Number						
	1	4	7	2	5	8	
	<—			g			—>
Aug 3	1.7	3.3	2.6	2.4	5.5	2.0	17.5
Aug 17	2.0	2.5	2.8	2.7	4.1	2.7	16.8
Aug 31	1.4	2.5	2.1	2.2	3.7	2.1	14.0
Sep 14	1.9	1.6	1.6	1.8	2.4	1.2	10.5
Sep 28	1.0	0.9	0.5	1.1	1.5	0.7	5.7
Oct 12	0.3	0.3	0.3	1.4	1.3	1.0	4.6
Oct 26	2.9	3.0	2.0	3.9	5.6	2.6	20.0
Nov 9	1.9	2.5	1.9	2.5	2.8	1.9	13.5
Nov 26	0.8	1.2	1.6	1.1	1.8	1.1	7.6
Dec 7	1.2	1.1	1.7	0.9	1.9	1.6	8.4
Dec 21	1.3	1.2	2.3	1.6	2.2	1.9	10.5
Total	16.4	20.1	19.4	21.6	32.8	18.8	129.1*

*Average yield per column was 21.5 g.

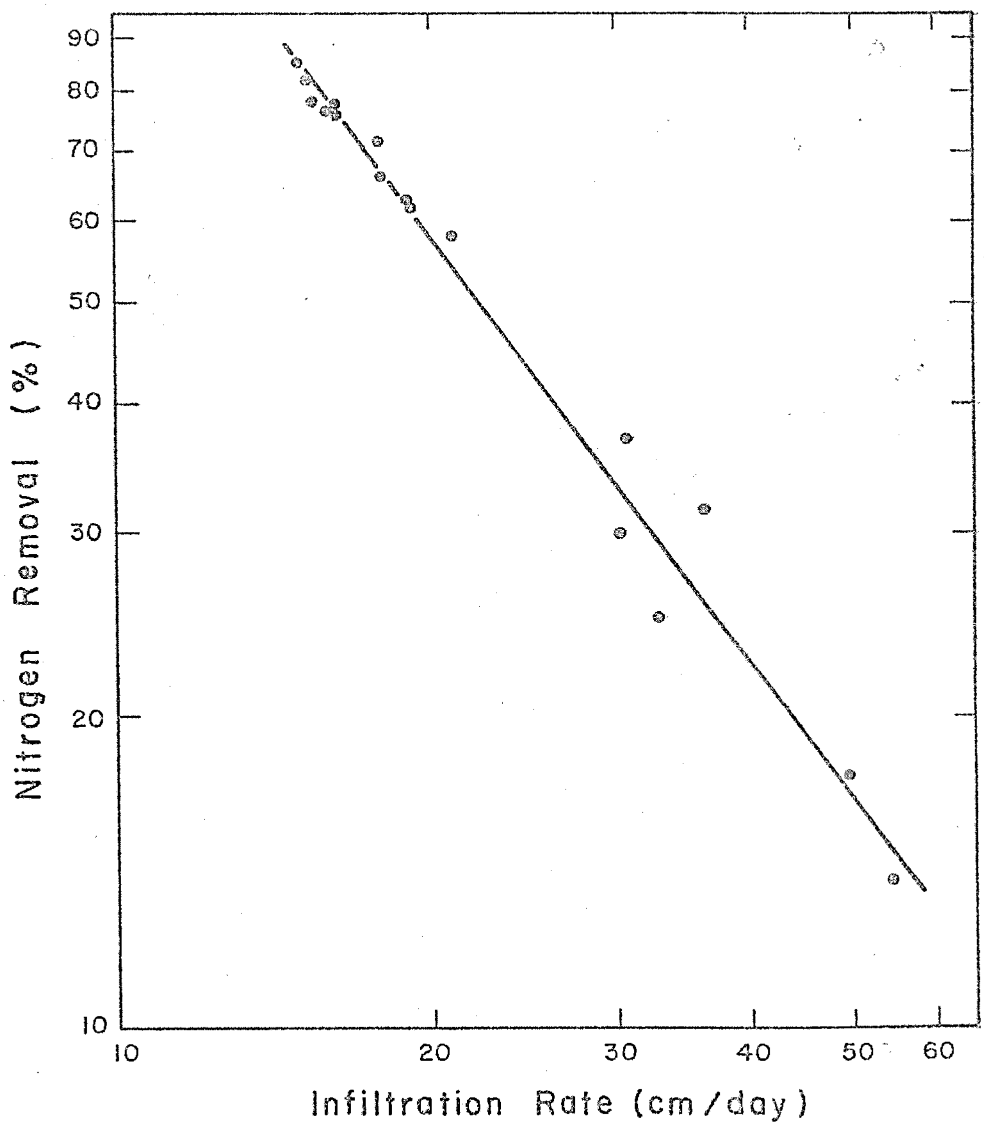

Figure 1. The effect of infiltration rate on % nitrogen removal from sewage water by soil columns.

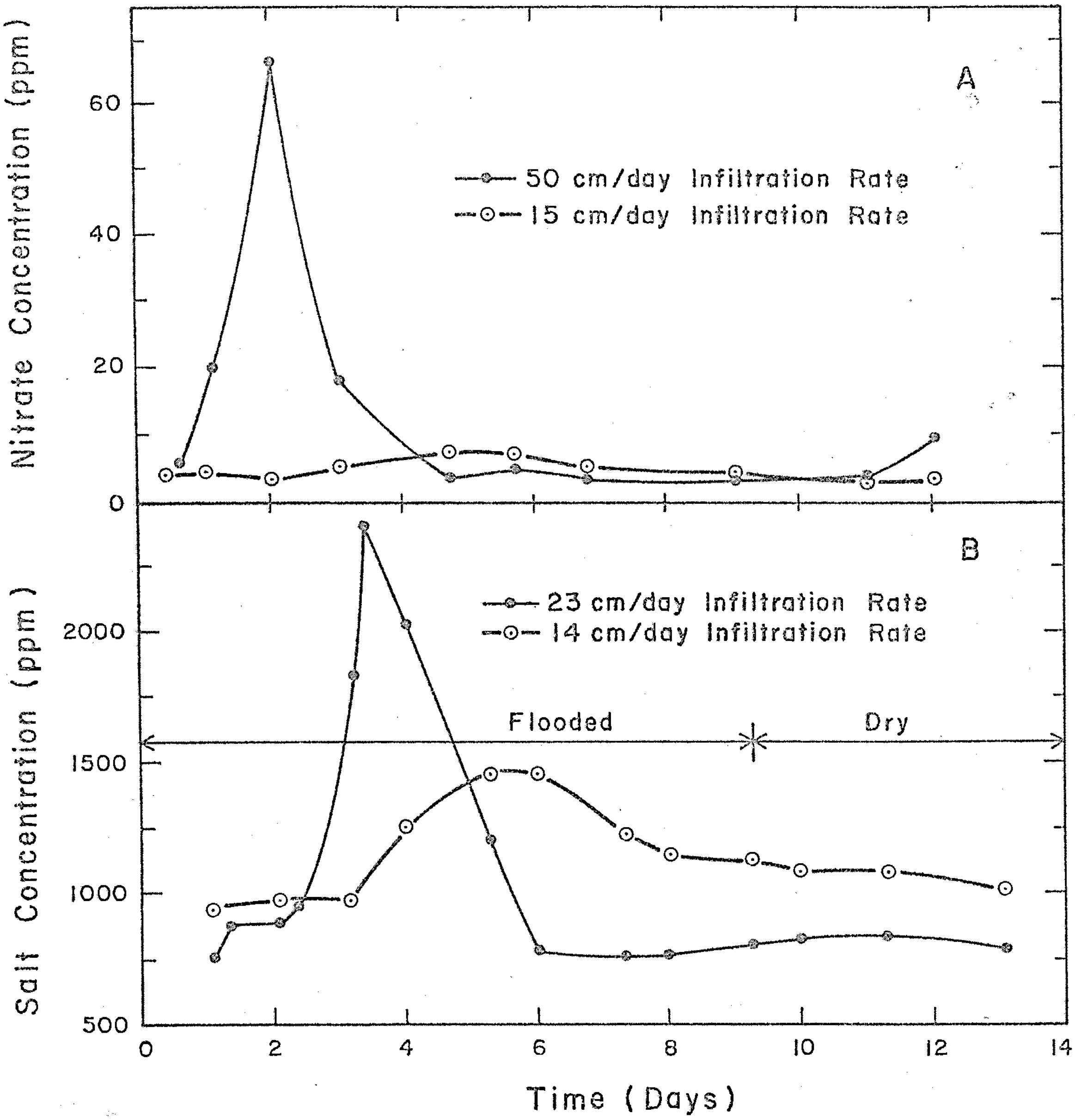

Figure 2. A.—The nitrate content from two soil columns flooded with sewage water at different infiltration rates.
B.—The salt content of water from two soil columns with different infiltration rates. The salt concentration of the first 1,500 ml of sewage water infiltrated was increased from 900 to 3,000 ppm by the addition of KCl.

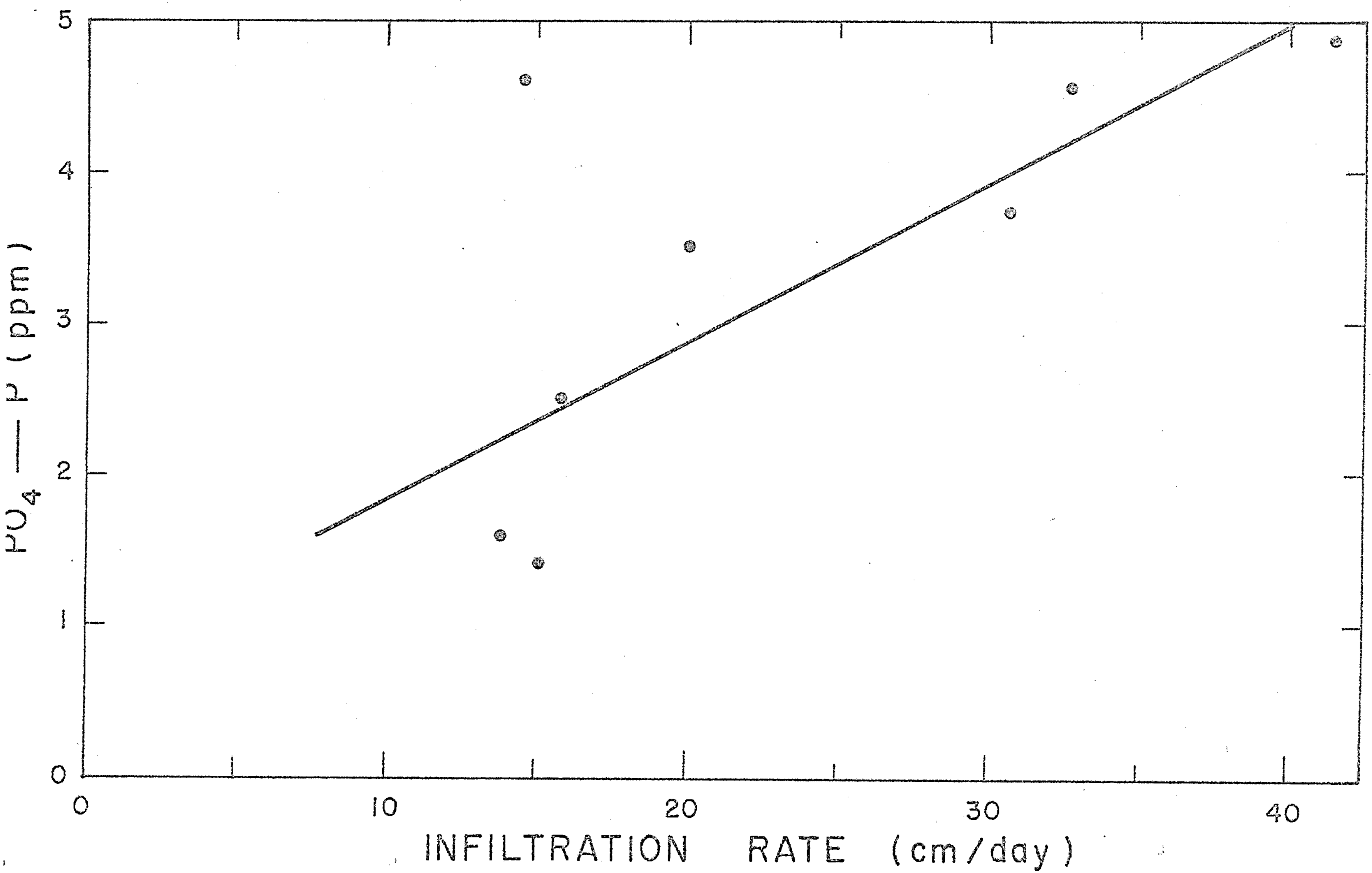

Figure 3. The effect of infiltration rate on the PO_4-P content of water from soil columns.

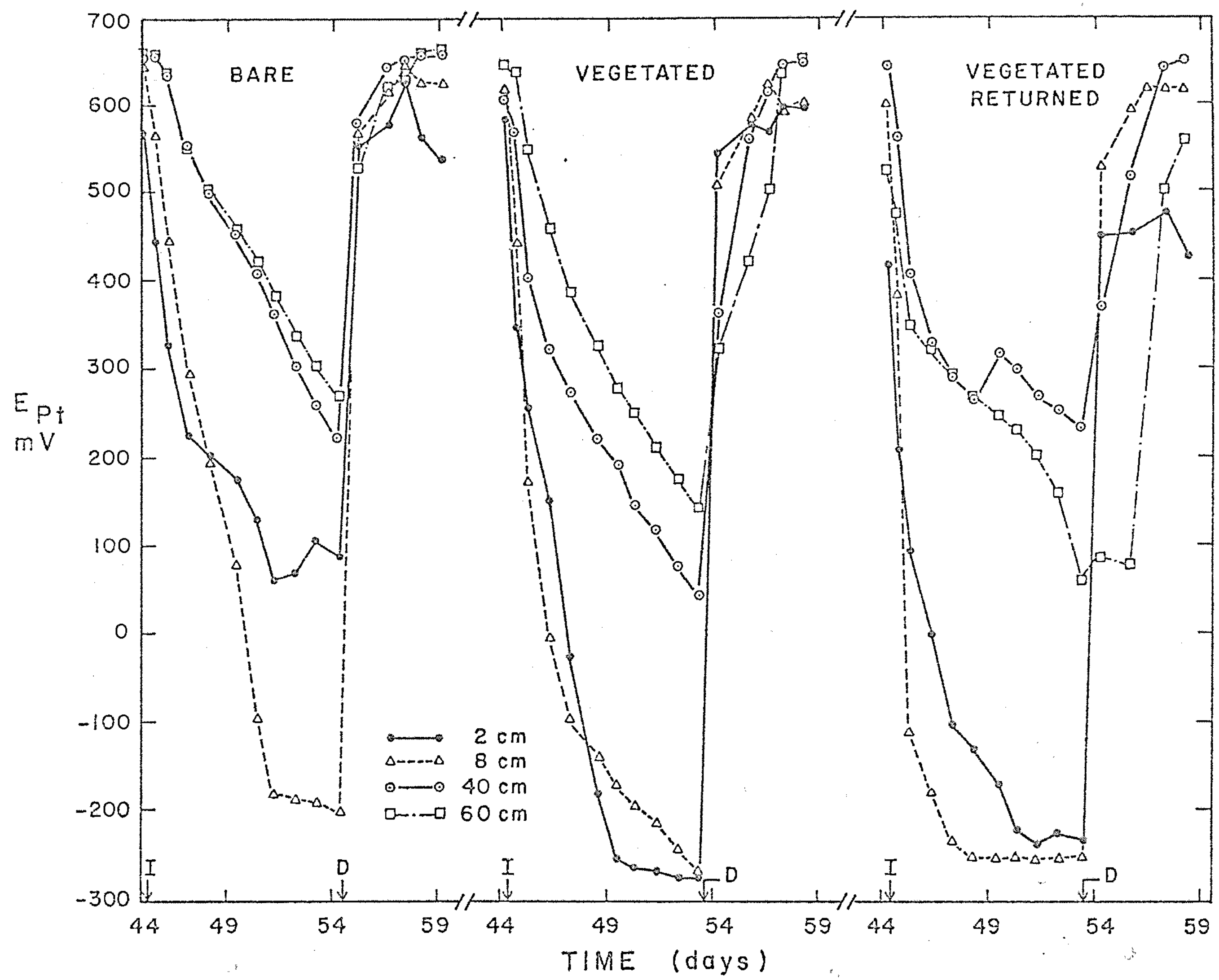

Figure 4. Redox potentials in vegetated and nonvegetated soil columns flooded with sewage water. I designates beginning of infiltration and D designates beginning of drainage.

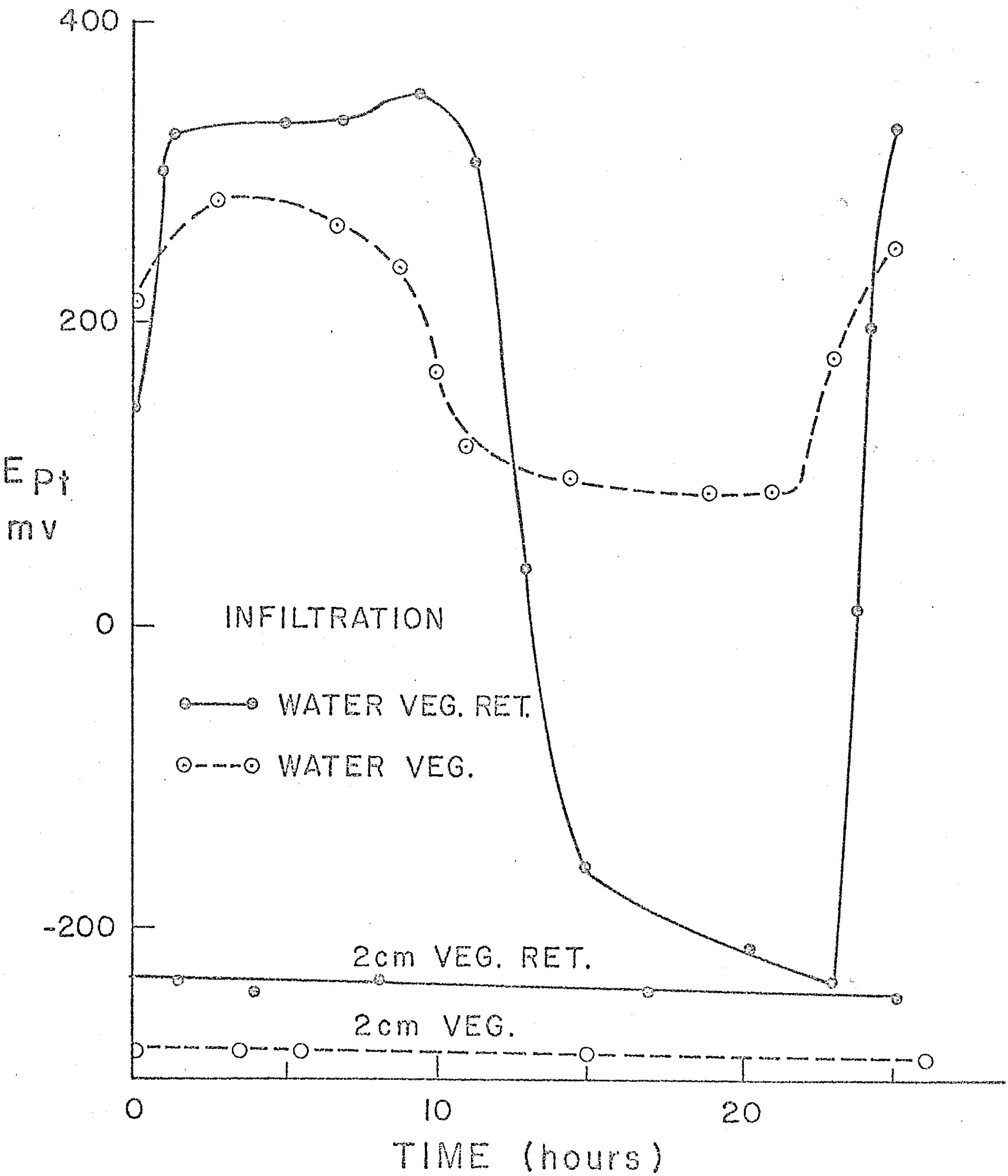

Figure 5. Diurnal redox changes near the surface of soil columns flooded with sewage water.

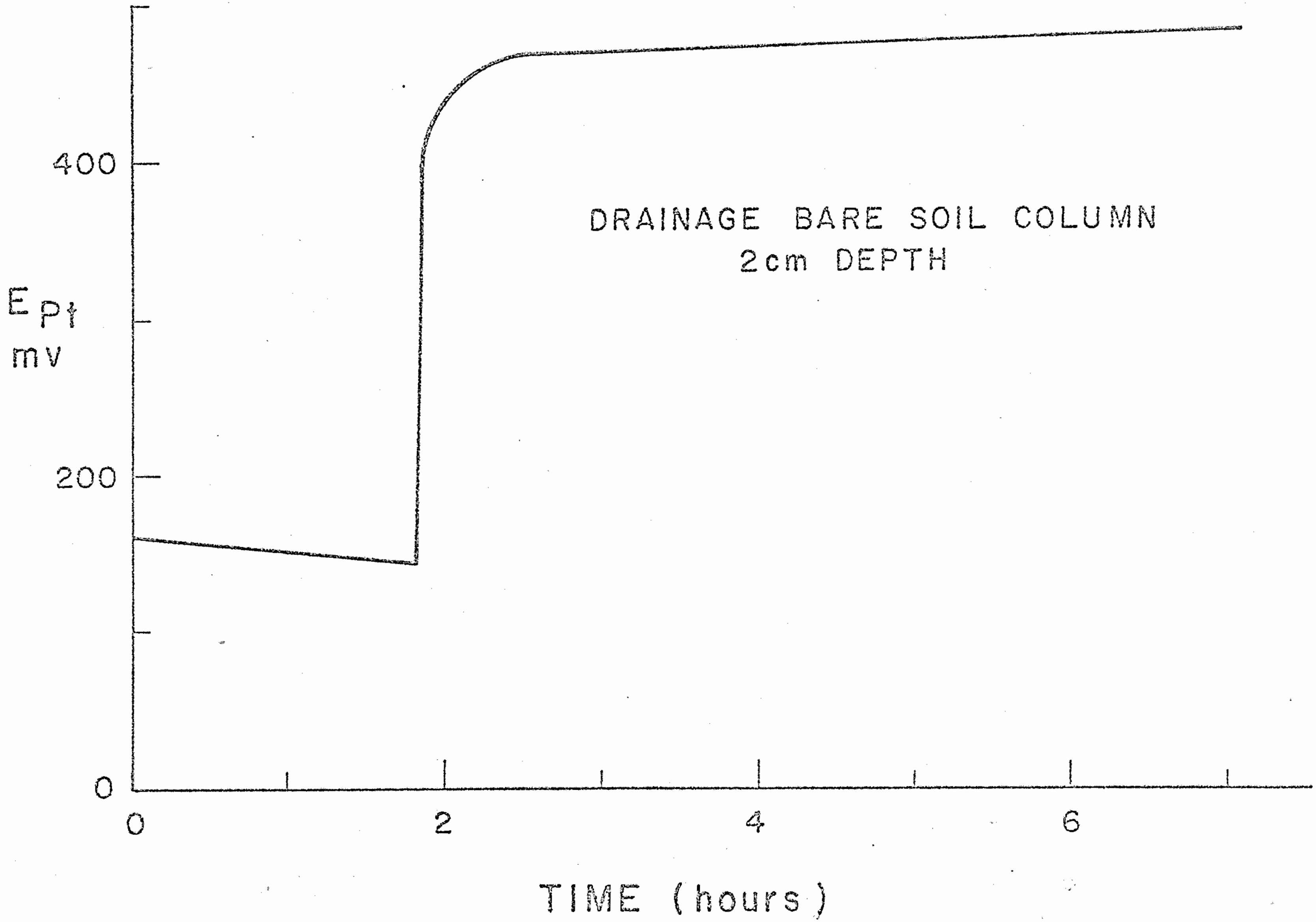

Figure 6. Redox changes at the 2-cm depth during the first 6 hours of drainage after 9 days flooding with sewage water.

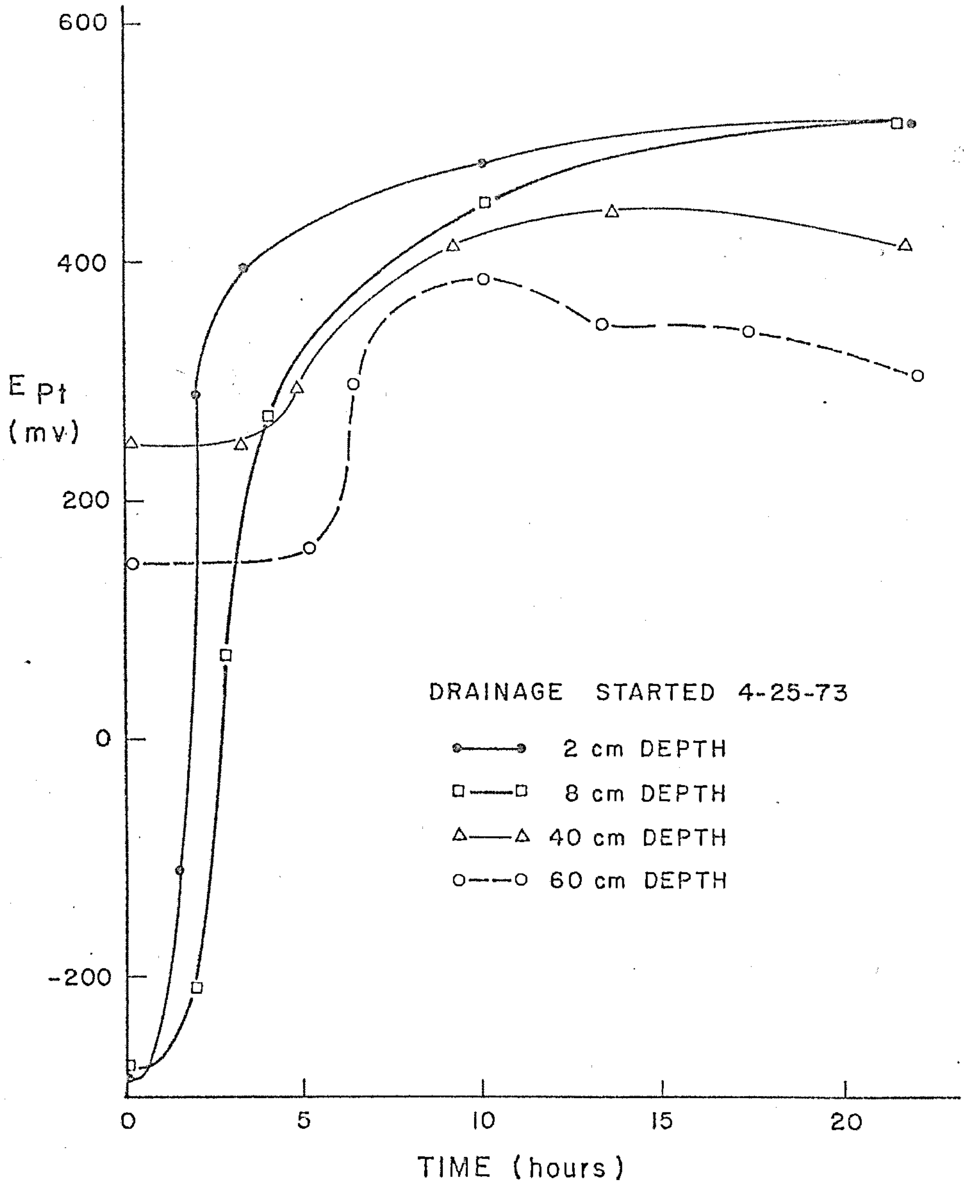

Figure 7. Redox changes during the first day of drainage after 9 days flooding with sewage water.

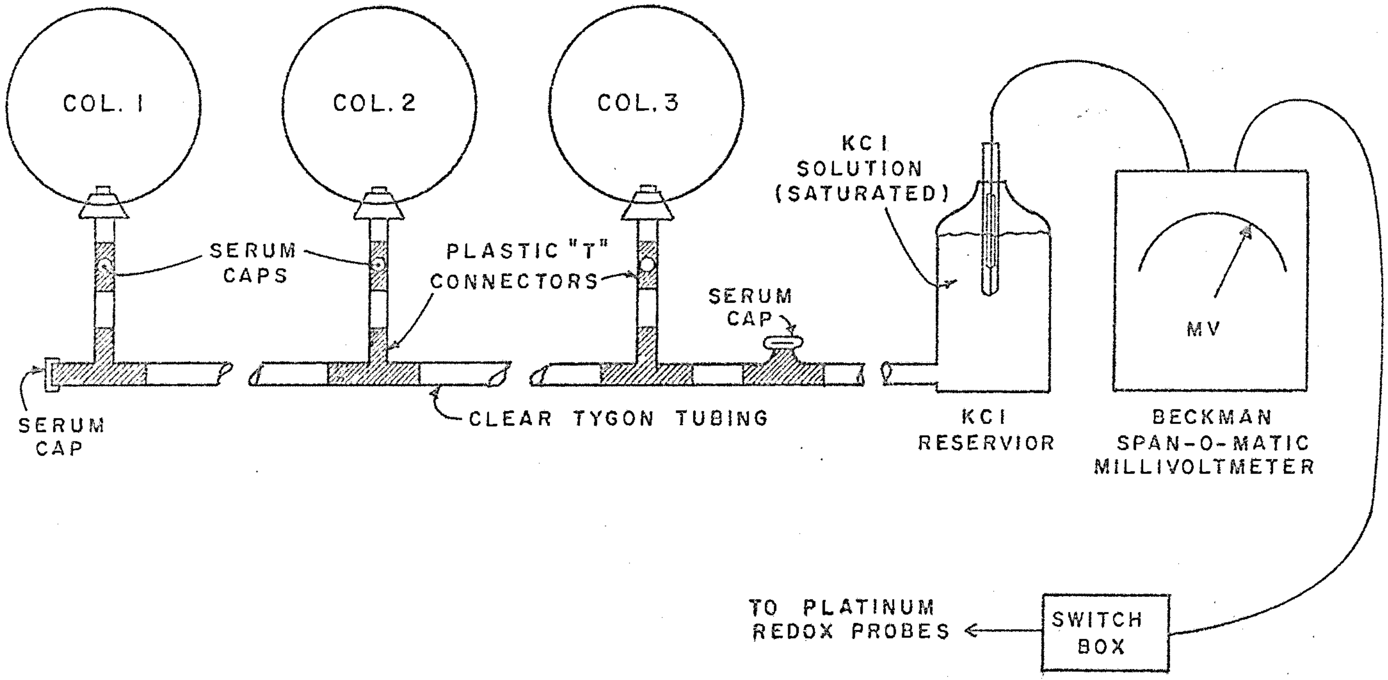

Figure 8. A salt bridge system to connect the reference electrode to several soil columns for continuous redox measurements.

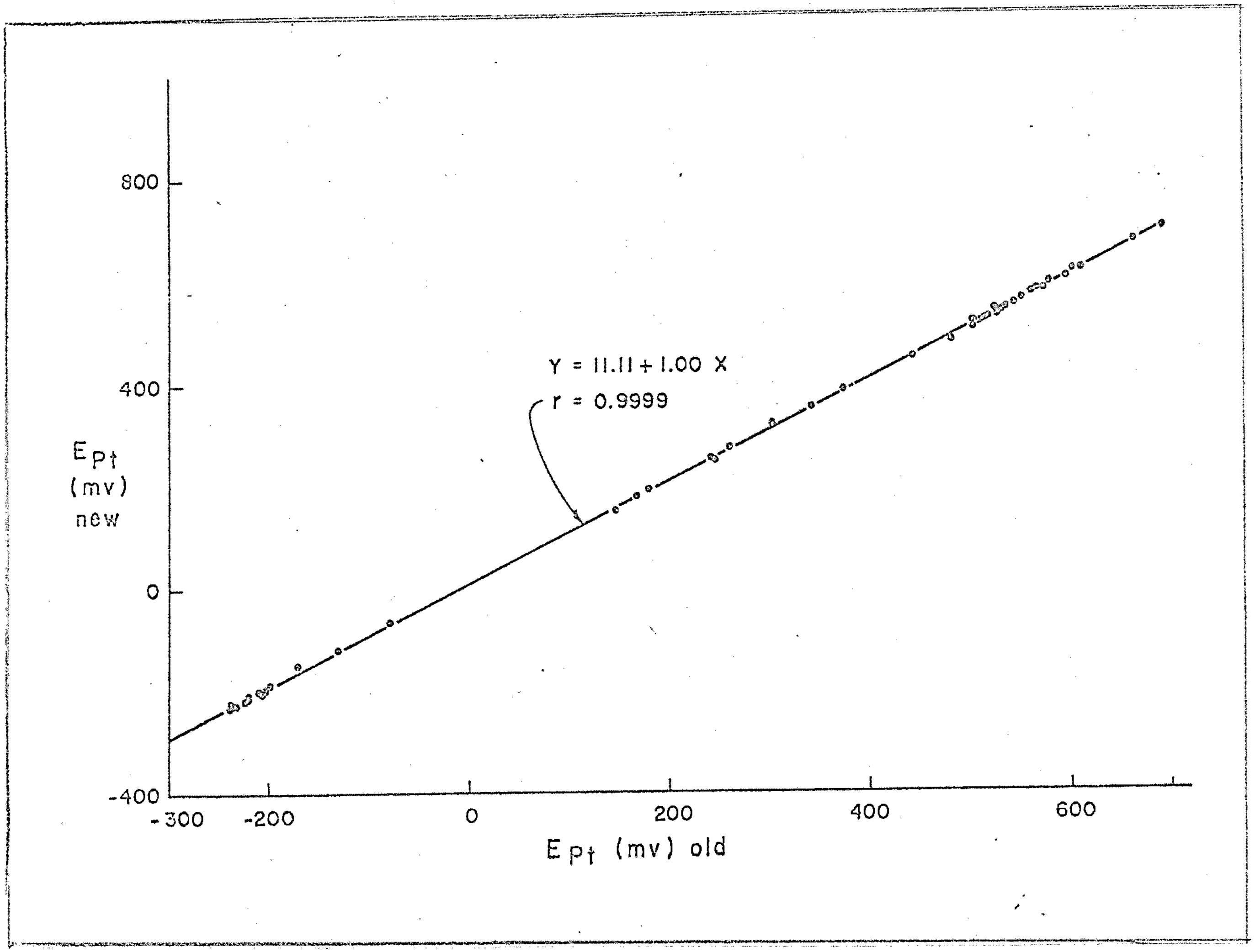

Figure 9. The least squares analysis of a comparison test between old and new methods for redox potential measurements.

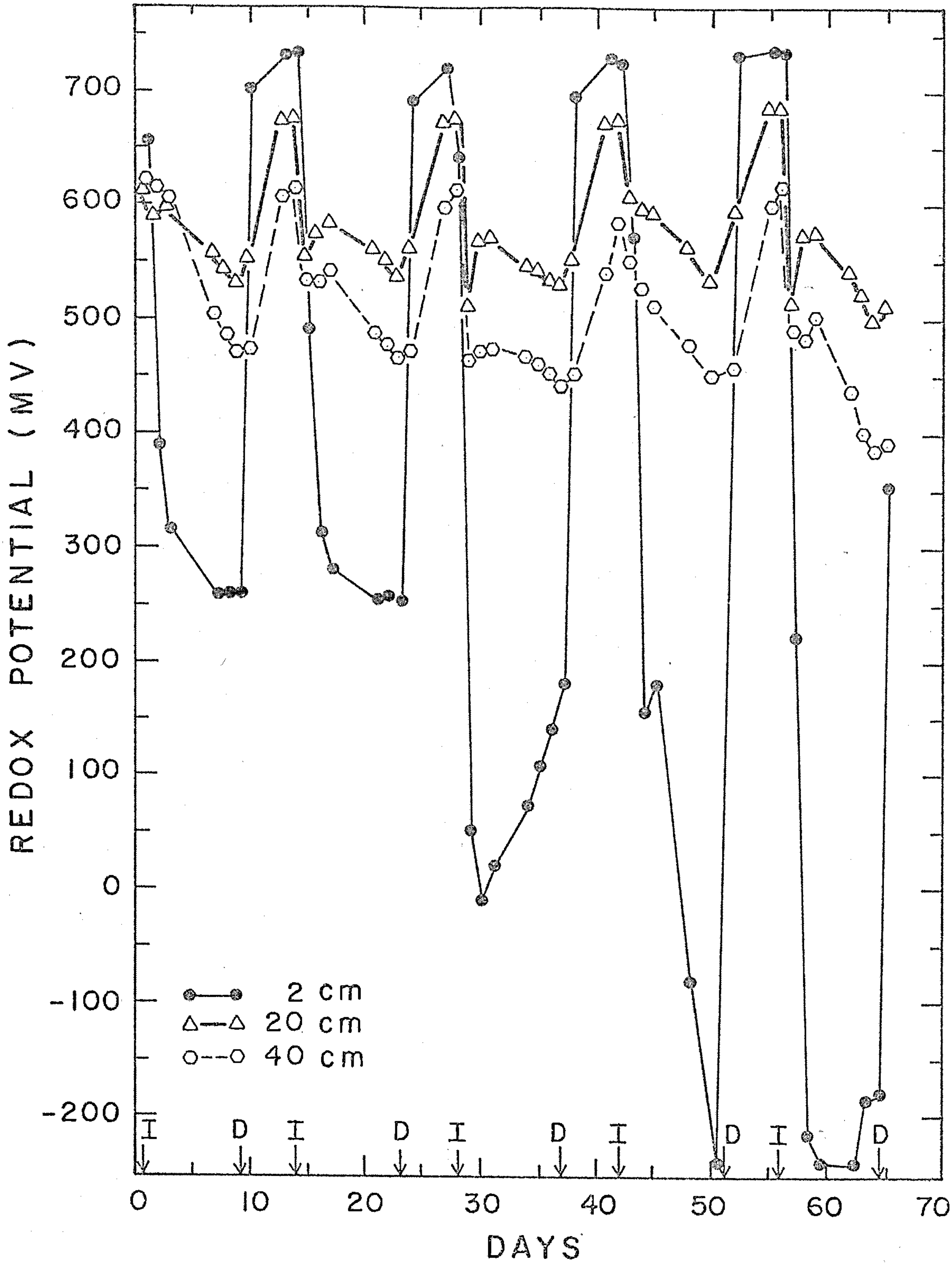

Figure 10. Redox potentials in a soil column where a pulse of carbon was added during the first 2 days of the flooding period. One hundred ppm dextrose was added at the beginning of infiltrations 3 - 5. I designates beginning of infiltration and D designates beginning of drainage.

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

CRIS WORK UNIT: 5402-12260-003 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 groundwater recharge.

The objectives 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.

PROCEDURE:

The procedures and methods and materials are identical to those described in the 1972 Annual Report, Section 7:1-4.

RESULTS AND DISCUSSION:

The microbial environment and biological processes affecting N removal in soil basins used for waste water renovation were investigated. The basins were flooded intermittently with secondary sewage effluent. Oxygen depletion in the soil profile was caused by a high biological oxygen demand (BOD) and/or retention of water in the surface soil. These factors contributed to a slow recovery of redox potential (Eh) at lower depths and a slightly reduced Eh at 2 cm during drying, and a rapid decline of Eh at 2 cm during flooding. Algal activity affected the decline and the diurnal cycles of Eh at 2 cm. Most of the BOD was in the top 15 cm and decreased rapidly during drying. Nitrification was rapid in the surface soil, but the detection of N_2O indicated denitrification occurred in reduced microsites during drying. Denitrification during flooding was unlikely because nitrate was rapidly leached.

The higher summer temperatures and longer days caused the soil basins to dry much faster after flooding and the algal activity in the flooded basin was greatly increased. In general, the system was influenced as follows under the summer climatic conditions:

1. Dissolved oxygen concentrations were higher in the effluent water, because of increased algal productivity. This may enhance nitrification at the soil surface during flooding.

2. The soil surface of the basin dried quickly after flooding, allowing oxygen to enter the soil profile at a faster rate and increase the depth of the aerobic zone.

3. Redox potentials recovered faster in lower portions of the soil profile during drying, because of the more rapid entry of oxygen into the soil.

4. The reduced microsites in the soil profile were rapidly converted to oxidized microsites after flooding, because of faster drying and oxygen entry in the soil profile. Less nitrous oxide was detected, indicating denitrification and nitrogen removal was less during the summer than in the winter.

5. Rates of nitrification were increased throughout the soil profile, because of the higher temperatures and larger aerobic zone. The majority of the nitrate formed accumulated in the soil and was leached into the groundwater during the next flood period.

6. Soil respiration rates were greater throughout the soil profile, thus the energy stored during flooding was utilized rapidly. Therefore, energy necessary for denitrification was not

available to combine with nitrate when reduced sites or zones were present in the soil.

We have concluded from these results that since the energy, nitrogen sources, and microbial activity are concentrated in the surface soil, we are limited to approximately the top 15 cm of the soil profile in which to promote N removal by denitrification. Accordingly, the flooding period should be only long enough to saturate that portion of the soil profile with ammonium-N where oxygen is not limiting nitrification during drying. The length of flooding will be determined by such factors as the cation exchange capacity of the aerobic zone, the concentration of ammonium-N in the sewage effluent and the infiltration rate of the sewage effluent into the soil recharge basin. The rate of nitrification will determine the length of the dry period. Therefore, to promote N removal in the surface layer of the soil recharge basin, we have proposed that when nitrification is well underway during drying, the soil surface should be maintained near saturation by intermittently applying small quantities of sewage effluent with a sprinkler system. This would result in little nitrate-N movement and would promote the establishment of a soil environment more favorable for denitrification. After periodic sprinkling and sufficient drying of the soil surface to recover the infiltration rate, the basin could be flooded normally. Hopefully, the sprinkling, flooding and drying cycles, which are presently being investigated, could be repeated on a time schedule that would achieve more N removal from the waste water recharge system by denitrification.

PUBLICATIONS:

1. Gilbert, R. G., Robinson, J. B., and Miller, J. B. The microbiology and nitrogen transformations of a soil recharge basin used for wastewater renovation. In Proceedings

of the International Conference on Land for Waste Management. 1-3 October 1973, Ottawa, Canada. 1974. (In Press).

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

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

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

CRIS WORK UNIT: 5402-12260-004 CODE NO.: Ariz.-WCL 65-2

INTRODUCTION:

Water harvesting studies in Hawaii consist only of the Maui plots which are being observed to evaluate the long-term weathering characteristics of the treatments. Measurement of the rainfall-runoff from these plots is not being conducted at the present time. The major research emphasis in the State continues to be the rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii.

RESULTS AND DISCUSSION:

Part I. Water Harvesting.

The four-plot water harvesting site on Maui is being maintained as a materials weathering site. The water meters for the rainfall-runoff measurements have been removed and returned to the laboratory. The site was not visited during 1973. The operational asphalt-fiberglass catchment on Kukaiau Ranch is reported to be performing satisfactorily. This site was not visited in 1973. An 11-acre catchment treated with sprayed asphalt on Puwaawaa Ranch on the Island of Hawaii was inspected in April 1973. This catchment was constructed by compacting cinders and then spraying with several coats of cutback asphalt. Runoff has been lower than expected because of the coarseness of the cinders. It is estimated that the threshold rainfall is approximately 0.5 inches.

Part II. Rainfall-runoff-erosion studies.

Problems have been encountered with the recorders on the five runoff-erosion sites. The recorder punch mechanism motors are failing after about 6 months of operation. This means that if one of the two instruments fails, the entire set of data for the site is lost. At present it is estimated that up to 20% of the data is unusable. Delays in translating the recorder data tapes to computer-compatible punched paper tape were experienced when several parts of the paper tape punch on the translator wore out. Approximately 50% of the recorder tapes have been translated and are ready for computer processing.

Observations at the five sites indicate the source of sediment is from the roads in the fields and during the harvesting operattions. There have been no visible signs of erosion from a field which has a growing crop.

The Mililani site, originally a pineapple site, has been termed a fallow site and covered with a wild plant growth. Two years ago the site was planted to potatoes for one crop. The Waialua pineapple site is in the process of being converted to sugar cane.

Measurements of the sediments as collected by the sediment samplers is being conducted by the University of Hawaii personnel. Rainfall has been unusually low and the amount of runoff has been quite low.

There are plans to convert the recorders at the sites to strip chart recorders in an attempt to speed the process of data analysis. This is planned for late 1974. At this time, a sixth site of pineapple will be instrumentd.

Part III. Rainulator Studies.

The University of Hawaii has been conducting extensive studies using a rainulator from Watkinsville, Georgia, to determine the relative erosion characteristics of the major agricultural soils. This work will be completed in early 1974. The data from the rainulator will be correlated with the results from the erosion plots.

SUMMARY AND CONCLUSIONS:

The major research emphasis in the State of Hawaii continues to be the rainfall-runoff-erosion studies conducted in cooperation with the University of Hawaii. Problems have been encountered with recorder motors on the five sites. It is estimated that up to 20%

of the data is unusable. Data processing is expected to be up-to-date by early 1974. Observations at the five sites indicate that the source of sediment is from the roads and the fields in the bare condition. Results from the rainulator studies will be correlated with the runoff-erosion results from the plots.

PERSONNEL: Gary Frasier and John Replogle

TITLE: PHYSICAL AND CHEMICAL CHARACTERISTICS OF HYDROPHOBIC SOILS

CRIS No.: 5402-12260-004 CODE No.: Ariz.-WCL 67-2

No matter the stage of development of the arid West, water seems always to be in limited supply. One way of supplying that needed water on site is by water harvesting off soils which have been chemically or physically modified to increase precipitation runoff. Field testing of materials and treatments is both costly and slow. Laboratory techniques for such evaluations which then reliably extrapolate to field situations are needed.

This year laboratory studies were directed at (1) searching for materials and treatments worthy of field testing, (2) checking effects of soil type and properties on water repellency after treatment with organic coatings, and (3) checking on relative effectiveness of six methods for measuring water repellency of soils.

The soils were compacted into petri dishes using a standardized procedure, dried, and treated with stabilizers and/or water repellents (Table 1). The soils, listed in Table 2, were all from water harvesting sites. The Pullman is a silty clay loam soil from Texas; the others - sandy loams from Arizona.

The methods of measuring water repellency were (1) the acqueous-alcohol drop test, (2) the water drop penetration time test, (3) the relative height of a large sessile drop resting on the smoothed, treated soil, (4) presence and persistence of air bubbles entrapped between the soil-water interface of the water drops used in test No. 2, (5) the same as test No. 4 except this test used the large sessile drops in test No. 3, (6) noting whether the large sessile drops from test No. 3 would infiltrate into the soil with time or else eventually would evaporate away. Soil stability against water erosion was determined by dropping 1000 5-mm-diameter water drops onto the treated soil surface in

5 minutes from a height of 2 m. Results are summarized in Table 2.

Two organic coating materials showed promise in the laboratory by producing highly water-repellent soils; they were the paraffin wax and the dust suppressant. The laboratory studies indicated that the optimum rates for maximum repellency were approximately 0.5 kg/m^2 for the paraffin and 1.0 l/m^2 for the dust suppressant.

These materials were applied with and without stabilizers. Stabilizers had no significant influence on water repellency, but did help control erosion (Table 2). For applications greater than 1.0 l/m^2 the dust suppressant alone stabilized the soil. For applications less than this, a stabilizer was required to prevent erosion for most soils. For the paraffin, the stabilizers controlled erosion, except for one or two soils receiving the light (0.27 kg/m^2) wax application. It is interesting to note that the paraffin-only treatment (treatment No. 1) failed the erosion test on all five soils, yet in the field where wax was applied without stabilizer, erosion has not been a problem. This tends to question the validity of such an erosion test.

Soil type did not significantly affect the results from the water repellency tests. As expected, once monolayer coverage had been achieved, repellency was strictly a function of the molecular structure of the organic coating material at the organic-water interface. Soil type, however, was a factor controlling erosion. Table 2 shows that the Granite Reef and Seneca soils over all were the most resistant to erosion.

Of the six tests for measuring water repellency, the sessile drop height test and the two entrapped air tests proved to be the most consistent and reliable. The drop height test was a quantitative test, while the two entrapped air tests were strictly qualitative in nature. Efforts are continuing to make the entrapped air test quantitative.

The two water repellents which showed the most promise in the laboratory (i.e., paraffin wax and the dust suppressant) have been applied to pilot plots in the field at the Granite Reef test site. Runoff results are tabulated in Table 3. Two wax plots and the dust suppressant are compared to a butyl-covered plot and to two smoothed-only plots. The wax plots were installed in late 1972; the dust suppressant in late 1973. The wax continues to yield approximately 90% runoff; thus shows no sign of deterioration at the end of 1973. The dust suppressant also is yielding nearly 90% runoff.

Currently, the dust suppressant is undergoing further testing on ten micro-plots in a runoff farming experiment to establish if water harvesting techniques can be used to increase the growth and yield of the native desert plant jojoba (Simmondsia chinensis).

PERSONNEL: Dwayne H. Fink.

Table 1. Water-repellent treatments.

Treat. No.	Treatment
	Paraffin wax (143-150 F MP)
1.	Wax at 0.68 kg/m^2
2.	Wax at 0.68 kg/m^2 + stabilizer (Dow 620); 3% at 1.5 l/m^2
	Paraffin wax (143-150 F MP) + stabilizer (PVA, Elvanol 72-60); 3% at 1.5 l/m^2
3.	Wax at 0.81 kg/m^2
4.	Wax at 0.54 kg/m^2
5.	Wax at 0.27 kg/m^2
	Paraffin wax (143-150 F MP) + stabilizer (Dow 209); 3% at 1.5 l/m^2
6.	Wax at 0.81 kg/m^2
7.	Wax at 0.54 kg/m^2
8.	Wax at 0.27 kg/m^2
	Paraffin wax (143-150 F MP) + stabilizer (Dow 233); 3% at 1.5 l/m^2
9.	Wax at 0.81 kg/m^2
10.	Wax at 0.54 kg/m^2
11.	Wax at 0.27 kg/m^2
	Paraffin wax emulsion (128-130 F MP); 47.5% wax by weight.
12.	Wax at 0.68 kg/m^2
13.	Wax at 0.68 kg/m^2 + stabilizer (Dow 209); 3% at 1.5 l/m^2
14.	Wax at 0.68 kg/m^2 + stabilizer (Dow 233); 3% at 1.5 l/m^2
	Lard
15.	Lard at 0.81 kg/m^2
16.	Lard at 0.81 kg/m^2 + stabilizer (Dow 233); 3% at 1.5 l/m^2
	Dust suppressant (DS), (Chevron Oil Co.), 70% resinous solids, 30% volatiles
17.	DS at 2.26 l/m^2
18.	DS at 1.13 l/m^2
19.	DS at 0.56 l/m^2
20.	DS at 1.13 l/m^2 + stabilizer (Dow 209); 3% at 1.5 l/m^2
21.	DS at 0.56 l/m^2 + stabilizer (Dow 209); 3% at 1.5 l/m^2
	Silicone (Dow XZ - 8 - 5079)
22.	Silicone, 3% at 1.5 l/m^2
23.	Silicone, 6% at 1.5 l/m^2

Table 2. Dripolator soil stability test.

Treat. No.	SOIL Granite Reef	Seneca	Pullman	Monument Tank 1-3	Monument Tank 2-3
1	S-2s	S-3m	S-3m	S-1m	S-1m
2	N	N	N*	N*	N
3	N	N	N	N	N
4	N	N	N	N	N*
5	N	N	N	N	N
6	N	M	N*	N*	L*
7	N	N	L*	L*	S*-1m
8	N	L	S*-2m	S-4m	S*-2m
9	N	N	L*	L	L*
10	N	N	S*-5m	N*	L*
11	N	N	L*	L*	L*
12	S-1m	S-2m	S-1m	S-30s	S-30s
13	N	M	M*	L*	S-5m
14	L	N	L*	L*	L*
15	N	N	N*	M	M
16	N	N	N	N	N*
17	N	N	N	N	N
18	N	N	N	N	M
19	N	N	S-3m	S-3m	S-3m
20	N	N	N*	N	N*
21	N	N	N*	N*	N*
22	S-2m	S-15s	S*-30s	S*-30s	S*-15s
23	N	S-4m	S-30s	S*-30s	S*-30s

N, no erosion; L, light; M, moderate; S, severe plus time to erode to bottom of petri dish (s, seconds; m, minutes).
*, soil cracked prior to dripolator test.

Table 3. Precipitation runoff yields of wax-treated and dust-suppressant-treated soils vs. smoothed and butyl-covered soil.

		Runoff					
		$10\ m^2$ plots				$200\ m^2$ plots	
Date	Precip.	#14 Smoothed	#11 Butyl	#13 Wax	Dust (#12) Suppressant	R-3 Smoothed	R-2 Wax
1973	mm	%					
1 Jan	2.8	0	90	79		0	94
4 Jan	2.8	36	100	93		0	90
10 Jan	3.3	0	82	70		0	71
17 Jan	2.6	0	85	92		0	74
11 Feb	4.4	11	86	68		0	70
12 & 13 Feb	11.3	31	98	98		28	91
15 Feb	5.7	0	100	84		1	92
20 & 22 Feb	26.4	22	98	91		6	97
7 Mar	2.5	0	68	44		0	54
8 Mar	3.0	0	100	*		0	79
12 Mar	25.8	35	107	101		22	96
13 Mar	9.5	33	95	86		19	86
21 Mar	5.5	0	84	80		0	93
22-23 Mar	5.5	0	91	85		0	85
26 Mar	2.5	16	104	104		0	84
28 Mar	13.6	22	98	93		8	92
30 Apr	4.1	0	98	80		0	76
13 May	2.7	0	85	59		0	73
13 Jun	3.5	0	89	80		0	80
3 Jul	1.8	0	0	0		0	62
11 Jul	10.0	39	80	96		14	76
14 Jul	22.3	63[1]	101[2]	*		63	92
5 Aug	3.1	0	71	64		0	40
15 Aug	2.5	0	68	64		0	68
18 Nov	12.8	8	95[2]	99	89	0	90
22 Nov	8.4	25	98[2]	96	87	1	88
22-26 Nov	9.4	0	89	77	85	0	81
SUMMARIES[3]							
1972	243.8	28	100	92	--	31	90
1973	207.8	17	94	88	87	14	87

1. Data taken from R-3.
2. Data taken from $200\ m^2$ butyl-covered plot, L-1.
3. Based on actual runoff events recorded rather than on total yearly precipitation.

* Data lost.

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

CRIS No.: 5402-12260-004 CODE NO.: Ariz.-WCL 68-2

INTRODUCTION:

Observations and water discoloration studies were continued in the evaluation of the performance of surface coatings for reinforced asphaltic membranes. Field studies consisted of the installation of a new asphalt-fiberglass membrane on the Nelson Road catchment. Observations were continued of existing operational field catchments.

RESULTS AND DISCUSSION:

Part I. Operational Catchments.

Reports of the performance of the unfenced Tombstone catchment indicate there is minimal animal traffic on the surface of the catchment. To date there has been no damage to the membrane. The Metate catchment was visited in August 1973. Around the perimeter of the catchment, the asphalt coating on the fiberglass has been damaged, presumably by insects. This damage extends onto the catchment for a distance of about 2 ft. On the remainder of the catchment the asphalt coating is starting to chip. There is a definite need for a new seal coat on the entire catchment. The asphalt-lined reservoir at Metate had about 2 ft of water in storage at the time of the inspection. There were numerous holes in the lining above the water line. This is believed to have been caused by ants. Several plants were growing through these holes. The lining appeared satisfactory below the water line.

The Bureau of Land Management at Safford, Arizona, is continuing to use the asphalt-fiberglass as a standard catchment material. Six new catchments were completed during the year. Two of the catchments use earthen reservoirs lined with the asphalt-fiberglass for the water storage. There have been some problems with insuring watertight seams at the lap joints.

On one of the units a motorcycle was driven on the catchment surface approximately one month after completion. The damage caused by the motorcycle was considered to be minimal.

In October 1973, a new asphalt-fiberglass catchment was installed in cooperation with the Bureau of Indian Affairs on the Hualapai Indian Reservation. This catchment, called the Nelson Road Catchment, has had various types of treatments during the last 10 years. Most of the treatments had failed because of the lack of maintenance. The last treatment, a two-phase asphalt treatment, was scraped from the surface, then the soil compacted with rubber-tired vehicles. Eight men retreated the catchment with asphalt-fiberglass in approximately 5 hours. Problems were encountered during treatment with plugging of the asphalt pump. The asphalt emulsion was over 6 months old and had become separated. A clay emulsion sealcoat was applied to the catchment by brushing 2 weeks later.

The bottom end of this catchment is directly connected to an excavated reservoir. The reservoir had previously been lined with asphalt-fiberglass in 1962. Since that time, essentially no maintenance had been performed and numerous holes had developed in the lining. The old lining was removed and a new asphalt-polypropylene lining will be installed in 1974.

Part II. Laboratory Studies.

Studies were continued on the small soil trays at the Granite Reef Testing Site in the evaluation of the weathering properties of various protective coatings for reinforced asphaltic membranes. Table 1 lists the treatments and a summary of the 1972 and 1973 water discoloration measurements. The 1973 data does not include data from January-March storms because of low degrees of discoloration from all samples. The Chevron D. T. coating on tray No. 3 shows the best result and is reducing discoloration by about 97%. Trays Nos. 5 and 9 treated with the Gaco Hypolon and the Chevron

D. T. No. 440, respectively, have essentially failed. The yellow highway paint, Tray No. 11, continues to chip from the asphalt surface but would be classified as a satisfactory treatment as would the United Paint Tray No. 2. The studies will be continued to determine the long period weathering of the coatings.

The only studies conducted on developing reinforced asphaltic membranes for reservoir linings was the testing of a sample of modified asphalt-polypropylene membrane from a catchment near Logan, Utah, for water tightness on the pressure plate apparatus. The sample was able to support an air pressure equivalent to 50 ft of water with no measurable leak. The asphalt modification will be tested on fiberglass in 1974.

Part III. Evaporation Covers.

The supported panels of asphalt-fiberglass on the two lined reservoirs at Safford District, Bureau of Land Management, were only partially successful. The units were very difficult to install and maintain satisfactorily.

SUMMARY AND CONCLUSIONS:

Studies were continued at the Granite Reef Testing Site on the evaluation of surface coatings for reinforced asphaltic membranes. Several coatings are performing satisfactorily after 2 years of weathering and are reducing the discoloration of runoff water by over 90 percent.

A new asphalt-fiberglass treatment was installed on the Nelson Road Catchment on the Hualapai Indian Reservation. Observations and reports on other operational catchments of asphalt-fiberglass indicate the units are generally performing satisfactorily if maintained. The Metate catchment was visited the past year and shows signs of needing a new seal coat. There has been essentially no maintenance on the membrane of the catchment or reservoir during the past 4 to 5 years. The reservoir was holding about 2 ft of water. Above the water line there were numerous holes, possibly caused by ants. There were indications that insects were eating the asphalt from the fiberglass on the perimeter of the catchment.

PERSONNEL: G. W. Frasier.

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	Reduction in Discoloration 1972	Reduction in Discoloration 1973 3/
			(kg/m^2)	(%) 1/	(%) 1/
1	Enjay 2-part butyl	27 Oct 71	.325	80	85
2	United paint	27 Oct 71	.325	90	90
3	Chevron D. T.	27 Oct 71	.325	95	97
4	Enjay 2-part butyl	5 Nov 71	.400	80	71
5	Gaco hypolon	10 Apr 72	.400	10	6
6	Basecoat alone	16 Jul 71	-	-	-
7	Gaco K4230 aluminum	10 Apr 72	.400	85	- 2/
8	Chevron D.T. No. 100	10 Apr 72	.400	85	77
9	Chevron D.T. No. 440	10 Apr 72	.400	85	32
10	Base coat alone	16 Jul 71	-	-	-
11	Highway paint yellow	Jun 72	.400	99	90
12	Gaco K4210R black	10 Apr 72	.400	90	71

1/ Based on the base coat alone Tray No. 6.

2/ Water sample collection broken three times. Insufficient data for true comparison.

3/ Did not include data from Jan-Mar storms.

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

CRIS WORK UNIT: 5402-12260-004 CODE NO.: Ariz.-WCL 71-6

INTRODUCTION:

Long range durability and efficiency studies were continued for several materials in 1973, including SSP foamed butyl, Mini-vaps, foamed wax blocks, and three continuous wax covers. A new blue dye material called Aquashade was tested, and granular wax was reevaluated. Two methods of applying wax in a thin film were also tried.

A report of the evaporation studies was presented at the Symposium on Water-Animal Relations in June at Twin Falls, Idaho, and later appeared in the symposium proceedings.

Field evaluation of two floating covers constructed of closed cell continuous sheeting was continued. The covers were installed in the fall of 1971 on tanks in southwest Utah. A paper published in the Journal of Range Management entitled "Floating Sheets of Foam Rubber for Reducing Stock Tank Evaporation" described the fabrication and initial performance of such covers.

Analyses of data from a wind tunnel study on model tanks were completed during the year. The study was to determine the effect of wind on floating covers used on tanks.

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, Aquashade, and granular wax were tested at the laboratory site, and the foamed wax blocks and three continuous wax covers were tested at Granite Reef.

The Mini-vaps and SSP foamed butyl tested at the laboratory site were the same as reported on last year. The Aquashade was applied at a rate of 0.78 cc/m^3, and 3.74 kg of the granular wax was applied to just cover the surface area.

The foamed wax blocks and three continuous covers tested at the Granite Reef site were the same as reported on last year. Two different methods of applying the wax were tested on the Granite Reef pond. The first method consisted of melting the wax and spraying it on the water surface through a nozzle. The second method consisted of melting the wax as above, except it was simply poured on the surface using 3-gallon buckets.

The main emphasis of the field evaluation of floating covers deals with physically maintaining the covers on the water surface and overall performance. To provide this information, two floating covers were fabricated from foam sheet stock, 48 inches wide and 3/16 inch thick, and installed on tanks in 1971. Both tanks were about 30 feet in diameter. Inspection reports are sent to us by Bureau of Land Management cooperators. The reports contain information regarding general condition and operation of the covers. Maximum wind gust anemometers have been installed near the tanks. Wind gust readings are included in the reports.

A wind tunnel study was completed for circular water-storage tanks. The main objective was to determine if an optimum freeboard for a floating cover (distance from top of tank to water surface) does exist and to define it for various tank heights and diameters. Model tank diameter was 12 inches. Freeboard-to-diameter ratios ranged from 0 to 4/9, and tank height-to-diameter ratios ranged from 0 to 1.

RESULTS AND DISCUSSION:

Laboratory Studies. The SSP foamed butyl was damaged during a tank cleaning operation in March and was removed from the tank. Over 3 years of exposure had caused the butyl to deteriorate and it was easily torn. Efficiency had also decreased considerably from 74% in 1970 to only 56% for the first 3 months of 1973. The decrease was probably due to weathering of the material since all other factors such as size, tanks, and procedure, were the same.

The Mini-vaps also appear to be deteriorating as efficiency dropped from 27% in 1971 to only 15% in 1973.

A blue dye called Aquashade was applied to tank #3 after the SSP foamed butyl was removed. This dye was supposed to reduce algae growth, but was tested mainly to see what effect it had on evaporation. Initial evaporation was greater than that from the control by about 8%; however, after 5 months the trend reversed and for the 9-month study evaporation varied from the control by less than 1%. Measurements indicated that algae growth was equal in the treated and untreated tanks although types of algae were different.

High melting point granular paraffin wax was applied to tank #4 for reevaluation since previous short tests were inconclusive due to frequent rain and flooding of the tanks. Some of the wax was flooded off the tank in March and a new treatment was made in April. For the year the efficiency was 21%, which compares with the Mini-vaps and previously tested perlite. Some means of providing an overflow with a screen to maintain the wax would be required in the field for this cover to be practical.

Granite Reef Studies. The evaporation reduction efficiency of the wax covers remained essentially the same during 1973. Averages for the year were 34, 73, 85, and 88%, respectively, for the foamed wax blocks, 125°-135° wax layer, 120°-125° wax layer, and the 125° charcoal-covered wax layer.

The methods of applying low melting point wax that were tested indicated that melting the wax and pouring it on the water surface may be more effective than melting it and spraying it on. The small particles produced when the molten wax was forced through the nozzle did not melt to form a continuous layer but rather became wet and remained as individual particles. The melting and pouring method also requires less equipment and no skilled labor.

Field Installations - Southwest Utah. Jackson Wash Tank, northwest of Cedar City, Utah -- Reports on the cover condition were completed for June 4 and September 6, 1973. When visited in June the tank was not being used, and only about 4 inches of water was in the bottom of the tank. A wind gust anemometer was installed at the site during the inspection. The cover came off the tank early in June, but the exact cause was not determined. Wind may have displaced it or wind in combination with overfilling may have caused the problem. The cover was not damaged and was placed back on the tank and functioned properly thereafter. The water level, from the top of the tank, was only 2 or 3 inches when inspected in September. We have recommended a freeboard of about 8 inches. The maximum wind gusts were 42 mph and 45 mph during July and August, respectively.

Beaver Dam tank, southwest of St. George, Utah --- The site was inspected seven times during the year, first in January and last in December. Water levels in the tank varied from nearly empty to 3 inches from the top. Some dust crusting on the cover was reported, but when visited 12 hours after a rain the bailing holes were clear and the cover had completely surfaced. Maximum wind gust reported was 27 mph. Hundreds of morning doves were observed watering from around the edge of the floating cover when visited in June, July, and August. The material was not affected by their activity.

A laboratory evaluation of four types of bonded joints was continued and has been under way 27 months. The experimental bonds have been evaluated periodically after subjecting the bonded material to continuous wet conditions --- submerged samples --- and occasional freezing and thawing conditions. The test period has included 85 freeze-thaw cycles. Evaluation includes both visual inspection and testing 1-inch-wide samples of the bonded materials for bond strength. The four types of bonds include: (a) butt, (b) lap --- 1, 2, and 4 inches, (c) butt with single overlay strip --- strip 1, 2, and 4 inches either side of joint, and (d) butt with overlay strip on both sides of the sheeting --- strip widths same as single overlay. When the 1-inch-wide samples were tested after 27 months, the butt joint had been the only joint failure (break strength 71% of original material strength). In all other cases the material failed rather than the joint.

The two floating covers in the field were fabricated with lap joints approximately 2 inches wide. No joint failures have been observed. The laboratory results would indicate that continued successful operation can be expected.

Wind Tunnel Studies. The optimum freeboard for a tank diameter and height combination was defined as the condition at which average lift forces (adverse pressures) at the water surface were minimized. Until a tank height-to-diameter ratio of 2/3 is reached, the lift forces over a circular tank increase. Beyond the 2/3 height-to-diameter ratio the average lift forces are essentially constant but high. Lift forces are less when the tank height is small (small height-to-diameter ratio).

An optimum freeboard did occur for all height-to-diameter ratios and ranged from 1/18 to 1/36 the tank diameter. Such a freeboard range is realistic for use in the field since the amount of lost storage is small. Using the optimum freeboard criteria alone and favoring the 1/36 factor, especially for tanks only out of the ground 1/3 the diameter, the recommended freeboard should be between 6 and 12 inches for tanks up to 40 feet diameter.

SUMMARY AND CONCLUSIONS:

SSP foamed butyl failed due to mechanical damage during a tank cleaning operation and was removed. The butyl had lost its strength and elasticity due to weathering. The mini-vaps also appear to be weathering, and efficiency has declined from 27% in 1971 to only 15% in 1973.

Aquashade blue dye had little effect on evaporation or algae growth over a 9-month study period.

High melting point granular wax was easily floated from the surface and only reduced evaporation by 21%.

The foamed wax blocks and three continuous wax covers tested at the Granite Reef site performed essentially the same as last year.

The efficiency of the foamed wax blocks was again about 35%, and the continuous wax covers reduced evaporation by 73 to 88%.

Melting the paraffin wax and pouring it on the water surface with buckets proved more effective than melting and spraying, and also required less equipment and no skilled labor.

The two floating covers being field tested have performed satisfactorily over a 2-1/2 year period. No joint failures have been observed in the field -- which was substantiated by findings from laboratory bonding studies. Wind gusts up to 45 mph did not displace the covers.

It appears that a floating cover is least likely to be affected by wind if the freeboard is about 1/36 of the tank diameter.

PERSONNEL: Keith R. Cooley and Allen R. Dedrick

TITLE: LOWER COST WATER HARVESTING SYSTEMS

CRIS No.: 5402-12260-004 CODE NO.: Ariz. WCL 71-12

INTRODUCTION:

Rainfall runoff measurements were continued at the Granite Reef testing site on the large plots at the Monument Tank testing site and at the Seneca catchment. A new treatment of water-repellent paraffin wax was applied to the Seneca catchment.

The effectiveness, suitability and durability of water barrier materials for use as reservoir, canal, or water catchment aprons are being evaluated by periodic observations, seepage measurements, and measurements to determine the type and rate of lining deterioration. Studies include laboratory testing, outdoor exposure tests, and actual field installations. Materials being evaluated include metal, plastic film, synthetic rubber, and asphalt membranes.

PART I. GRANITE REEF TESTING SITE

A total of 207.8 mm of rainfall was measured at the Granite Reef test site.

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

The two-phase asphalt treatments on plots L-5 and L-6 averaged 64.4% and 71.9% rainfall runoff, respectively. This is a significant decrease in runoff efficiency compared to 1972 and is believed a result of major cracking in the pavement surfaces. No maintenance has been performed on either plot since January 1972.

Rainfall runoff from the plots covered with thin films, L-1 (30 mil chlorinated polyethylene), L-4 (15 mil butyl), and L-7 (1 mil aluminum foil) averaged 98.2%, 61.8%, and 83.9%, respectively. Average runoff efficiency from the aluminum foil and the chlorinated polyethylene did not change from the previous year. Runoff from the butyl continued to decrease, a result of an increased number of small holes in the sheeting.

The membrane treatments A-1 (aluminum coated asphalt-fiberglass) and A-2 (gravel coated roofing) averaged 95.5% and 74.4% runoff, respectively. These results have not changed in the past 2 years. Runoff from the concrete catchment A-5 averaged 78.9% for the year. The asphalt-fiberglass strips covering the cracks need a new asphalt seal coat to maintain flexibility permitting the concrete to expand and contract without damaging the seal strips.

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

Rainfall runoff from the three watersheds W-1, W-2, and W-3 averaged 14.4%, 9.1%, and 17.1%, respectively. This compares to the 9-year average of 17.7%, 13.6%, and 23.0% runoff for W-1, W-2, and W-3, respectively. Runoff from the two smoothed untreated plots L-2 and A-3 was 13.6% and 20.5%, respectively. The two untreated ridge and furrow plots R-1 and R-3 averaged 15.8% and 13.9% runoff, respectively.

Runoff from the water-repellent alone plot, L-3, averaged only 44.4% runoff. Plot R-4, treated with water repellent and low cost stabilizer, averaged 55.9% runoff for 1973. Plot A-3, treated similar to R-4 but 1 year later, produced 75.6% runoff. These runoff results are 10 to 20% less than was measured in 1973. The average runoff efficiency by years from the three silicone-treated plots, L-3, R-4, and A-4, and the two smoothed untreated plots L-2 and A-3 is presented in Figure 1. All the plots had relatively higher runoff in 1972 which may be a result of the patterns of rainstorms. There does appear to be a gradual decline in runoff efficiencies of L-3 and R-4 over the past 3 years. The two smoothed untreated plots runoff indicate the long term average has not changed.

Plot R-2, treated with paraffin wax, yielded 87.2% runoff for the year. The treatment shows no signs of deterioration. Plot R-2, a similar untreated ridge and furrow plot, developed a good growth of weeds during the year. Plot R-2 had only four plants growing on the entire surface, indicating insufficient water penetrated the treatment to germinate seeds or sustain plant growth.

Outdoor Weathering Panels: Forty-three flexible membrane specimens were exposed on 6 December 1973 as ground panels at the Granite Reef testing site, Table 5. The panels were anchored by burying the edges. Exposed sheet size ranged between 2 ft x 3 ft and 2 ft x 4 ft. Gauge marks, approximately 1 ft apart in both the machine and transverse direction, were painted on the panels at the time of exposure. Periodic measurement of the gauge lengths will indicate film or membrane stability.

Materials exposed include polyvinyl chloride (PVC), polyethylene (PE), chlorinated polyethylene (CPE), butyl, hypalon, neoprene and EPDM with substrates or reinforcement materials of nylon, polyethylene and polypropylene. Liquid elastomeric coatings were applied to oriented PE, PVC, and PE--17 panels. Five different coating formulations were used. The purpose of the coatings was to protect the substrate materials (already watertight) from U-V damage. Coatings were applied with a paint roller at rates ranging between 0.11 and 0.28 gal/100 ft^2 (approximately 3/4 to 2 mil thickness). The nonsupported 30-mil butyl (sample 43) was originally exposed as a 5 ft x 20 ft test plot (plot 2) on 18 May 1961. Original plot 2 was abandoned during 1973 and a piece of the material was exposed at the new site for continued observation.

Laboratory physical properties have been evaluated for all materials exposed. Properties include tensile strength, elongation, tear strength, puncture resistance, burst strength, and effect of heat and ozone. Samples will be cut from the test panels and physical properties reevaluated in an effort to detect deterioration which would go unnoticed from visual observation.

PART II. MONUMENT TANK

Rainfall at the site for the period of 18 December 1972 through 4 December 1973 totaled 248 mm, which for the second year in a row is considerably below the long-term average. Maximum runoff from any of the four watersheds was less than 5 mm. Rainfall runoff as measured by the flumes was 0.5%, 0.5%, 1.7%, and 0.1% of the precipitation for watersheds 1 to 4, respectively, for the year. Trouble is still being encountered with maintaining the mechanical weather stations in operating condition.

PART III. OPERATIONAL FIELD CATCHMENTS

Seneca catchment: The Seneca catchment was treated on 21-22 June 1973 with paraffin wax. The wax, a refined grade with a melting point of 125-128 F, was melted in the "tar baby" and sprayed on the plot surface at a rate of 1.1 to 1.2 lbs/yd^2. Prior to treatment, the plot had been mowed, hand raked, and burned with a hand burner to reduce the quantity of vegetation on the plot. The actual soil surface was not disturbed and was considered to have a good desert pavement, but was considered a rough-uneven surface.

The wax was melted in 500-lb loads. The propane burners on the "tar baby" were not working to full heat capacity and it required about 4 hours to melt 500 lbs. During the melting process the wax would reach a maximum temperature of about 170 F. It required about 20 minutes to spray a load of wax. The hot wax would immediately penetrate the soil during the middle of the day. In the early morning or late afternoon when the soil temperatures were lower, the wax would solidify on the soil, then remelt during the next day and penetrate the soil. There was a small quantity of wax which solidified on the grass stems. This wax was still evident 3 months after treatment.

Rainfall runoff from the catchment by individual storm for the period after treatment is presented in Table 6. The total runoff is considerably less than was originally hoped for. Closer analysis of the runoff data indicates the reduced effectiveness of the treatment can partially be explained on the basis of the roughness of the plot surface. The runoff and rainfall data by storms is plotted in Figure 2. This shows there is approximately 4.6 mm of precipitation required before surface runoff will occur. Once this threshold rainfall has been exceeded, the runoff is about 62%. The point represented by the (⊛) in Figure 2 is the data from the first runoff event after treatment occurring on 10 July 1973. Inspection of the plot shortly after this date indicated the water retention on the plot was higher than might be considered normal because of small grass stems bridging between the grass clumps. The loose grass did not appear to be a factor in subsequent runoff events.

Inspection of the plot in January 1974 indicated the treatment had undergone major change. The soil stability from the wax treatment was much reduced and the soil-water repellency appeared changed. This is also evident in the storms of 7 and 8 January 1974 of Table 6 and the points (⊡) on Figure 2. Preliminary laboratory studies indicate that loss of soil stability and water repellency is a result of water on the soil during a freezing of the soil. The exact mechanism and extent of this problem will be examined in more detail the next year.

Fishlake National Forest: Fifteen water harvesting systems have been installed on the Fishlake National Forest in Central Utah in cooperation with the Forest Service. The first installation was in 1960 and the most recent in 1969. The systems have been periodically inspected since their installation, the results of which are summarized in Research Report 4 from the Utah State University entitled "Operation, Serviceability and Material

Evaluation of Raintraps on the Fishlake National Forest--1960-1971" dated March 1973. In the report, problems associated with field use were delineated. They included material failure, mechanical damage, system malfunction, maintenance deficiencies, and improper design. Of the problems identified, damage by vermin was the most extensive.

A cooperative agreement was initiated in 1973 with Utah State University to study the vermin problem. The project title is "Prevention of small mammal damage to flexible membrane materials used as water barriers." Objectives are to identify the small mammal species damaging flexible membrane materials being used as water barriers; determine the ecological factors associated with the damage; and develop methods whereby the damage can be prevented.

During 1973, twelve raintrap sites on the Fishlake National Forest were initially evaluated with respect to tears, gnawed holes, patches, and vegetational damage that had occurred to aprons and storage bags. Eight raintrap sites were studied intensively with respect to (1) soil analyses, (2) vegetation analyses, (3) air temperature (high and low), (4) ground cover estimation, (5) aspect and orientation, and (6) live trapping. This information will be used to determine if ecological factors are associated with small mammal damage to raintrap systems. At three of the most heavily damaged raintraps, constructional changes were undertaken in an effort to prevent small animal damage. Changes made for the separate raintraps included: (Raintrap 1) sheets of butyl were glued around edge of existing catchment to simulate a centrally located storage, fence moved closer to catchment, and a 30-ft raptor perch was erected near the site; (Raintrap 2) fence moved closer to catchment for livestock removal of surrounding vegetation; and (Raintrap 3) chemical ground sterilant applied around storage area inside fenced area to minimixe vegetational growth. These changes are an effort to decrease vegetational cover near the systems and thereby create small mammal susceptibility to predation.

Cache National Forest: Two water harvesting systems are located on the Cache National Forest in Northern Utah and both were inspected in October 1973. They are referred to as Spawn Creek and Chicken Creek. The Spawn Creek system is a 50 ft x 50 ft butyl apron with a 25,000 gal open storage pit lined with nylon-supported butyl rubber. Several holes in the pit liner were noted above and below the water line. A new storage system is required to make the system operable. The apron had been extensively damaged by rodents. All holes should be patched. Considerable burrowing, probably by gophers, was noted under the apron as well as around the entire enclosure. The water harvesting system at Chicken Creek consists of a 50 ft x 50 ft butyl apron with a plastic-lined steel tank used for storage. The tank was installed in 1972, since a one-piece nylon reinforced butyl bag had been destroyed by rodents. Tank diameter is 30 ft, height 5.33 ft, and capacity about 28,000 gal. Thirty mil PVC film was used to maintain watertightness. When inspected in October there was about 1 ft of water in the tank and the trough was still in operation. The storage system appeared to be operating satisfactorily. No holes were observable in the plastic liner. A few holes needed to be patched on the apron.

IV. RIVER LABORATORY AND TEST SITES AT LOGAN, UTAH

Outdoor Weathering Racks: The appearance and condition of membrane and film specimens exposed on racks at Logan according to ASTM D 1435 are summarized in Table 7. No new materials were exposed on the racks during 1973. Upon inspection of the materials in October 1973, many samples were removed from the racks. Those removed included 1, 5, 6, 19 and 20 (returned to cooperating company), 7 and 10 (taken to Phoenix for laboratory analysis), and 9-2, 12-2, 12-3 and 17 (destroyed because of deterioration). The history of the exposures was sent to the cooperators.

Outdoor Exposure Panels: Some 66 potential water barrier materials, of the flexible sheeting and film type, had been exposed as ground panels at Logan--in a manner similar to that described at Granite Reef. Arrangements were made with some cooperators to return samples of materials which they had furnished for evaluation. Those sampled, how disposed of, and condition at the time of removal are outlined in Table 8. The black and white vinyls (panels 8 and 7) illustrated for some time the importance of using black vinyl when weathering important. The vinyl film taken from pond B-1 and exposed as panels 19 and 20 in 1970 was still flexible after 13 years (originally exposed as pond liner in 1960). The synthetic rubber based coating used on the polypropylene (PP) (panels 28 through 31) and PE substrate (panels 35 through 37) could be dusted from the surface, but the substrates were in excellent condition. Chlorobutyl-coated nylon (panels 21 and 22) and the joints were both in excellent condition when removed after 3 years exposure. Thirty-six exposure panels remain at Logan and are shown in Table 9. The successful use of a liquid coating for PVC is illustrated by the coated sample (panel 43 in Table 9) contrasted against the uncoated sample (panel 39 in Table 8). For the particular PVC formulation, the uncoated film had become very stiff after 2 years exposure--two summers--while the coated maintained similar characteristics of new film. The coating originally averaged slightly over 3 mils. The cost of such a coating would be about $0.90/yd^2. The oriented polyethylene (Fabrene) appears to have shrunk slightly--at least the samples are tighter than originally installed. Any continuation will be closely watched.

Many of the materials were sampled for laboratory analyses of the physical properties. These analyses will be completed and reported to the various cooperators.

Water Harvesting Catchments: Prototype catchments have been used at the Logan test site to evaluate physical performance and efficiency and for demonstrational purposes. Several were transferred to cooperators during 1973 for field use and others were relocated or kept at the test site. The status of the catchments at the end of 1973 was:

R-1 Butyl, unreinforced, 15 mil, installed July 1963, destroyed in May 1973 (10 years), condition poor with many holes. Original R-10 moved to this site.

R-2 Butyl, unreinforced, 30 mil, installed August 1963, condition good to excellent with chalking, one tear, and some rodent damage.

R-3 Butyl, reinforced, 30 mil, installed June 1963, condition excellent with chalking and a few ant holes.

R-4 Oriented PE (Fabrene, TM), installed October 1972, condition excellent but sheeting extremely tight over berms and had caused one tear over a rock on the berm. May have shrunk.

R-5 PVA copolymer, 8 mil, installed October 1966. Poor with large number holes but not changed appreciably from previous years.

R-7 Asphalt emulsion and polypropylene, installed August 1967, recoated September 1972, destroyed June 1973.

R-7b Asphalt emulsion, asbestos, water slurry over polypropylene, installed September 1972, condition excellent.

R-8 Nylon-reinforced EPDM (Vistalon), 1/32 inch, installed October 1969, arrangements have been made for its use on the Cache National Forest, condition excellent but had shrunk and had been damaged by rock-throwing vandals.

R-9 Galvanized steel, 20 gage, installed November 1963, transferred to Utah Cooperative Wildlife Research Unit, Utah State University, June 1973 (10 years), condition excellent.

R-10 Butyl, unreinforced, 30 mil, installed September 1958, moved to R-1, condition excellent.

R-12 Nylon-reinforced polyethylene, installed June 1968, destroyed in June 1973 (5 years), condition poor, delaminated.

Test Reservoirs at Logan: Several water barrier materials have been evaluated at Logan in small test reservoirs (approximately 8,000 to 12,000 gal capacity excavated pits). Some liners remain in place and are outlined in Table 10 along with measured seepage rates. Rates were measured for 51 rainfree days during 1973. Water surface drop is corrected for evaporation losses. The 20-mil unreinforced butyl rubber in pond C-1 was removed in June 1973. Seepage losses measured during 12 of the 15 years averaged 0.012 ft/day. The extreme seepage rate of 0.073 ft/day was recorded during 1967 and was attributed to puncturing and faulty patches. The liner was patched during 1968, with corresponding decreases in seepage rates measured thereafter. The asphalt-jute laminate (C-2) installed in 1956, was also removed in June 1973. Seepage losses were negligible except for 1 year, 1967, when the water level was above the normal operating level. Marked degradation was evident above this point and probably lead to the excess losses. New seal coats should have been applied during the test period to ensure a serviceable liner. The two 8-mil buried plastic liners in ponds A-4 and A-5 continue to control seepage after 19 years.

Canal Lining Investigations: Several materials potentially useful for lining small on-farm irrigation ditches have been under investigation for a number of years in the Logan vicinity. They have included (a) polypropylene-asphalt emulsion, (b) galvanized steel, (c) fiberglass-reinforced polyester resin, and (d) bituminized fiber.

Polypropylene-asphalt emulsion -- A canal liner constructed of polypropylene matting sealed with an asphalt emulsion-asbestos fiber mixture was installed in test channel A at the River Laboratory in August 1972. Seepage losses were not detectable during a 5-week period during the fall of 1972. Losses during 1973, from 25 June through 29 September, ranged from 0 to less than 0.5 ft^3/ft^2/day. The higher losses were measured directly after water was turned into the channel after having been drained during the winter months. Losses approached zero in a few days of continual operation and were minimal in all cases after about 30 days. The lining material continues to show promise and plans have been made for lining two excavated pits during 1974.

Galvanized steel--A 24-inch diameter galvanized sheet metal canal liner, 273 ft long, was installed in 1965 near Avon, Utah. The metal was 22 gage. The liner has not been used during the past 2 years and is in need of maintenance. One small area (3 inch x 3 inch) was starting to corrode but over all, the liner was still in excellent condition.

Fiberglass-reinforced polyester resin--Two precast fiberglass-reinforced polyester resin canal liners, each 100 ft long, were installed in 1970 near Avon, Utah. Surface resin has chipped from the liner with subsequent exposure of the fiberglass. These areas are undoubtedly not watertight since their appearance is similar to liners that leaked in previous studies. The liners were watertight originally. Improved coatings would be required before this material could successfully be used for the application intended.

Bituminized fiber--A 267-foot reach of half round sectional slope drain constructed of bituminized cellulose fiber was installed as an irrigation ditch liner in 1966. The specifications of the liner were 36" (half round, sections 10 ft, thickness ½ inch, weight 16.4 lbs/linear ft. The lining material had performed satisfactorily until 1973. Large amounts of pitch could be seen on the liner surface when inspected in October 1973. The loss of the pitch may have resulted in the edges of the liner being frayed extensively. The edges had the appearance that they had been subjected to intense heat, but burning (for example, weed burning) had not occurred. The sudden change in physical condition may have been caused by extremely cold temperatures during the winter of 1972-1973 (-35 to -40° F). These temperatures were the only item that was substantially different from previous years.

Some problems had been encountered with maintaining watertight joints. Several joint sealers had been tried, all unsuccessfully.

An asphaltic tape--Ram-Nek--performed satisfactorily from 1970 through 1972 but had loosened during 1973. The cold temperatures may have caused the failure. The overall liner material and system were not functional after 7 years. Material degradation, joint problems and shape instability dictated that the liner was beyond repair and consequently it has been abandoned.

Concrete Rehabilitation: An asphaltic tape, Ram-Nek, was installed over cracks in a concrete-lined canal near Providence, Utah, in 1970. It performed satisfactorily through 1972 but had loosened when observed in October 1973. A thin layer of concrete remained attached to the tape indicating possible slaking of the concrete (substrate failure) and not tape failure. The extremely cold temperature previously noted may have attributed to this failure. Performance of the material has not been investigated at temperatures as low as -40 F, either by the manufacturer or ARS. Further trials using the tape are planned for 1974.

SUMMARY AND CONCLUSIONS:

Rainfall-runoff measurements were continued at the Granite Reef Testing Site. Runoff results from the two-phase asphalt treatments indicate a loss of efficiency, a probable result of no maintenance being performed on the treatment in the past 12 months. The silicone water repellent treated plots also show a gradual decline in runoff efficiency which would indicate a deterioration of the treatments. No maintenance has been performed on the butyl-covered plot in 24 months to demonstrate the performance that might be expected as a treatment suffers severe deterioration. Runoff from the remainder of the membrane-covered plots and the bare-soil untreated plots has not changed in the past year. The paraffin-wax-treated plot continued to yield over 85% with no visible signs of treatment deterioration.

A set of 43 outdoor weathering panels was installed at Granite Reef to study the long-term weathering properties of flexible membranes and elastomeric coatings. Laboratory physical properties have been evaluated for all materials exposed. Samples will be cut from the test panels at periodic intervals and the physical properties reevaluated in an effort to detect deterioration which would go unnoticed from visual observation.

Runoff measurements were continued at the Monument Tank test site. Runoff continues to be less than 2% of the annual precipitation. The Seneca catchment was treated in June 1973 by spraying molten paraffin wax at a rate of 1.2 lbs/yd^2 on the undisturbed catchment surface. Runoff from the catchment since treatment was less than originally hoped for. The plot surface is considered very rough and data analyses indicate the threshold rainfall before runoff occurs is approximately 4.5 mm. Runoff results in the winter of 1973 indicate the wax treatment may be affected by freezing and thawing of the treatment. Studies are being conducted to determine the extent of this problem.

Cooperatively installed operational catchments in Arizona and Utah are being reported on, and/or visited periodically, to determine performance of materials, design and possible causes of catchment failures. A cooperative study was initiated with Utah State University to study the vermin problem associated with failure of water harvesting structures. The objectives of this study will be to identify the small mammal species damaging flexible membranes being used for water barriers; determine the ecological factors associated with the damage; and develop methods whereby the damage can be prevented.

Observations were continued of several test materials used for canal linings on small farm irrigation ditches in the Logan, Utah vicinity. A polypropylene-asphalt-emulsion membrane lining continues to show promise and will be investigated further as a canal and storage lining material. A galvanized steel ditch lining shows a start of corrosion after 8 years. A fiberglass-reinforced polyester resin lining shows signs of needing improved seal coats. A bituminized fiber lining shows signs of deterioration which may have been caused by extreme cold temperatures during the winter of 1972-1973. An asphaltic tape for concrete rehabilitation may have been affected by the cold weather also.

PERSONNEL: Gary Frasier, Allen Dedrick, John Griggs, Wayne R. Williamson.

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

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

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

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

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

Date	Rainfall	L-1 Runoff		L-4 Runoff		L-5 Runoff	
1973	mm	mm	%	mm	%	mm	%
1 Jan	2.5	2.6	104.0	1.5	60.0	1.6	52.0
4 Jan	2.8	2.8	100.0	1.6	57.1	1.6	57.1
10 Jan	3.3	2.7	81.8	1.6	48.5	1.6	48.5
17 Jan	2.6	2.2	84.6	1.2	46.2	1.3	50.0
11 Feb	4.4	4.7	106.8	2.6	59.1	2.0	45.5
12 Feb	1.2	0.7	58.3	0.2	16.7	0.2	16.7
13 Feb	10.1	10.0	99.3	7.8	77.2	8.3	82.2
15 Feb	5.7	6.0	105.3	3.6	63.2	3.5	61.4
21-22 Feb	26.4	27.4	103.8	16.3	61.7	19.4	73.5
7 Mar	2.5	1.5	60.0	0.8	32.0	0.6	24.0
8 Mar	3.0	2.8	93.3	1.6	53.3	1.3	43.3
12 Mar	25.8	25.9	100.4	18.3	70.9	20.3	78.7
13 Mar	9.5	8.4	88.4	6.2	65.3	6.8	71.6
21 Mar	5.5	5.4	98.2	3.0	54.5	2.4	43.6
22-23 Mar	5.5	5.2	94.5	3.1	56.4	2.6	47.3
26 Mar	2.5	2.7	108.0	1.6	64.0	1.2	48.0
28 Mar	13.6	12.7	93.4	8.8	64.7	8.7	64.0
30 Apr	4.1	4.9	119.5	2.3	56.1	1.7	41.5
13 May	2.7	3.3	122.2	1.7	63.0	1.3	48.1
13 Jun	3.5	4.1	117.1	1.7	48.6	1.5	42.9
3 Jul	1.8	1.7	94.4	1.0	55.6	0.9	50.0
11 Jul	10.0	10.1	101.0	6.8	68.0	7.5	75.0
14 Jul	22.3	22.6	101.3	19.5	87.4	22.1	99.1
5 Aug	3.1	2.4	77.4	1.0	32.3	0.3	9.7
15 Aug	2.5	2.6	104.0	1.3	52.0	1.9	76.0
18 Nov	12.8	12.2	95.3	6.5	50.8	6.7	52.3
22 Nov	8.4	8.2	97.6	4.6	54.8	4.9	58.3
23-26 Nov	9.4	8.3	88.3	2.2	23.4	2.0	21.3
Total	207.8	204.1	98.2	128.4	61.8	134.2	64.4

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

Date	Rainfall	L-6 Runoff		L-7 Runoff		A-5 Runoff	
1973	mm	mm	%	mm	%	mm	%
1 Jan	2.5	1.8	72.0	2.1	84.0	11.9	76.0
4 Jan	2.8	1.9	67.9	2.1	75.0	2.2	78.6
10 Jan	3.3	1.5	45.5	2.3	69.7	1.9	57.6
17 Jan	2.6	1.1	42.3	1.7	65.4	1.6	61.5
11 Feb	4.4	2.4	54.5	3.2	72.3	2.9	65.9
12 Feb	1.2	0.2	16.7	0.3	25.0	0.4	33.3
13 Feb	10.1	7.6	75.2	9.5	94.1	9.6	95.0
15 Feb	5.7	3.9	68.4	4.8	84.2	4.5	78.9
21-22 Feb	26.4	19.4	73.5	24.4	92.4	25.3	95.8
7 Mar	2.5	1.0	40.0	1.4	56.0	1.1	44.0
8 Mar	3.0	1.6	53.3	2.2	73.3	2.0	33.3
12 Mar	25.8	22.9	88.8	23.2	89.9	24.0	93.0
13 Mar	9.5	7.1	74.7	8.1	85.3	7.8	82.1
21 Mar	5.5	3.3	60.0	4.1	74.5	4.0	72.7
22-23 Mar	5.5	3.1	56.4	4.4	80.0	3.9	70.9
26 Mar	2.5	1.5	60.0	2.0	80.0	1.5	60.0
28 Mar	13.6	9.1	66.9	11.0	80.9	11.5	84.6
30 Apr	4.1	1.8	43.9	3.2	78.0	3.2	78.0
13 May	2.7	2.4	88.9	2.4	88.9	2.0	74.1
13 Jun	3.5	2.1	60.0	2.8	80.0	2.2	62.9
3 Jul	1.8	1.4	77.8	1.6	88.9	0.6	33.0
11 Jul	10.0	8.7	87.0	8.7	87.0	5.6	56.0
14 Jul	22.3	21.4	96.0	22.2	99.6	18.3	82.1
5 Aug	3.1	1.6	51.6	1.9	61.3	1.4	45.2
15 Aug	2.5	1.7	68.0	2.1	84.0	1.5	60.0
18 Nov	12.8	9.6	75.0	10.4	81.3	10.7	83.7
22 Nov	8.4	6.1	72.6	6.6	78.6	6.9	82.1
23-26 Nov	9.4	3.2	34.0	5.6	59.6	5.5	58.5
Total	207.8	149.4	71.9	174.3	83.9	164.0	78.9

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

Date	Rainfall	A-1 Runoff		A-2 Runoff		Runoff	
1973	mm	mm	%	mm	%	mm	%
1 Jan	2.5	2.5	100.0	1.3	52.0		
4 Jan	2.8	2.8	100.0	1.6	57.1		
10 Jan	3.3	2.6	78.8	1.5	45.5		
17 Jan	2.6	2.1	81.2	1.4	53.8		
11 Feb	4.4	4.4	93.4	1.8	40.9		
12 Feb	1.2	0.7	58.3	0.0	0.0		
13 Feb	10.1	9.9	98.2	9.1	90.1		
15 Feb	5.7	5.6	98.2	4.3	75.4		
21-22 Feb	26.4	27.3	103.4	24.6	93.2		
7 Mar	2.5	1.7	68.0	0.3	12.0		
8 Mar	3.0	2.7	90.0	1.5	50.0		
12 Mar	25.8	25.5	98.8	23.2	89.9		
13 Mar	9.5	8.5	89.5	7.4	77.9		
21 Mar	5.5	5.4	98.2	3.9	70.9		
22-23 Mar	5.5	5.1	92.9	3.4	61.8		
26 Mar	2.5	2.5	100.0	1.1	44.0		
28 Mar	13.6	12.4	91.2	10.7	78.7		
30 Apr	4.1	4.5	109.8	1.9	46.3		
13 May	2.7	3.3	122.2	4.4	163.0		
13 Jun	3.5	3.7	105.7	1.4	40.0		
3 Jul	1.8	1.4	77.8	0.0	0.0		
11 Jul	10.0	9.3	93.0	8.1	81.0		
14 Jul	22.3	22.0	98.7	20.1	90.1		
5 Aug	3.1	2.3	74.2	0.9	29.0		
15 Aug	2.5	2.4	96.0	1.0	40.0		
18 Nov	12.8	12.2	95.3	8.9	69.5		
22 Nov	8.4	7.9	94.0	6.2	73.8		
23-26 Nov	9.4	8.1	86.2	4.6	48.9		
Total	207.8	198.5	95.5	154.6	74.4		

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

Plot	Treatment Date	Treatment
L-2	30 Nov 1961	Smoothed soil, 14.14 m x 14.14 m plot
L-3	4 Aug 1965	Smoothed soil, 14.14 m x 14.14 m plot treated with silicone water repellent at 0.057 kg m^{-2}
	6 Nov 1969	Retreated at 0.04 kg m^{-2}
R-1	1 Mar 1965	Ridge and furrow, 20% sideslope
R-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-4	10 Nov 1971	Smoothed soil treated with 3% silicone water repellent and 2% soil stabilizer - 1.2 liters of solution m^{-2}
W-1	1 Dec 1963	Uncleared watershed
W-2	1 Dec 1963	Uncleared watershed
W-3	1 Dec 1963	Cleared watershed

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

Date	Rainfall	W-1 Runoff		W-2 Runoff		W-3 Runoff	
1973	mm	mm	%	mm	%	mm	%
1 Jan	2.5	0	0	0	0	0	0
4 Jan	2.8	0.1	3.6	0.1	3.6	2.0	7.1
10 Jan	3.3	0	0	0	0	0	0
17 Jan	2.6	0	0	0	0	0	0
11 Feb	4.4	0	0	0	0	0	0
12 Feb	1.2	0	0	0	0	0	0
13 Feb	10.1	4.2	41.6	2.8	27.7	4.4	43.6
15 Feb	5.7	0	0	0	0	0	0
21-22 Feb	26.4	3.0	11.4	1.3	4.9	2.9	11.0
7 Mar	2.5	0	0	0	0	0	0
8 Mar	3.0	0.1	3.3	0	0	0.1	3.3
12 Mar	25.8	6.3	24.4	4.0	15.5	6.7	26.0
13 Mar	9.5	0.1	1.1	1.0	10.5	1.9	20.0
21 Mar	5.5	0	0	0	0	0	0
22-23 Mar	5.5	0	0	0	0	0	0
26 Mar	2.5	0	0	0	0	0	0
28 Mar	13.6	1.2	8.8	0.6	4.4	1.4	10.3
30 Apr	4.1	0	0	0	0	0	0
13 May	2.7	0	0	0	0	0	0
13 Jun	3.5	0	0	0	0	0	0
3 Jul	1.8	0	0	0	0	0	0
11 Jul	10.0	1.2	12.0	0.4	4.0	1.2	12.0
14 Jul	22.3	13.3	59.6	8.7	39.0	14.7	65.9
5 Aug	3.1	0	0	0	0	0	0
15 Aug	2.5	0	0	0	0	0	0
18 Nov	12.8	0.2	1.6	0	0	0.1	0.8
22 Nov	8.4	0	0	0.2	2.4	0	0
23-26 Nov	9.4	0	0	0	0	0	0
Total	207.8	29.9	14.4	18.9	9.1	35.5	17.1

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

Date	Rainfall	R-2 Runoff		R-4 Runoff		A-4 Runoff	
1973	mm	mm	%	mm	%	mm	%
1 Jan	2.5	2.4	96.0	1.6	52.0	1.9	76.0
4 Jan	2.8	2.5	89.6	1.6	57.1	2.2	78.6
10 Jan	3.3	2.4	72.7	1.2	36.4	1.9	57.6
17 Jan	2.6	1.9	74.0	1.6	61.9	1.6	61.5
11 Feb	4.4	3.1	70.5	1.8	40.9	2.7	61.4
12 Feb	1.2	0.5	41.7	0	0	0	0
13 Feb	10.1	9.8	98.0	8.3	82.2	9.4	93.1
15 Feb	5.7	5.3	93.0	3.1	54.4	4.5	78.9
21-22 Feb	26.4	25.7	97.3	17.2	65.2	24.0	90.9
7 Mar	2.5	1.3	52.0	0.5	20.0	0.9	36.0
8 Mar	3.0	2.4	80.0	1.2	40.0	1.9	63.3
12 Mar	25.8	24.8	96.1	19.1	74.0	23.0	89.1
13 Mar	9.5	8.2	86.3	6.4	67.4	7.6	80.0
21 Mar	5.5	5.1	92.7	2.0	36.4	3.6	65.5
22-23 Mar	5.5	4.7	85.5	2.6	47.3	3.7	67.6
26 Mar	2.5	2.1	84.1	0.8	32.7	1.3	52.0
28 Mar	13.6	12.5	91.9	8.7	64.0	11.1	81.6
30 Apr	4.1	3.1	75.6	1.2	29.3	2.2	53.7
13 May	2.7	2.0	74.1	0.8	29.6	1.7	63.0
13 Jun	3.5	2.8	80.3	1.0	28.6	2.2	62.9
3 Jul	1.8	1.1	61.1	0.2	11.1	0	0
11 Jul	10.0	7.6	76.0	5.5	55.0	8.9	89.0
14 Jul	22.3	20.5	91.9	18.0	80.7	20.5	91.9
5 Aug	3.1	1.2	38.7	0.4	12.9	0.9	29.0
15 Aug	2.5	1.7	68.0	0.6	24.0	1.2	48.0
18 Nov	12.8	11.5	89.8	5.4	42.2	8.3	64.8
22 Nov	8.4	7.4	88.1	4.1	48.8	6.2	73.8
23-26 Nov	9.4	7.6	80.9	1.2	12.8	3.6	38.3
Total	207.8	181.2	87.2	116.1	55.9	157.0	75.6

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

Date	Rainfall	L-3 Runoff		R-1 Runoff		R-3 Runoff	
1973	mm	mm	%	mm	%	mm	%
1 Jan	2.5	0.8	28.6	0.7	28.0	0	0
4 Jan	2.8	0.9	32.1	0	0	0	0
10 Jan	3.3	0.7	21.2	0	0	0	0
17 Jan	2.6	0.3	11.5	0.4	16.1	0	0
11 Feb	4.4	1.1	25.0	0	0	0	0
12 Feb	1.2	0	0	0	0	0	0
13 Feb	10.1	8.0	79.2	4.7	46.5	3.1	30.8
15 Feb	5.7	1.7	29.8	0.7	12.3	0.1	1.8
21-22 Feb	26.4	16.0	60.6	4.8	18.2	1.7	6.4
7 Mar	2.5	0	0	0	0	0	0
8 Mar	3.0	0	0	0	0	0	0
12 Mar	25.8	18.1	70.2	7.7	29.8	5.7	22.1
13 Mar	9.5	5.0	52.6	3.1	32.6	1.8	18.9
21 Mar	5.5	0.9	16.4	0	0	0	0
22-23 Mar	5.5	1.2	21.8	0	0	0	0
26 Mar	2.5	0	0	0	0	0	0
28 Mar	13.6	7.2	52.9	2.5	18.4	1.0	7.4
30 Apr	4.1	0	0	0	0	0	0
13 May	2.7	0	0	0	0	0	0
13 Jun	3.5	0.1	2.9	0	0	0	0
3 Jul	1.8	0	0	0	0	0	0
11 Jul	10.0	5.3	53.0	2.3	23.0	1.4	14.0
14 Jul	22.3	19.5	87.4	4.7	17.9	14.0	62.8
5 Aug	3.1	0	0	0	0	0	0
15 Aug	2.5	0	0	0	0	0	0
18 Nov	12.8	3.8	29.7	0	0	0	0
22 Nov	8.4	1.6	19.0	1.2	14.3	0.1	1.2
23-26 Nov	9.4	0	0	0	0	0	0
Total	207.8	92.2	44.4	32.8	15.8	28.9	13.9

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

Date	Rainfall	L-2 Runoff		A-3 Runoff	
1973	mm	mm	%	mm	%
1 Jan	2.5	0	0	0	0
4 Jan	2.8	0	0	1.1	39.3
10 Jan	3.3	0	0	0	0
17 Jan	2.6	0	0	0	0
11 Feb	4.4	0	0	0	0
12 Feb	1.2	0	0	0	0
13 Feb	10.1	3.2	31.7	5.2	51.5
15 Feb	5.7	0	0	0	0
21-22 Feb	26.4	1.2	4.5	4.6	17.4
7 Mar	2.5	0	0	0	0
8 Mar	3.0	0	0	0	0
12 Mar	25.8	6.3	24.4	8.0	31.0
13 Mar	9.5	1.1	11.6	2.2	23.2
21 Mar	5.5	0	0	0	0
22-23 Mar	5.5	0	0	0	0
26 Mar	2.5	0	0	0	0
28 Mar	13.6	0.6	4.4	2.1	15.4
30 Apr	4.1	0	0	0	0
13 May	2.7	0	0	0	0
13 Jun	3.5	0	0	0	0
3 Jul	1.8	0	0	0	0
11 Jul	10.0	1.5	15.0	3.0	30.0
14 Jul	22.3	14.3	64.1	16.0	71.7
5 Aug	3.1	0	0	0	0
15 Aug	2.5	0	0	0	0
18 Nov	12.8	0	0	0	0
22 Nov	8.4	0	0	0.4	4.8
23-26 Nov	9.4	0	0	0	0
Total	207.8	28.2	13.6	42.6	20.5

Table 5. Test panels for outdoor exposure of water barrier materials at Granite Reef. Materials exposed 6 December 1973.

Panel Number	Material and/or Treatment
1	Cross laminated poly film, 4 mil, white, Tu Tuf, Sto-Cote
2	Same as 1 except gray
3	Oriented polyethylene, Fabrene TM, duPont of Canada
4	Same as 3 plus liquid elastomeric coating (coating) 0.27 gal/100 ft^2, Tan Poly-R (5-950), Matcote
5	Same as 3 plus coating, 0.19 gal/100 ft^2 clear Elastuff 400, United Paint
6	Same as 3 plus coating, 0.22 gal/100 ft^2, gray 1 part, United Paint
7	Same as 3 plus coating, 0.14 gal/100 ft^2, gray Elastuff 400, United Paint
8	Polyvinyl Chloride (PVC) film, 10 mil, black, Environmental Water Control (EWC)
9	PVC film, 15 mil, black, EWC, plus coating, 0.13 gal/100 ft^2, gray Elastuff 400, United Paint
10	Same as 8 plus coating, 0.26 gal/100 ft^2, clear Elastuff 400, United Paint
11	Same as 8 plus coating, 0.17 gal/100 ft^2, gray 1 part, United Paint
12	Polyethylene (PE) film, 4 mil, clear, Mobil
13	Same as 12 plus coating, 0.15 gal/100 ft^2, gray Elastuff 400, United Paint
14	Same as 12 plus coating, 0.10 gal/100 ft^2, gray 1 part, United Paint
15	Same as 12 plus coating, 0.14 gal/100 ft^2, clear Elastuff 400, United Paint

Table 5. Test panels for outdoor exposure of water barrier materials at Granite Reef. Materials exposed 6 December 1973 (continued).

Panel Number	Material and/or Treatment
16	Same as 12 plus coating, 0.14 gal/100 ft^2, Tan Poly-R (5-950), Matcote
17	PVC film, 15 mil, black, EWC
18	Chlorinated Polyethylene, nylon reinforced, 32 mil, black Hodgman
19	Tedlar/vinyl laminate, 14 mil, white, Flexcon
20	Fiber reinforced PE, 12 mil, black, Type 85, Griffolyn
21	Fiber reinforced PE, 14 mil, black, Type 105, Griffolyn
22	Butyl, nylon reinforced, 32 mil, black (KK 243), Hodgman
23	Hypalon, polypropylene substrate, 23 mil, black, Hodgman
24	Hypalon, double coated on nylon, 24 mil, black (KK 206) Hodgman
25	Same as 12 plus coating, 0.21 gal/100 ft^2, Tan Chem-Elast (5501), Plas-Chem
26	Same as 8 plus coating, 0.22 gal/100 ft^2, Tan Chem-Elast (5501), Plas-Chem
27	Same as 8 plus coating, 0.19 gal/ft^2, Tan Poly-R (5-950), Matcote
28	Same as 8 plus coating, 0.15 gal/100 ft^2 of primer (9002) and 0.17 gal/100 ft^2 of Black Chem-Elast (5500X), Plas-Chem
29	Same as 3 plus coating, 0.28 gal/100 ft^2, Tan Chem-Elast (5501), Plas-Chem
30	Same as 3 plus coating, 0.23 gal/100 ft^2 of primer (9002) and 0.20 gal/100 ft^2 of Black Chem-Elast (5500X), Plas-Chem.

Table 5. Test panels for outdoor exposure of water barrier materials at Granite Reef. Materials exposed 6 December 1973 (continued).

Panel Number	Material and/or Treatment
31	Neoprene, nylon-reinforced, 31 mil, black (KK235), Hodgman
32	Hypalon, nylon-reinforced, 32 mil, black (KK205), Hodgman
33	Hypalon, nylon-reinforced, 37 mil, black (KK208), Hodgman
34	Butyl/EPDM blend, 35 mil, black (MBM), Miner
35	Chlorinated Polyethylene, nylon reinforced, 32 mil, white (KK209), Hodgman
36	Butyl, nylon-reinforced, 55 mil, black (KK244) with seam, Hodgman
37	Hypalon, nylon-reinforced, 40 mil, black, Burke
38	PVC coated polypropylene mesh, 22 mil, black (24B), Hercules
39	PVC coated polypropylene mesh, 22 mil, black (24F), Hercules
40	PVC coated polypropylene mesh, 12 mil, black (24 E), Hercules
41	PVC film, 20 mil, black, EWC
42	PVC film, 30 mil, black EWC
43	Butyl, non-reinforced, 30 mil, originally exposed 18 May 1961, Carlisle

Table 6. Rainfall runoff results from the Seneca catchment after treatment with paraffin wax.

Date	Rainfall	Runoff		Date	Rainfall	Runoff	
	mm	mm	%		mm	mm	%
3 Jul 73	5.6	0	0	23 Nov 73	1.8	0	0
10 Jul 73	14.6	2.9	19.9	25 Nov 73	0.2	0	0
13 Jul 73	10.2	3.7	36.3	27 Nov 73	3.2	0	0
15 Jul 73	7.0	0.4	5.7	28 Nov 73	1/	0.1	-
15 Jul 73	1.4	0	0	1 Jan 74	0.6	0	0
16 Jul 73	6.8	0.8	11.8	2 Jan 74	0.6	0	0
16 Jul 73	4.4	0.2	4.5	4 Jan 74	1.0	0	0
28 Jul 73	11.0	3.9	35.5	5 Jan 74	17.8	0.4	2.2
2 Aug 73	3.4	0.1	2.9	7 Jan 74	22.4	0	0
2 Aug 73	0.2	0	0	8 Jan 74	1.6	0	0
3 Aug 73	0.4	0	0				
11 Aug 73	14.0	6.3	45.0				
13 Aug 73	1.6	0	0				
19 Aug 73	0.4	0	0				
20 Aug 73	0.6	0	0				
20 Aug 73	2.6	0	0				
20 Aug 73	0.4	0	0				
21 Aug 73	0.2	0	0				
26 Aug 73	0.4	0	0				
4 Nov 73	2.2	0	0				
18 Nov 73	5.0	0.5	10.0				
19 Nov 73	0.2	0	0				
19 Nov 73	1/	0.5	-				
20 Nov 73	5.6	0.2	3.6				
22 Nov 73	0.2	0	0				

1/ Melted snow runoff.

Table 7. Condition of materials on exposure racks--inspection October 1973.

Sample No. [1/]	Material	Initial exposure date	Condition [2/]	Physical description
1*	Low-temp butyl, 1/16"	8/03/64	Excellent	Slight chalking
2	Butyl-coated cotton, TDA-3909, Hodgman	1/02/64	Excellent	Slight chalking
3	Ethylene vinyl acetate copolymer, 20 mil	1/02/64	Excellent	Shrinking
4	Nylon-reinforced hypalon, Burke	10/26/71	Excellent	Slight shrinkage
5*	Butyl-coated nylon	1953	Good to fair	Extreme chalking and delaminating
6*	Butyl-coated nylon	1953	Fair	Light chalking and cracking
7*	Butyl-coated cotton (one side), Aldan	1/02/64	Excellent	Slight chalking
9	1 Chlorinated PE, white, Dow	8/25/70	Excellent	Slight chalking and stiffening
	2* Chlorinated PE, white, Dow	8/25/70	Poor	Shrinking, stiffening, cracking and fading
	3 Chlorinated PE, white, Dow	8/25/70	Fair	Cracking, shrinking and chalking
10*	Butyl-coated cotton (one side), Aldan	2/13/64	Fair	Slight cracking and shrinking, some tearing
11	Butyl-coated cotton TDA-3909, Hodgman	2/13/64	Fair	Cracking, shrinking and chalking, two holes
12	1 Chlorinated PE, white, Dow	8/25/70	Fair	Cracking, shrinking and chalking
	2* Chlorinated PE, white, Dow	8/25/70	Poor	Cracking, shrinking and stiffening
	3* Woven PE, green, Coated Fabrics	8/25/70	Poor	Substrate material completely deteriorated
14	PE film, 6 mil	7/10/63	Excellent	
15	Ethylene vinyl acetate copolymer, 6 mil	7/10/63	Excellent	Slight shrinking
16	Nylon-reinforced hypalon, yellow, Canton	8/20/70	Excellent	Slight shrinking and chalking
17*	Polyisobutylene	8/20/63	Poor	Shrinking, stiffening and weathering
18	Asphalt-coated jute, Flintkote	1/02/64	Good to Excellent	Slight stiffening

Table 7. Condition of materials on exposure racks--inspection October 1973 (continued).

Sample No. 1/	Material	Initial exposure date	Condition 2/	Physical description
19*	Vistalon-coated polypropylene, Exxon	10/09/70	Excellent	Slight chalking
20*	Vistalon-coated polypropylene, Exxon	10/09/70	Excellent	Slight chalking

1/ * Removed from racks October 1973.

2/ Excellent, good, fair, poor

Table 8. Outdoor exposure panels removed from Logan, Utah test site during 1973.

No.	Removal Code [1/]	Material	Date Installed	Condition [2/] and Comments Upon Removal
6	ab	EPT, Exxon	17 Nov 65	Excellent
7	b	Vinyl, 35 mil, white, Staff	8 Sep 65	Poor, stress crack, very brittle, plasticizer loss
8	b	Vinyl, 35 mil, black, Staff	8 Sep 65	Excellent
18	ab	Nylon-reinforced EPDM (Vistalon) green on black, green exposed, Reeves	31 Oct 69	Excellent, slight shrinkage
19	b	Vinyl from pond B-1, flexible, Union Carbide 1960	3 Nov 70	Fair to poor, plasticizer loss but still flexible
20	b	Vinyl from pond B-1 half flexible, Union Carbide, 1960	3 Nov 70	Poor on flexible part, stiff part completely deteriorated
21	ab	Chlorobutyl-coated nylon, bonded with Lock Bond, Aldan Rubber	9 Nov 70	Excellent, seam in excellent condition
22	ab	Same as 21, bonded with SWB-66-35 from Inmont	9 Nov 70	Excellent, seam in excellent condition
28	ab	Coated PP, 1.31 gal/sq (Sample 11)	13 Sep 71	Good to excellent, coating dusting, substrate excellent
29	ab	Coated PP, 1.09 gal/sq (Sample 2)	13 Sep 71	Good, coating cracked in one area, can be peeled
30	ab	Coated PP, 0.62 gal/sq (Sample 3)	13 Sep 71	Same as 28.
31	ab	Coated PP, 0.68 gal/sq (Sample 4)	13 Sep 71	Same as 28.
35	c	Coated PE, 10 mil, 0.17 gal/sq (Sample 8)	13 Sep 71	Poor, coating dusted off, PE showing through
36	c	Coated PE, 6 mil, 0.20 gal/sq (Sample 9)	13 Sep 71	Same as 35.
37	c	Coated PE, 6 mil, 0.27 gal/sq (Sample 10)	13 Sep 71	Same as 35.
39	b	Uncoated PVC, 10 mil, Goodrich (Sample 16)	13 Sep 71	Poor, very stiff
47	b	Coated PP 78 (Sample 3)	1 May 72	Coating excellent, substrate deteriorated where coating thin

Table 8. Outdoor exposure panels removed from Logan, Utah test site during 1973 (continued).

No.	Removal Code 1/	Material	Date Installed	Condition 2/ and Comments Upon Removal
48	b	Coated PP 78 (Sample 12)	1 May 72	Poor, numerous small holes, brittle
49	c	Coated PP 75 (Sample 6)	1 May 72	Poor, complete breakdown of substrate
50	b	Coated PP 65 (Sample 2)	1 May 72	Poor, substrate failure where inadequate coating
51	b	Coated PP 65 (Sample 14)	1 May 72	Same as 50.
52	b	Coated PP 75 (Sample 15)	1 May 72	Same as 50.
53	ab	Coated PP (Sample 16)	1 May 72	Excellent, some chalking
54	ab	Coated PP (Sample 13)	1 May 72	Excellent, torn along one edge--appeared to be vandalism
55	ab	Coated PP (Sample 1)	1 May 72	Same as 53.
56	ab	Coated PP (Sample 4)	1 May 72	Same as 53.
57	ab	Coated PP (Sample 7)	1 May 72	Same as 53.
58	ab	Coated PP (Sample 10)	1 May 72	Same as 53.
59	c	Uncoated PP	1 May 72	Complete deterioration
61	b	Coated Fabrene (Sample 17)	1 May 72	Excellent, had been cut from exposure frame by vandals

1/ a - Sample returned to cooperator.
b - Sample taken for laboratory testing.
c - Sample destroyed.

2/ Rating Date 4 October 1973.

Table 9. Outdoor exposure panels at Logan, Utah test site.

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

Table 9. Outdoor exposure panels at Logan, Utah test site (continued).

No.	Material	Date Installed	Condition [1/] and Comments
25	Vinyl, 20 mil, Union Carbide 9234-84-2	15 Apr 71	Fair, still flexible but stiffening around board edging.
26	Vinyl, 20 mil, Union Carbide 9236-86-1	15 Apr 71	Excellent, flexible
27	Uncoated PVC, 10 mil, Union Carbide	13 Oct 71	Excellent
32	Coated PE, 8 mil, 0.76 gal/sq (Sample 5)	13 Oct 71	Good, chalking, coating can be scraped from PE
33	Coated PE, 8 mil, 0.26 gal/sq (Sample 6)	13 Oct 71	Fair to poor, extreme chalking, PE showing through
34	Coated PE, 8 mil, 0.46 gal/sq (Sample 7)	13 Oct 71	Good, chalking, coating can be scraped from PE
38	Coated PVC, 10 mil, Union Carbide (Sample 15)	13 Oct 71	Excellent
40	Uncoated PE, 10 mil	13 Oct 71	Excellent
41	Uncoated PE, 8 mil	13 Oct 71	Excellent
42	Uncoated PE, 6 mil	13 Oct 71	Poor, mechanical damage, appeared to be claw marks
43	Coated PVC, 10 mil, Goodrich (Sample 16)	13 Oct 71	Excellent, very slight chalking
44	Butyl coated CLS, 32 mil, Hercules	1 May 72	Excellent, extreme chalking
45	Butyl coated CLS, 17 mil, Hercules	1 May 72	Excellent, extreme chalking
46	CPE lammate, Goodyear	5 May 72	Excellent, slight stiffening
60	Coated Fabrene (Sample 18)	1 May 72	Excellent, tight--may have shrunk
62	Coated Fabrene (Sample 11)	1 May 72	Excellent, slight shrinkage, extreme chalking
63	Coated Fabrene (Sample 5)	1 May 72	Excellent, slight chalking
64	Coated Fabrene (Sample 8)	1 May 72	Poor, coating can be removed by rubbing. Substrate excellent.
65	Coated Fabrene (Sample 9)	1 May 72	Poor, coating can be removed by rubbing. Substrate excellent.
66	Uncoated Fabrene	1 May 72	Excellent, slight shrinkage

Table 10. Average daily drop in water-surface elevation due to seepage 1/ of water storage systems at Logan.

Reservoir No.	Description	Date installed	Years used to determine seepage rate	Seepage rate, ft/day Max	Min	Mean
A-1	Asphalt plank lining, Gulf Seal, exposed	August 1962	12	.002	+.006	+.001
A-2	PE, black, 4 mil, buried	October 1954	13	.020	.001	.009
A-4	PE, black, 8 mil, buried	July 1954	13	.006	+.005	0.000
A-5	PVC, VU-5965, olive, 8 mil, buried	July 1954	13	.008	+.003	.003
B-4	Chlorinated PE, black, 20 mil, exposed	October 1965	8	.003	+.005	+.002
C-1	Butyl rubber, unreinforced, 20 mil, exposed	July 1958	12	.073	+.005	.012
C-2	Asphalt-jute laminate, exposed	August 1956	12	.025	+.005	.002
C-4	Butyl-coated CLS, 17 mil	May 1972	2	+.001	+.002	+.002
E-4	PVC (30 mil) lined galvanized steel grain bin (24 ft dia) with roof	March 1967	6	.004	.002	.003

1/ Drop in water surface is corrected for evaporation, using a factor of .9 for buried linings and .75 for exposed linings. Plus values indicate that correction was larger than it should be, or that the accuracy of the measurement was insufficient for values of the order reported.

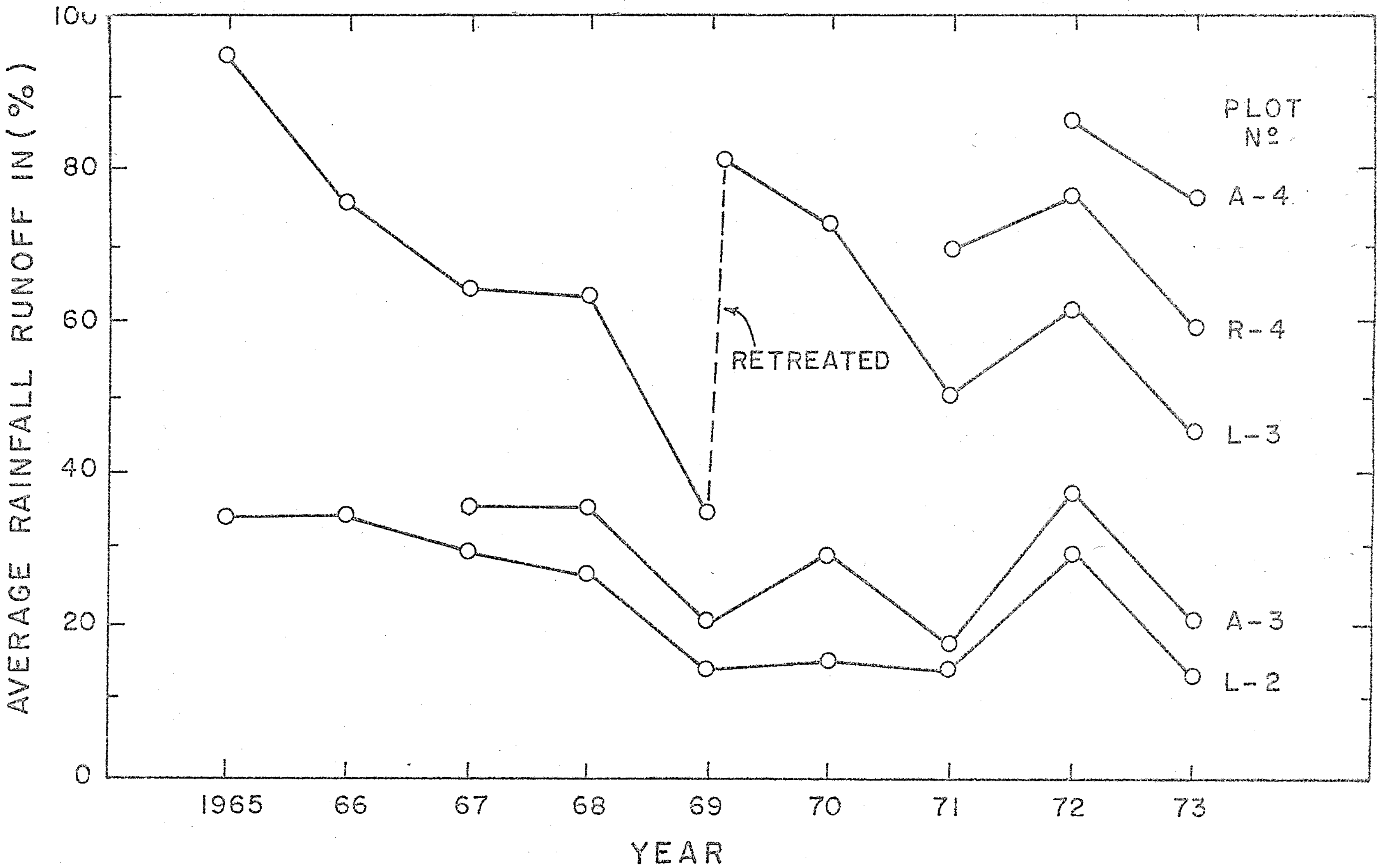

Fig. 1. Rainfall-runoff results from five bare-soil treatments at the Granite Reef Testing Site.

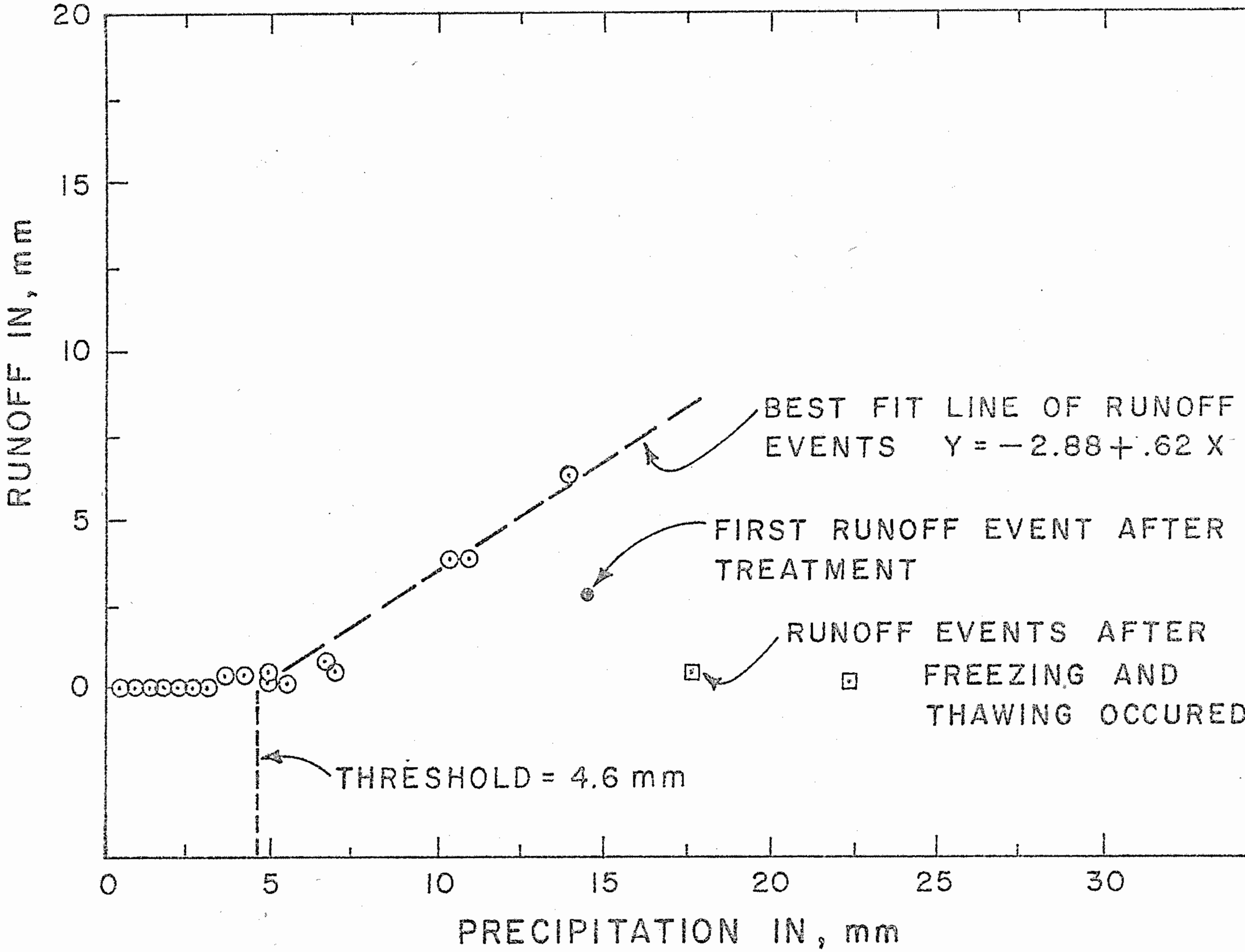

Fig. 2. Runoff results by individual storms from the Seneca catchment after treatment with paraffin wax.

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

CRIS WORK UNIT: 5402-12260-004 CODE NO.: Ariz.-WCL 72-1

INTRODUCTION:

Annual Reports for 1966-1972 contain summaries of studies on 16 simple critical-flow flumes with cross-sectional shapes that were trapezoidal, triangular or rectangular. The mathematical model for predicting flume calibrations was extended to allow the introduction of more complex shapes into computation for cross-sectional area. These shapes included non-symmetrical flumes and flumes whose sideslopes change at certain flow depths, usually to flatter slopes at deeper depths, to increase capacity for high discharge rates. Predictions of the non-symmetrical and complex shapes were satisfactory. The computational procedure has remained essentially static, but differs in several respects from previous accountings. Therefore, it is reproduced here in condensed form along with the Flow Diagram, Computer Listing, and a computational example.

Basic theories describing the operation of critical-flow measuring flumes have long been known. Ackers and Harrison (1) were successful in applying allowances for energy losses to accurately predict the calibration for some flume shapes. The friction loss estimate was modified by Replogle (4) using a boundary-drag procedure that proved reliable for a wide variety of flume cross-sectional shapes. The success at accurately predicting flume flow characteristics, to within $\pm$ 2%, for simple triangular-, rectangular-, and trapezoidal-sectional shapes has been extended to more complex shapes in order to tailor the stage-discharge relation to control tailwater, avoid submerged-flow operation, increase sensitivity, or achieve specified velocities to aid sediment movement. The simple shapes and the equations developed for iteration solution on computers and laboratory verifications have been previously reported (3 and 4).

THEORETICAL CONSIDERATIONS:

Figure 1 illustrates a general, complex-shaped, critical-flow flume having an entrance, labeled Section 1; a converging portion, labeled Section 2; and a constricted throat portion, labeled Section 3. From basic hydraulics theory, critical discharge in any flume -- circular, rectangular, trapezoidal, or other shape -- in terms of geometric parameters in the critical-flow section (Section 3) is given by

$$Q = [gA_3{}^3/(\alpha_3 T_3)]^{1/2} \qquad (1)$$

where Q = volume discharge rate; g = gravitational constant; A = cross-sectional area of flow; α = energy distribution coefficient (2, p. 27); T = top width of flow; and the subscript 3 designates values for Section 3, Figure 1. In practice it is usually necessary to relate some upstream depth, Y_1, in Section 1, to discharge using energy relations, because the point of critical depth, Y_3, in a flume throat is difficult to locate. The specific energy in Section 3 for critical flow (2, p. 41-43) is

$$H_3 = Y_3 + A_3/2T_3 \qquad (2)$$

Likewise, the specific energy, H_1, relative to the same datum plane, for the location where flow depth, Y_1, is usually sensed, in Section 1, is

$$H_1 = Y_1 + \alpha_1(V_1{}^2/2g) \qquad (3)$$

where V_1 is the average velocity in Section 1 and α_1 is the velocity distribution coefficient for the same location.

The specific energy difference between these two locations is represented by the frictional losses, H_f. Thus, combining equations (2) and (3) with H_f

$$Y_3 = Y_1 + \alpha_1 Q^2/(2gA_1^2) - A_3/(2T_3) - H_f \qquad (4)$$

Both A_3 and T_3 are functions of Y_3. Likewise V_1 is represented as Q/A_1, where A_1 is the cross-sectional area in Section 1 and is a function of Y_1, plus any sill height, Y_8, that may be built into the floor of Section 3.

Any cross-sectional shape where area, A, and top width, T, can be expressed in terms of Y_1 and Y_3, respectively, for A_1 and A_3 is subject to iteration solution on a computer for Q in terms of Y_1, provided that a suitable evaluation for H_f is available along with estimates for α_1 and α_3. The total friction loss H_f is the sum of the friction losses in each flume section or

$$H_f = H_1 + H_2 + H_3 \qquad (5)$$

where the subscript refers to the flume section under consideration. A more comprehensive review of the total method of arriving at satisfactory estimates of each component of equation (5) is given by Replogle (4). Summarized, the most important part is the loss H_3 in Section 3. Here, a laminar boundary layer is assumed to begin its development at the throat entrance, after which the drag will be determined by turbulent boundary layer concepts. The composite total drag coefficient, C_F', for a given throat length (5, p. 538) is

$$C_F' = C_F - (R_c/R_L)(C_{F,t} - C_{F,1}) \qquad (6)$$

where C_F is the total drag coefficient for the section; $C_{F,t}$

Annual Report of the U.S. Water Conservation Laboratory

and $C_{F,1}$ denote the coefficient of turbulent and laminar skin friction, respectively, for the total drag up to a distance producing a Reynolds Number, R_c (estimated by $R_c = 350{,}000 + L_3/K$, where K is the absolute roughness height), at which transition to turbulent flow occurs; and R_L is a Reynolds Number based on the entire throat length, $R_L = V_3L_3/\nu$, where ν is the kinematic viscosity.

Having estimated R_c it is then possible to solve for $C_{F,t}$, $C_{F,1}$, and hence C_F' by iteratively solving of the equation [Replogle (3)]

$$C_F = \frac{0.544\ C_F}{5.61\ C_F^{0.5} - 0.638 - \log_e[(R_L C_F)^{-1} + (4.84\ C_F^{0.5}\ L_3/K)^{-1}]} \qquad (7)$$

for both C_F and $C_{F,t}$ (the latter simply by substituting $C_{F,t}$, R_c, and X_c for C_F, R_L, and L_3, respectively ($X_c = R_c\ \nu/V_3$).

The value for $C_{F,1}$, the laminar region contribution to the drag, is obtained from (5, p. 122)

$$C_{F,1} = 1.328/R_c^{0.5} \qquad (8)$$

The drag force D_F, of a fluid flowing through a flume section can be expressed as (2, p. 94)

$$D_F = C_F \rho PLV^2/2 \qquad (9)$$

where C_F is the total drag coefficient, ρ is the mass density of the fluid, and the flume-section surface area is given by the product of the wetted perimeter, P, and the length of the flume section for which friction is being computed. In terms of head loss equation (9) can be represented as a drag force retarding a volume of water with weight γ per unit volume moving under the influence of an energy gradient such as that it loses H head in a distance L, or $D_F = \gamma A L H/L$, or for Section 3,

$$H_{f3} = D_F/(\gamma A_3) \tag{10}$$

Combining equation (10) with equation (9), observing the restraints of equation (6) and equation (8) concerning C_F', and recognizing that $\gamma = \rho g$,

$$H_{f3} = C_F' P_3 L_3 V_3^2/(2gA_3) \tag{11}$$

Other minor drag force losses are approximated for H_1 and for H_2 by the following equations [Replogle (3)]:

$$H_{f1} = 0.00235 P_1 X_1 V_1^2/(2gA_1) \tag{12}$$

$$H_{f2} = \frac{1}{2}\left[\frac{0.00235 P_1 L_2 V_1^2}{2gA_1} + \frac{0.00235 P_e L_2 V_e^2}{2gA_e}\right] \tag{13}$$

where X_1 is the length to the depth measurement location, Figure 1, and the subscript e refers to conditions near the exit of Section 2, based on the approximation [Replogle (3)] that $Y_e = Y_3 + 0.62 (Y_1 - Y_3)$.

Equation (5) for H_f can now be satisfactorily evaluated from equations (11), (12), and (13).

The value of 1.04 for α_1 for Section 1 is sufficiently accurate since the flume calibration is relatively insensitive to conditions in Section 1. The value for α_3 is more complex and is a function of Section 3 shape and length. An approximation is [Replogle (3)]

$$\alpha_3 = 1 + [3 E^2 - 2 E^3][1.5 D_3/R_3 - 0.5][0.025 L_3/R_3 - 0.05] \tag{14}$$

where D_3 is the hydraulic depth (area/top width) in Section 3, and $E = 1.77\ (C_F)^{0.5}$ (2, p. 211).

COMPUTATIONAL PROCEDURES:

The prediction of the calibration relationship for a given flume involves applying these equations in an iteration sequence suitable for computer solution. For a given Y_1 and flume shape, equation (1) is solved using a trial value for Y_3 to obtain A_3 and T_3. This provides a trial Q for use in equation (4) and for determining trial velocities needed to evaluate equations (6), (7), (8), (11), (12), and (13), which then permits a trial estimate of H_f by equation (5). Finally, α_3 is estimated by equation (14). This completes one iteration loop and the results for α_3 and Y_3 are returned for evaluating equation (1), etc., until convergence is obtained. A new Y_1 is then selected and the process repeated until a calibration table has been developed for the particular flume. The equations can be readily programed for solution in either FORTRAN or BASIC.

A Flow Diagram and a listing of a BASIC Program incorporating the above equations are attached. The printout example is for the specially designed flume described later. The symbols and names on the printout table are as follows:

SILL HEIGHT = Elevation of the throat bottom with respect to the flume bottom of the approach section where depth Y1 is detected. Value may be positive (raised) or negative (depressed), expressed in feet.

B1 = Bottom width of the approach section, Section 1, feet.

B3 = Bottom width of the throat section, Section 3, feet.

K = Absolute roughness height of material in flume throat, feet.

X1 = Distance from point of depth sensing to transition section, i.e. that length of Section 1 that contributes to friction loss, starting at the point of depth sensing, feet.

L2 = Length of the transition section, Section 2, feet

L3 = Length of the throat section, Section 3, feet.

D1 = Vertical distance from floor of Section 1 to first change in wall slope, if any, feet.

D2 = Vertical distance from floor of Section 1 to second change in wall slope, if any, feet.

D3 = Vertical distance from floor of Section 3 to first change in wall slope, if any, feet.

D4 = Vertical distance from floor of Section 3 to second change in wall slope, if any, feet.

Z1 = Sideslope of lower portion of Section 1 to depth, D1, feet.

Z3 = Sideslope of lower portion of Section 3 to depth D1, feet.

Z4 = Sideslope of Section 1 between depth D1 and D2, feet.

Z5 = Sideslope of Section 1 above depth D2, feet.

Z8 = Sideslope of Section 3 between depth D3 and D4, feet.

Z9 = Sideslope of Section 3 above depth D4, feet.

The program prints out nine columns of information:

Column 1: Y1, FT = depth detected in Section 1 referenced to floor elevation of Section 3.

Column 2: Q, cfs = computed discharge rate for depth Y1 and the other geometrical data.

Column 3: CRITICAL-DEPTH-FT = Depth of flow in flume throat, also approximate limiting depth for backwater on flume before submergence effects begin.

Column 4: FROUDE NO. at Y = Froude Number in Section 1; Indicates stability of depth reading and sediment moving ability;

Should be less than 0.6 for a stable water surface but greater than 0.3 to aid sediment movement.

Column 5: IDEAL-Q = Computed discharge for an ideal fluid which ignores frictional effects and velocity distribution effects.

Column 6: DISC.C = Discharge coefficient, comparing the ideal A, Column 5, to the computed discharge in Column 2.

Column 7: V1 = Average velocity in Section 1, ft/sec.

Column 8: ALF3 = The velocity distribution coefficient for the throat section, Section 3

Column 9: V3 = Average velocity in Section 3, ft/sec.

To operate the program, supply the appropriate data values for the read statements of 109 to 190. The statement numbers contain the following data in the format of the BASIC Program attached.

Data Statement Number	Contents	Comments
110	B1, B3	Bottom widths Sec. 1 and 3.
120	Z1, Z3	Sideslopes, bottom portion.
130	S, I, LO	Beginning, increment, end of Y1.
140	K	Absolute roughness height.
150	L3	Length of Section 3.
160	Y8	Sill height.
170	L1, L2	L1 = X1.
180	Z4, Z5, Z8, Z9	Sideslopes defined previously.
185	D1, D2, D3, D4	Depths to sideslope changes, defined previously.
190	R2, G, V1	Rounding constant for number of significant figures in printout. Gravitational constant, (use G = 32.16 in English system, or 9.803 in metric system).

Data Statement Number	Contents	Comments
190 (Continued)		Kinematic viscosity of flowing fluid (use V1 = 1.288×10^{-5} ft^2/sec, in English system or V1 = 1.16×10^{-6} m^2/sec in metric system at 18° C)

A SPECIFIC FLUME DESIGN:

A flume was designed at the request of the Salt River Project to measure flows in the Roosevelt Water Conservation District northeast of Mesa, Arizona. The basic requirements of the installation were to avoid submerged flows, achieve minimum upstream head for minimum pump lift at the most frequent flow rates and provide wide measuring range. Sediment accumulation was not judged to be a problem, so a sill height of 1.4 ft was allowable. The structural details and construction design were done by the Salt River Project. The flume throat had a complex cross-section with the above mentioned sill height of 1.4 ft, a trapezoidal low flow portion with 1 to 1 sideslopes, and a bottom width in the throat section of 1 ft. This low-flow part was only 0.75 ft deep, measured from the throat bottom, whereupon the sides widened at a rate of 6 horizontal to 1 vertical for another 2 ft of depth and finally changed to 1 to 1 sideslopes for the remainder of the canal depth. The original canal has sideslopes of 1 1/3 horizontal to 1 vertical. Construction was completed in the fall of 1973. Full flows are expected in the spring of 1974.

The calibration table is presented as the printout example to the program listing attached. Note the small change in calibration caused by a 10-fold change in roughness height, changing from K = 0.0005 to K = 0.005.

SUMMARY AND CONCLUSIONS:

The mathematical model for predicting critical-depth flume calibrations has remained essentially the same since incorporation of methods to handle more complex shapes into the computations for cross-sectional area and friction loss. These shapes included non-symmetrical flumes, and flumes whose sideslopes change at particular flow depths, usually to flatter sideslopes at deeper depths, to increase capacity for high discharge rates. Predictions of the non-symmetrical and complex shapes was satisfactory. The computer program, flow diagram, and explanation of program inputs and use is now available in BASIC Programing language. The calibrating capability is being applied in a companion research project aimed at providing sediment handling capability in flow metering flumes for sand-bed streams.

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3. Replogle, J. A. Critical-depth flumes for determining flow in canals and natural channels. Transactions of the ASAE 14(3):428-433, 436. 1971.

4. Replogle, J. A. Tailoring critical-depth measuring flumes. Proc., Symposium on Flow: Its Measurement and Control in Science and Industry (Pittsburgh), Instrument Society of America, May 1971. 1974.

5. Schlichting, H. Boundary layer theory. McGraw-Hill Book Co., New York. 1960. 647 pp.

PERSONNEL: J. A. Replogle

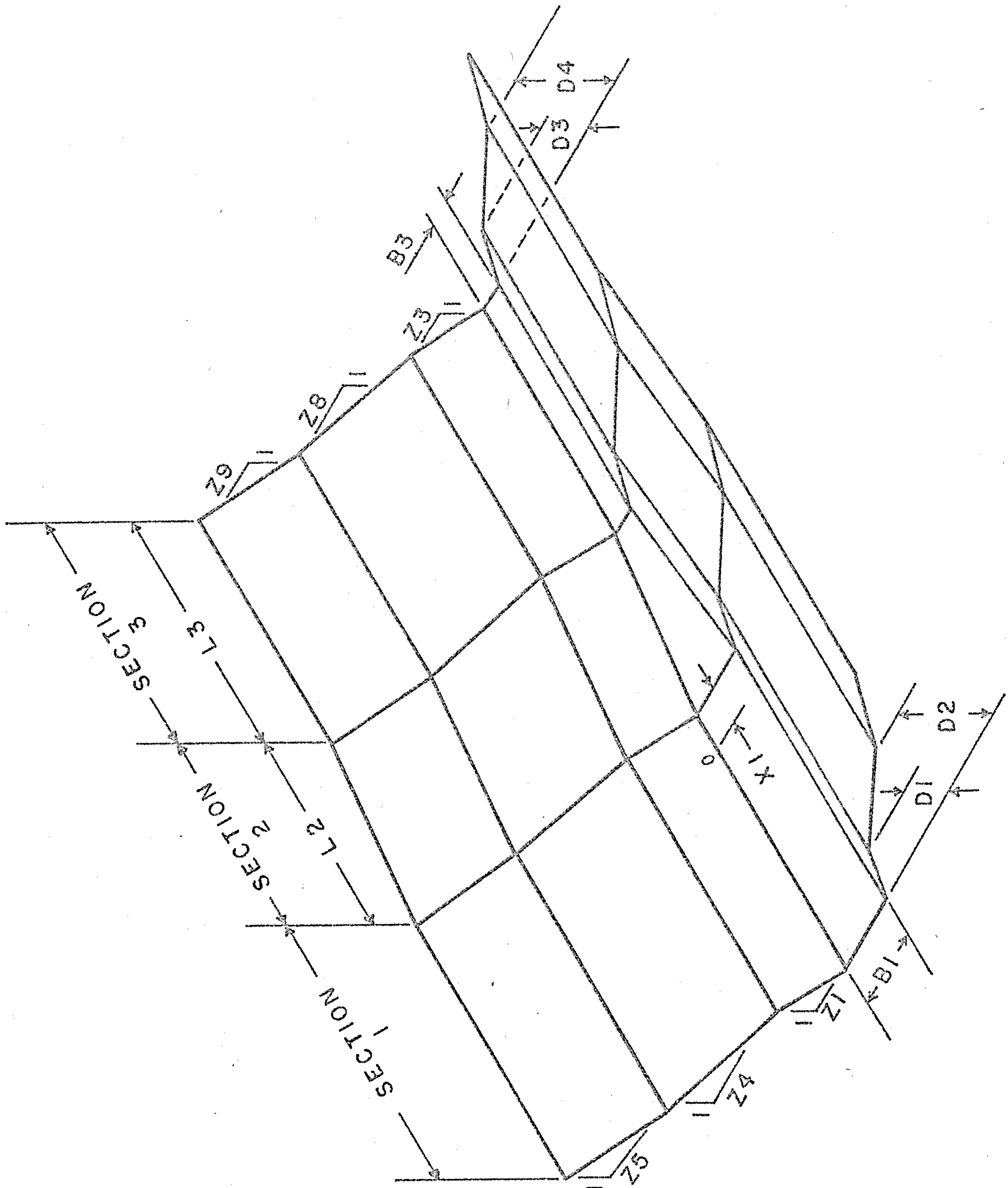
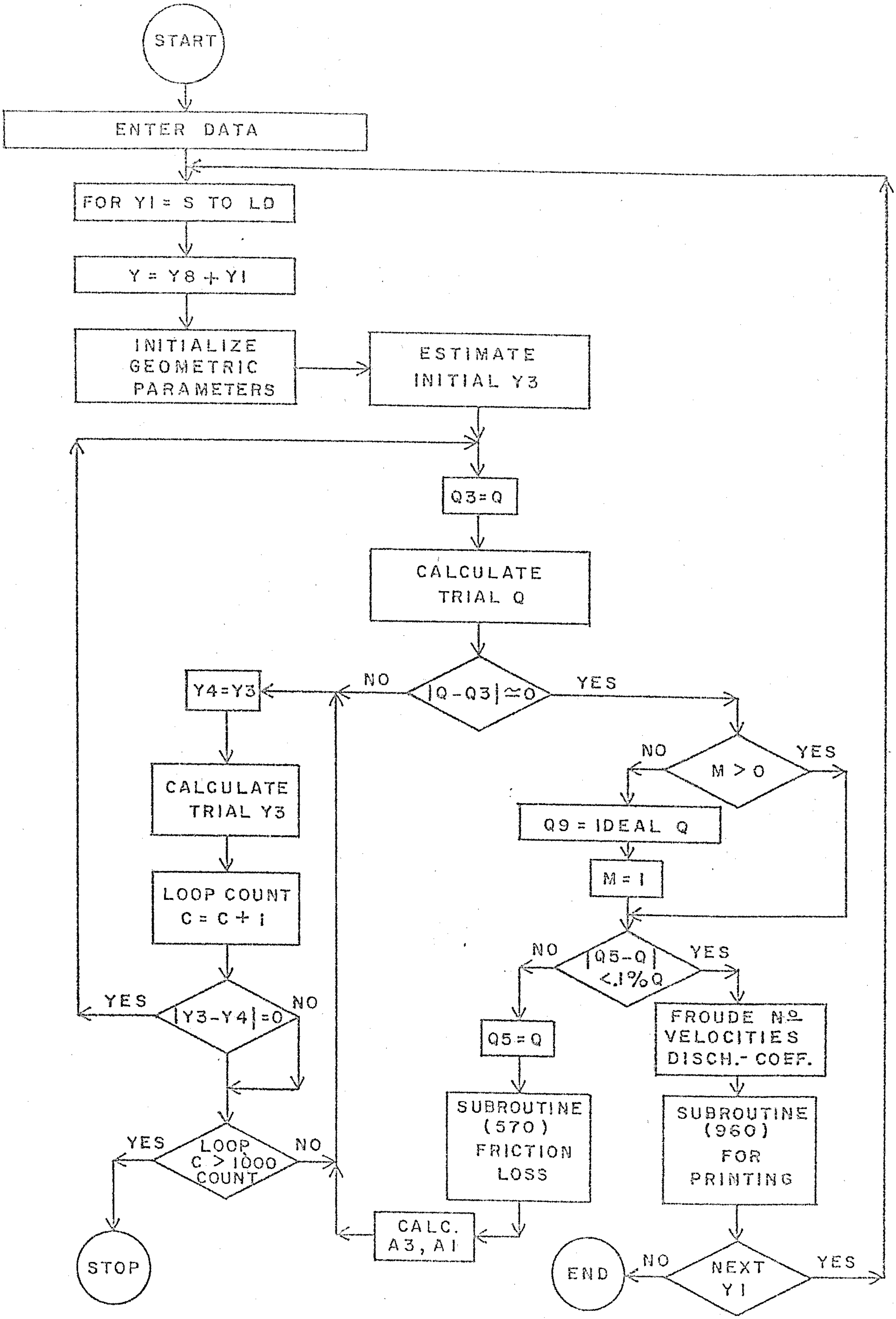
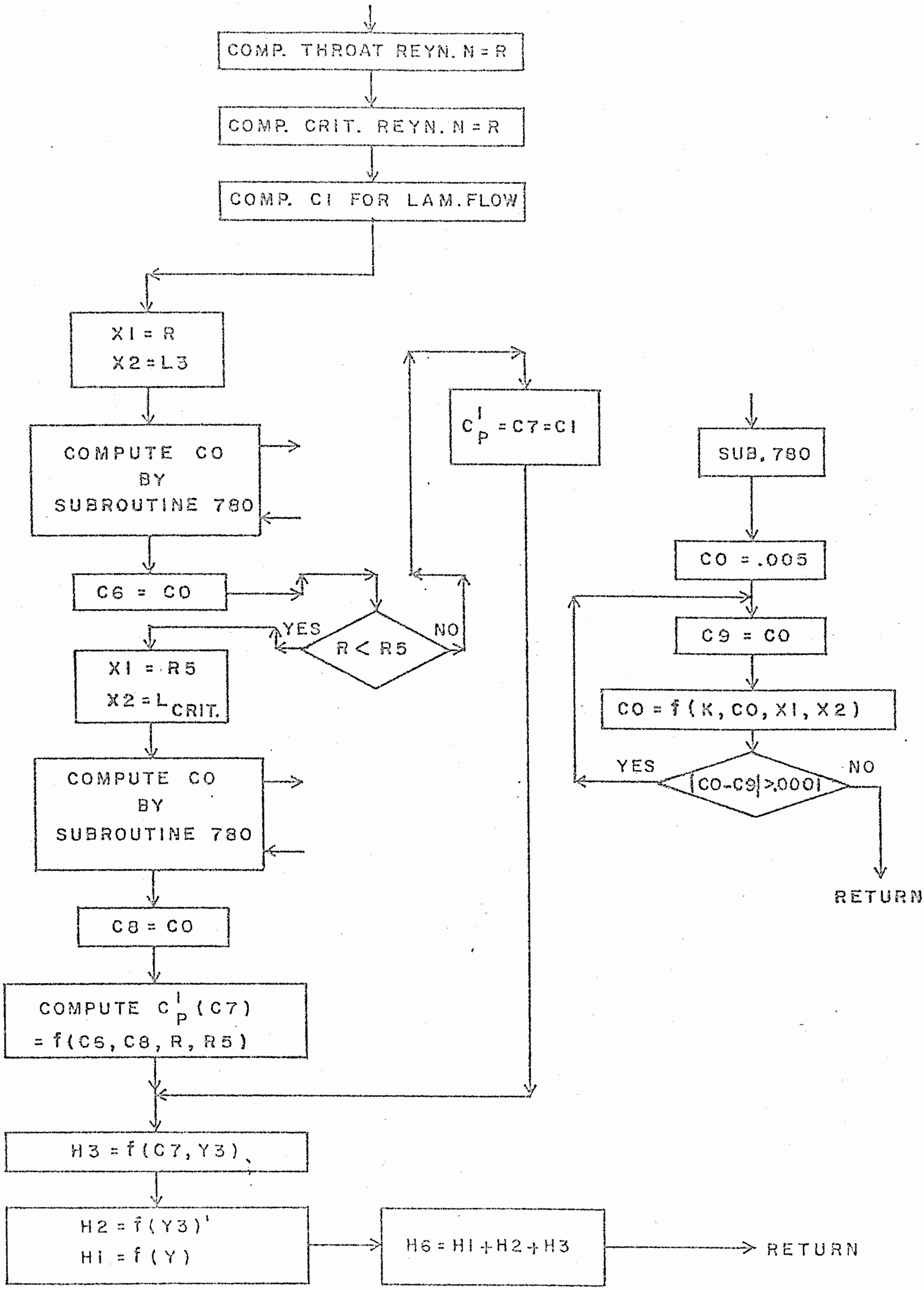

SECTION 3
SECTION 2
SECTION 1
L3
L2
Z9
Z8
Z3
Z1
Z4
Z5
B3
B1
D1
D2
D3
D4
X1
0

Figure 1.

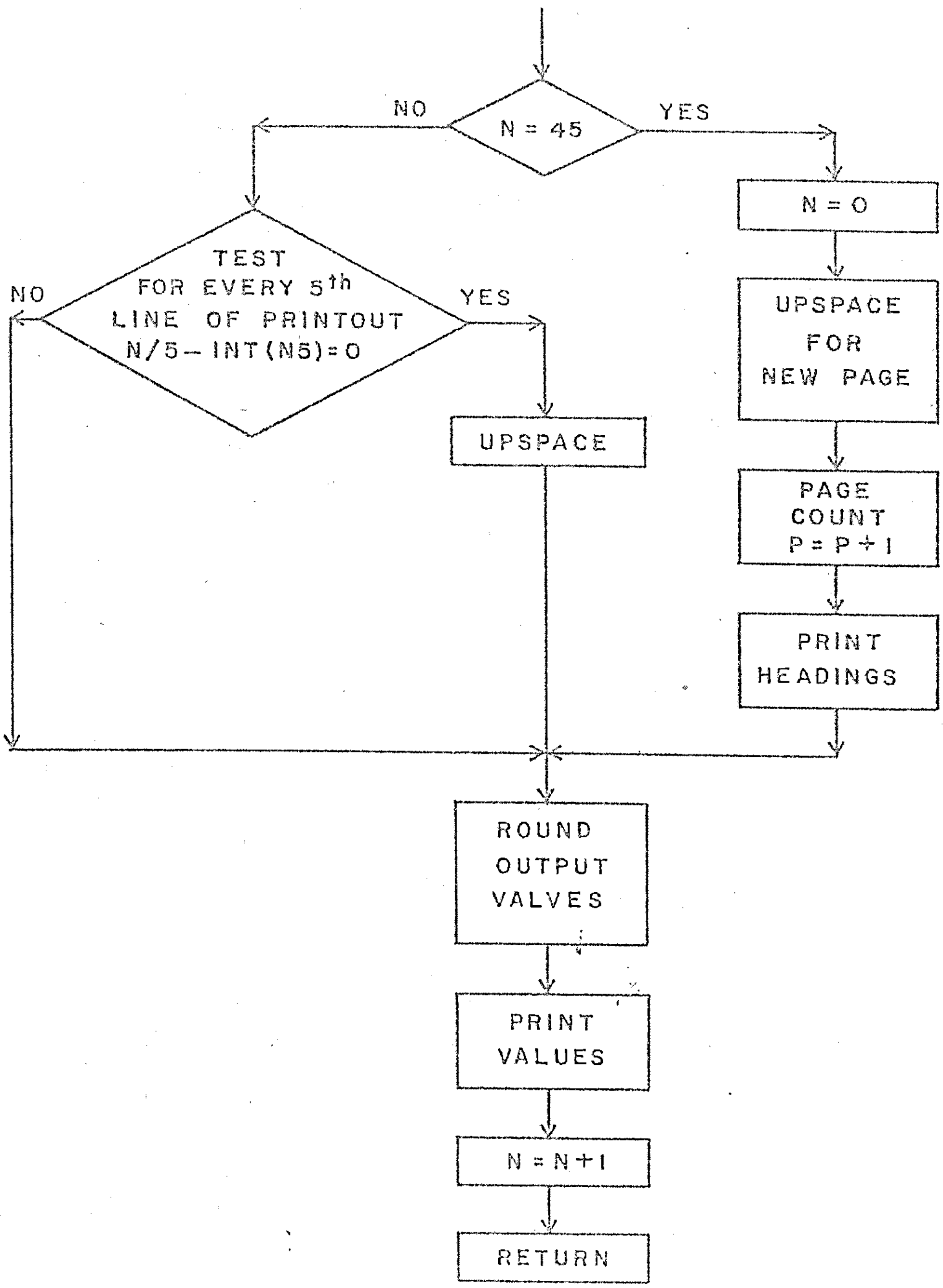

START
ENTER DATA
FOR YI = S TO LD
Y = Y8 + YI
INITIALIZE GEOMETRIC PARAMETERS
ESTIMATE INITIAL Y3
Q3 = Q
CALCULATE TRIAL Q
|Q-Q3| ≃ 0
NO
YES
Y4 = Y3
CALCULATE TRIAL Y3
LOOP COUNT C = C + 1
|Y3-Y4| = 0
YES
NO
LOOP C > 1000 COUNT
YES
NO
STOP
M > 0
NO
YES
Q9 = IDEAL Q
M = 1
|Q5-Q| <.1%Q
NO
YES
Q5 = Q
SUBROUTINE (570) FRICTION LOSS
CALC. A3, A1
FROUDE №
VELOCITIES
DISCH.- COEF.
SUBROUTINE (960) FOR PRINTING
NEXT YI
NO
YES
END

SUBROUTINE FOR FRICTION LOSS



SUB 960

SUBROUTINE FOR PRINTING



```
0001 PRINT
0002 PRINT "     NØVA 800        DATE:.........TIME:.........."
0003 PRINT
0004 REM EXPRESSIØNS FØR CØMPLEX ØR SIMPLE CRØSS-SECTIØNAL SHAPES
0005 REM                  AREA, ENTRANCE SECTIØN
0006 DEF FNM(X)=M2*((B1+Z1*D1)*D1+((B1+2*Z1*D1)+Z4*(X-D1))*(X-D1))
0008 DEF FNB(X)=M3*(((B1+2*Z1*D1)+Z4*(D2-D1))*(D2-D1))
0010 DEF FNA(X)=M1*((B1+Z1*X)*X)+FNM(X)+FNB(X)+M3*((B1+Z1*D1)*D1)
0016 DEF FNE(X)=FNA(X)+M3*(B1+2*(Z1*D1+Z4*(D2-D1))+Z5*(X-D2))*(X-D2)
0018 REM                       TØP-WIDTH, ENTRANCE SECTIØN
0020 DEF FNG(X)=M1*(B1+2*Z1*X)+M2*(B1+2*Z1*D1+2*Z4*(X-D1))
0022 DEF FNW(X)=FNG(X)+M3*(B1+2*Z1*D1+2*Z4*(D2-D1)+2*Z5*(X-D2))
0024 REM                      TØP-WIDTH, CRITICAL SECTIØN
0026 DEF FNH(X)=M4*(B3+2*Z3*X)+M5*(B3+2*Z3*D3+2*Z8*(X-D3))
0028 DEF FNN(X)=FNH(X)+M6*(B3+2*Z3*D3+2*Z8*(D4-D3)+2*Z9*(X-D4))
0029 REM                    CRITICAL SECTIØN AREA
0030 DEF FNF(X)=M6*(((B3+2*Z3*D3)+Z8*(D4-D3))*(D4-D3))
0031 DEF FNV(X)=M5*((B3+Z3*D3)*D3+((B3+2*Z3*D3)+Z8*(X-D3))*(X-D3))
0032 DEF FND(X)=M4*((B3+Z3*X)*X)+FNV(X)+FNF(X)+M6*((B3+Z3*D3)*D3)
0038 DEF FNC(X)=FND(X)+M6*(B3+2*(Z3*D3+Z8*(D4-D3))+Z9*(X-D4))*(X-D4)
0040 REM                       WETTED PERIMETER ØF ENTRANCE SECTIØN
0042 DEF FNI(X)=M1*(B1+2*X*(1+Z1*Z1)↑.5)
0044 DEF FNJ(X)=M2*(B1+2*D1*(1+Z1*Z1)↑.5+2*(X-D1)*(1+Z4*Z4)↑.5)
0046 DEF FNK(X)=M3*(B1+2*D1*(1+Z1*Z1)↑.5+2*(D2-D1)*(1+Z4*Z4)↑.5)
0048 DEF FNP(X)=M3*(2*(X-D2)*(1+Z5*Z5)↑.5)+FNK(X)+FNJ(X)+FNI(X)
0050 REM                       WETTED PERIMETER ØF CRITICAL SECTIØN
0052 DEF FNQ(X)=M4*(B3+2*X*(1+Z3*Z3)↑.5)
0054 DEF FNT(X)=M5*(B3+2*D3*(1+Z3*Z3)↑.5+2*(X-D3)*(1+Z8*Z8)↑.5)
0056 DEF FNU(X)=M6*(B3+2*D3*(1+Z3*Z3)↑.5+2*(D4-D3)*(1+Z8*Z8)↑.5)
0058 DEF FNØ(X)=M6*(2*(X-D4)*(1+Z9*Z9)↑.5)+FNU(X)+FNT(X)+FNQ(X)
0060 DEF FNL(X)=LØG(X)/2.30258
0062 DEF FNR(X)=INT(X*10↑INT(R2-FNL(X))+.5)/10↑INT(R2-FNL(X))
0064 DEF FNS(X)=ABS(INT(4+FNL(X))+ABS(7-INT(4+FNL(X)))/10)
```

```
0109 READ B1,B3
0110 DATA 16,1
0119 READ Z1,Z3
0120 DATA 1.33333,1
0129 READ S,I,LO
0130 DATA .5,.5,4.5
0139 READ K
0140 DATA .0005
0149 READ L3
0150 DATA 8
0159 READ Y8
0160 DATA 1.4
0169 READ L1,L2
0170 DATA 2,15
0179 READ Z4,Z5,Z8,Z9
0180 DATA 1.33333,1.33333,6,1
0184 READ D1,D2,D3,D4
0185 DATA 1,1,.75,2.75
0189 READ R2,G,V1
0190 DATA 4,32.16,1.228E-5
0200 LET N=40
0205 LET P=0
0210 FØR Y1=S TØ LO STEP I
0220   LET Y=Y8+Y1
0221   IF Y1<(D1-Y8) THEN GØTØ 0227
0222   IF Y1<(D2-Y8) THEN GØTØ 0231
0223   LET M3=1
0224   LET M1=0
0225   LET M2=0
0226   GØTØ 0235
0227   LET M1=1
0228   LET M2=0
0229   LET M3=0
0230   GØTØ 0235
```

```
Ø231    LET M2=1
Ø232    LET M1=Ø
Ø233    LET M3=Ø
Ø235    LET C=Ø
Ø236    LET M=Ø
Ø237    LET Q5=Ø
Ø238    LET H6=Ø
Ø239    LET Q=Ø
Ø24Ø    LET A1=1
Ø25Ø    LET A3=1
Ø26Ø    LET Y3=.7*Y1
Ø261    LET Q3=Q
Ø262    IF Y3<D3 THEN GOTO Ø269
Ø263    IF Y3<D4 THEN GOTO Ø274
Ø264    LET M6=1
Ø265    LET M4=Ø
Ø266    LET M5=Ø
Ø268    GOTO Ø28Ø
Ø269    LET M4=1
Ø27Ø    LET M5=Ø
Ø271    LET M6=Ø
Ø273    GOTO Ø28Ø
Ø274    LET M5=1
Ø275    LET M4=Ø
Ø276    LET M6=Ø
Ø28Ø    LET Q=(G*FNC(Y3)↑3/(A3*FNN(Y3)))↑.5
Ø29Ø    IF ABS(Q-Q3)<.ØØØ1*Q THEN GOTO Ø36Ø
Ø3ØØ    LET Y4=Y3
Ø31Ø    LET YØ=Q*Q/(2*G*FNE(Y)↑2)
Ø312    LET YØ=YØ*A1+Y1-H6
Ø314    LET Y3=YØ-FNC(Y3)/(2*FNN(Y3))
Ø32Ø    LET C=C+1
Ø33Ø    IF ABS(Y3-Y4)<.ØØØ1*Y4 THEN GOTO Ø261
Ø34Ø    IF C>1ØØØ THEN GOTO 123Ø
Ø35Ø    GOTO Ø3ØØ
```

```
0360   IF M>0 THEN GOTO 0390
0370   LET Q9=Q
0380   LET M=1
0390   IF ABS(Q5-Q)<.001*Q THEN GOTO 0510
0400   LET Q5=Q
0410   GOSUB 0570
0420   REM                ESTIMATE ALPHA 3
0430   LET E=1.77*C6↑.5
0440   LET A2=1.5*FNO(Y3)/FNN(Y3)-.5
0450   IF A2<2 THEN GOTO 0460
0455   LET A2=2
0460   LET A4=.025*L3/(FNC(Y3)/FNO(Y3))-.05
0470   IF A4<1 THEN GOTO 0480
0475   LET A4=1
0480   LET A3=1+(3*E*E-2*E↑3)*A2*A4
0490   LET A1=1.04
0500   GOTO 0310
0510   LET F1=Q/(FNE(Y)↑1.5*(G/FNW(Y))↑.5)
0518   LET V=Q/FNE(Y)
0519   LET V3=Q/FNC(Y3)
0520   LET C4=Q/Q9
0530   GOSUB 0960
0540 NEXT Y1
0550 PRINT
0551 PRINT "K=";
0552 INPUT K
0553 IF K>=1 THEN GOTO 1240
0554 LET N=0
0555 PRINT
0556 GOTO 0210
```

```
Ø56Ø REM                    SUBROUTINE FOR FRICTION LOSS
Ø57Ø LET R=Q/FNC(Y3)*L3/V1
Ø58Ø LET R5=35ØØØØ+L3/K
Ø59Ø LET C1=1.328/R↑.5
Ø61Ø LET X1=R
Ø62Ø LET X2=L3
Ø63Ø GOSUB Ø78Ø
Ø64Ø LET C6=CØ
Ø645 IF R<R5 THEN GOTO Ø71Ø
Ø65Ø LET X1=R5
Ø66Ø LET X2=R5*V1/(Q/FNC(Y3))
Ø67Ø GOSUB Ø78Ø
Ø68Ø LET C8=CØ
Ø69Ø LET C7=C6-(R5/R)*(C8-C1)
Ø7ØØ GOTO Ø72Ø
Ø71Ø LET C7=C1
Ø72Ø LET H3=C7*FNO(Y3)*L3*Q*Q/(2*G*FNC(Y3)↑3)
Ø73Ø LET Y2=Y3+(5/8)*(Y1-Y3)
Ø74Ø LET H2=FNP(Y)*L2*Q*Q/FNE(Y)↑3
Ø742 LET H2=H2+FNO(Y2)*L2*Q*Q/FNC(Y2)↑3
Ø744 LET H2=H2*.ØØ235/(4*G)
Ø75Ø LET H1=.ØØ235*FNP(Y)*L1*Q*Q/(2*G*FNE(Y)↑3)
Ø76Ø LET H6=H1+H2+H3
Ø77Ø RETURN
Ø78Ø LET CØ=.ØØ5
Ø79Ø LET C9=CØ
Ø8ØØ LET J=(.544*CØ↑.5)
Ø8Ø5 LET CØ=J/(5.61*CØ↑.5-.638-LOG(1/(X1*CØ)+1/(4.84*X2/K*CØ↑.5)))
Ø81Ø IF ABS(CØ-C9)>.ØØØØ1 THEN GOTO Ø79Ø
Ø82Ø RETURN
```

```
0959 REM                        SUBRØUTINE FØR PRINTING
0960 IF N=40 THEN GØTØ 1010
0970 IF N/5-INT(N/5)=0 THEN GØTØ 0990
0980 GØTØ 1140
0990 PRINT
1000 GØTØ 1140
1010 LET N=0
1020 LET P=P+1
1030 PRINT
1040 PRINT "   FLUME DIMENSIØNAL DATA:  SILL HEIGHT=";Y8;"    K=";K
1050 PRINT  TAB(7);"B1=";B1; TAB(19);"Z1=";Z1; TAB(33);"X1=";L1;
1060 PRINT  TAB(45);"B3=";B3; TAB(57);"Z3=";Z3
1070 PRINT  TAB(7);"D1=";D1; TAB(19);"Z4=";Z4; TAB(33);"L2=";L2;
1080 PRINT  TAB(45);"D3=";D3; TAB(57);"Z8=";Z8
1085 PRINT  TAB(7);"D2=";D2; TAB(19);"Z5=";Z5; TAB(33);"L3=";L3;
1086 PRINT  TAB(45);"D4=";D4; TAB(57);"Z9=";Z9
1090 PRINT  TAB(2);"Y1"; TAB(12);"Q"; TAB(17);"CRITICAL"; TAB(27);"FRØUD
1100 PRINT  TAB(2);"FT."; TAB(11);"CFS"; TAB(17);"DEPTH-FT NØ.AT Y";
1110 PRINT  TAB(34);"IDEAL-Q"; TAB(43);"DISC.C  V1     ALF 3    V3"
1120 PRINT "====================================";
1130 PRINT "===================================="
1132 LET Q=FNR(Q)
1134 LET C4=FNR(C4)
1136 LET V=FNR(V)
1138 LET A3=FNR(A3)
1140 LET Q9=FNR(Q9)
1143 LET Y1=FNR(Y1)
1144 LET R2=3
1146 LET Y3=FNR(Y3)
1148 LET F1=FNR(F1)
1150 LET V3=FNR(V3)
1152 LET R2=4
1170 PRINT USING "##.### #####.###   ##.##   #.### ",Y1,Q,Y3,F1,
1175 PRINT USING "#####.###  ##.#### ###.## ##.### ##.##",Q9,C4,V,A3,V3
1180 LET N=N+1
1185 RETURN
1230 PRINT "C=";C
1240 END
```

RUN

NØVA 800 DATE:.........TIME:..........

FLUME DIMENSIØNAL DATA: SILL HEIGHT= 1.4 K= .0005

B1= 16	Z1= 1.33333	X1= 2	B3= 1	Z3= 1
D1= 1	Z4= 1.33333	L2= 15	D3= .75	Z8= 6
D2= 1	Z5= 1.33333	L3= 8	D4= 2.75	Z9= 1

Y1 FT.	Q CFS	CRITICAL DEPTH-FT	FRØUDE NØ.AT Y	IDEAL-Q	DISC.C	V1	ALF 3	V3
0.500	1.337	0.34	0.005	1.469	0.9098	0.04	1.042	2.90
1.000	4.975	0.72	0.013	5.268	0.9444	0.11	1.024	4.00
1.500	15.514	1.24	0.030	16.340	0.9495	0.27	1.018	3.88
2.000	38.868	1.66	0.059	40.370	0.9628	0.56	1.012	4.51
2.500	78.367	2.08	0.094	80.700	0.9711	0.95	1.009	5.13
3.000	137.694	2.50	0.135	141.000	0.9766	1.43	1.006	5.72
3.500	220.182	2.90	0.180	224.300	0.9816	1.99	1.005	6.41
4.000	320.489	3.28	0.222	325.100	0.9857	2.56	1.003	7.20
4.500	436.607	3.66	0.260	441.600	0.9887	3.10	1.003	7.91

K= ? .005

0.500	1.289	0.34	0.005	1.469	0.8770	0.04	1.064	2.85
1.000	4.854	0.71	0.013	5.268	0.9215	0.11	1.038	3.96
1.500	15.176	1.24	0.030	16.340	0.9287	0.26	1.029	3.85
2.000	38.220	1.66	0.058	40.370	0.9467	0.55	1.019	4.48
2.500	77.320	2.07	0.093	80.700	0.9582	0.94	1.014	5.11
3.000	136.149	2.49	0.134	141.000	0.9657	1.42	1.010	5.70
3.500	218.098	2.90	0.179	224.300	0.9723	1.98	1.007	6.38
4.000	317.953	3.27	0.220	325.100	0.9779	2.54	1.005	7.17
4.500	433.589	3.65	0.258	441.600	0.9819	3.08	1.004	7.89

K= ?

TITLE: SEDIMENT TRANSPORT CHARACTERISTICS OF CRITICAL-DEPTH FLUMES

CRIS WORK UNIT: 5402-12260-004 CODE NO.: Ariz.-WCL 72-2

INTRODUCTION:

General hydraulic characteristics of flumes have been reported in past years under research outlines Ariz.-WCL 67-1, WCL 72-1, with emphasis on sediment transport starting in 1972 under the present research outline, 72-2. With the former outlines computer and mathematical tools were developed that permitted tailoring flume shapes to produce hydraulic characteristics that might assist sediment movement. The present outline attempts to define these desired hydraulic characteristics. The need for the studies became apparent when several field-installed flumes regularly plugged with sediments.

Preliminary investigations of literature and field observations indicated the problem was nearly universal. Appropriate variables appeared to be particle size, concentration of particles in the flow, velocity of the flow, and discharge rate, though the latter is inter-related with the others. Field site experience indicated that some flumes remained clean, others did not, probably a function of concentration and hence dune movement of bedload. Efforts have concentrated on studying methods of affecting dune movement, on changing sediment concentrations at critical times during a storm, and on design changes in the flumes that would aid sediment movement.

A presentation, as paper No. 73-226, was made before the American Society of Agricultural Engineers, June 17-20, 1973, Lexington, Kentucky, and a paper prepared and accepted for the 8th International Congress of Agricultural Engineering (CIGR) in Wageningen, The Netherlands for September 24-28, 1974. The titles, respectively, are "Flumes Designed for Resistance to Sedimentation" and "Avoiding Sediment Accumulations in Flow Metering Flumes."

PROCEDURE:

Moving-bed model studies through a rectangular and a triangular flume were made in a laboratory environment using locally obtained "Engine Sand" (D_{50} = 0.5 mm) as the bedload material. Sand was introduced at uncontrolled rates into the upstream bed and allowed to move as dunes toward the flume. Several hopeful sediment-moving mechanisms were tried, drop-box designs, Froude Number control, friction bars, and flume slope. Observations were made on the relative success at keeping the flume clear of sediment accumulations.

RESULTS AND DISCUSSION:

Observation of existing flume installations has clearly shown that suspended sediments rarely cause measurement problems. The real concern is with bedload sediment moving as dunes into and through a flume, rendering it inoperative. Basically, the flume should be capable of disposing of bedload, in some form other than dune movement, faster than the bedload moves down the channel. Three concepts were found helpful: Froude Number tailoring, sloping flume floor, and side-wall vanes to induce vortexes. Of no significant value were drop-box inlets (dunes reformed almost immediately below the drop) and friction strips.

Theoretical concepts and the tests qualitatively indicated that it is desirable to tailor the flume so that Section 1 has higher Froude Numbers than the channel. Also, the hydraulic depth, D, should be made larger in the flume than in the channel.

Theoretical concepts also indicate that the flume should be rougher than the channel. This appears paradoxical, but high drag (rough boundaries) are desirable to erode particles from the flume floor. However, the flume-sediment interface should be smooth to discourage sediment from adhering to the flume. Thus, smooth boundaries are probably best because among suggested methods of preventing dune formation is that of forcing the particles to experience "flume-tractive-force" at a smooth boundary by somehow passing individual particles across smooth flume floors. This concept is substantiated in part because smooth flume throats (Section 3) which have high Froude Numbers and velocities seldom collect sediments. This means that some minimum width of smooth, flat bottom should be placed in a flume throat avoiding sharp, narrow "V" sections that can initiate sediment accumulation in the corner region. Upstream in Sections 1 and 2 a low flow rate is likely to occur that will allow the bottom to coat over, and the smooth floor concept in these sections will not apply. Energy-gradient and sloping flume floor were found to be mildly helpful. Energy gradient, regardless of how achieved, appears more important than absolute flume slope.

To retain computer-calibration ability, critical-flow flumes require a level floor in Section 3. Thus, if a particular slope in the flume is desired in order to handle the bedload size and concentration of a stream, it may be applied to Sections 1 and 2, but not to Section 3. The slope in Sections 1 and 2 causes the floor of the flume in Section 3 to be lower than that of Section 1, and might be termed a "negative-sill".

Too frequently, the slope and Froude Number adjustments are inadequate to keep the flume clear of heavy sediment loads. Another method that shows considerable potential, and can be added to the above adjustments, is a combination roughness element and vortex vane. These vanes, acting somewhat in reverse of particle precipitators that form vortexes for separating particles from smokestacks, temporarily suspend the bedload until it is carried through the flume. The vanes proposed for the flumes are simple 90° angle iron inserted on the sidewalls only (to avoid trash trapping), and are installed at 45° upward in the direction of flow. The action achieved is to erode the bottom at each contraction where a pair of opposing vanes are installed; lift the particles up the face of the inclined vanes, as well as in the vortex formed on the downstream side of each vane; and drop the particles into the flow in time to be acted upon by the next vane. Calibrations are unaffected if vanes are upstream from the point of pressure sensing even though the velocity distribution coefficient in Section 1, α_1, may be changed (α_1 has a small influence on calibration). Increased roughness must be considered if the vanes are extended beyond the pressure sensing location and, therefore, vanes should not be planned for Section 2. Vane spacing appears to be a function of the sideslope Z_1, the fall velocity of the bedload material, and the velocity of the flow Section 1. The spacing should be close enough to prevent settling between vanes. A first approximation without knowledge of the bedload material is to space the vanes 3- to 5-vane heights apart. There appears to be some advantage to using square ended structural angle iron that will leave a space at the flume bottom on trapezoidal sections. Floor movement and bedload jetting seem to improve slightly.

Design Notes and Recommendations

Design limitations imposed to achieve nearly parallel flow in Section 1 and Section 3 require a minimum length of about two times the maximum expected flow depth, Y_1, but Section 3 should not exceed 20 times the minimum expected Y_1 because of the large influence of slight changes in friction loss at low flow depths. To avoid submerged flow, downstream depth should not exceed the Y_3 depth in Section 3 (critical depth) calculated for each discharge rate. Downstream channel protection may be necessary near the flume outlet.

The flume should be designed for a minimum velocity of 1 to 2 feet per second in Section 1 if possible, or at least keep the Froude Number greater than 0.3 for sediment transport but less than 0.6. Froude Numbers greater than about 0.6 cause standing waves and result in poor flow depth detection.

The slope of the floor in Sections 1 and 2 should be equal to or steeper than the stream slope if practical. However, sloping the floor causes high Froude Numbers at low flow depths, making the low flow ranges difficult to measure.

Section 3 should not be a sharp bottomed "V." The low velocity at the sharp corner tends to allow dune formations even at the high Froude Numbers (and velocities) of Section 3. A minimum bottom width of 1 inch is recommended to assure that the bedload particles will experience smooth "flume-wall tractive forces" rather than cling to the rough surface of a dune.

In high bedload situations, insert structural angle iron, as previously described above, on the walls of Section 1. They should act as isolated roughnesses. Compute the flume clear-flow area as if the angle edges constituted a new wall boundary to make sure that each set of vanes does not act as a weir. (The vanes work best if placed in opposing pairs, not staggered.) The vanes should be large enough so that the local Froude Number at each set of vanes approaches 0.5 or 0.6.

These suggested systems can be overpowered by high sediment concentrations, or by prolonged low flow rates quickly following a high peak flow. This tends to drop sediments throughout the channel including the flume. However, we were able, with the vanes, to carry higher concentrations of sand (D_{50} = 0.5 mm) at average Froude Numbers in Section 1 of about 0.3, than Section 3, the throat section, could handle. Since the throat is normally the least vulnerable place for accumulating sediments, the capability of increasing the sediment carrying ability to the point where the throat is now the limiting device is highly encouraging. Simple criteria for identifying the severity of the sediment problem at a given site prior to installing a flume are still needed.

FIELD INSTALLATIONS:

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

<u>Tucson A</u>. This flume is still passing sand bedload satisfactorily; no major problems.

Tucson H. The extremely small bedload and stable channel offer no problems.

Tucson R. The heavy bedload still exists which renders the flume inoperative. Telephone conversations with University personnel indicate that it is cutting down at the outlet, but is still plugged. This would indicate a high bedload concentration problem. No remedial efforts are planned at this time.

K-3B. This flume is near Tombstone, Arizona, and was patterned after one designed to be installed in clear flows of irrigation canals. The stream had a heavy bedload and the flume accumulated sediment deposits. Froude Number tailoring was tried and was overpowered. Vortex vanes were installed in the summer of 1973. Only one small storm occurred which never exceeded 1 foot of depth in the flume. This flow was near the minimum depth that was expected to function to self-clearing of the flume. The flow succeeded in carrying a 3-ft high dune through the flume that had been left from construction efforts.

SUMMARY AND CONCLUSIONS:

Simple angle-iron vanes installed on the sides of flow-metering flumes cause vortex action that is capable of moving large sediment loads through the approach section of the flumes where the sediments would ordinarily accumulate. Flow velocieits in the contracted throat sections of flumes are usually sufficient to keep them clear of sediment accumulations. Accumulations in the approach section, where velocities are slower, are almost inevitable, especially when sediment bedloads move down the channel. In laboratory tests, the vanes were capable of maintaining satisfactorily clear approach sections at sediment concentrations of such magnitude that the throat section, where accumulation of sediment is usually difficult, did accumulate sediment, and became the limiting factor. This indicates that flumes can be designed to remain clear of sediment accumulations and still retain the capability of accurately computing the discharge rating curve. A field installation using the vanes was made in a flume that attempted to measure a sand-bottomed stream. The flume had previously failed because of sediment accumulations. A 3-foot-high dune left upstream from the flume after installing the vanes successfully passed through the flume. Significant is that it accomplished this at about 1-foot-deep flow through the flume, near the minimum anticipated workable flow depth for the size flume and type of sediment in question.

These flumes are of particular interest because their discharge ratings can be accurately predicted with theoretically based equations which permit tailoring the flumes to contend with submergence and other channel problems. The use of vortex vanes further extends their usefulness into streams with bedload sediments. This permits more accurate information on water supplies and water distributions.

PERSONNEL: John A. Replogle

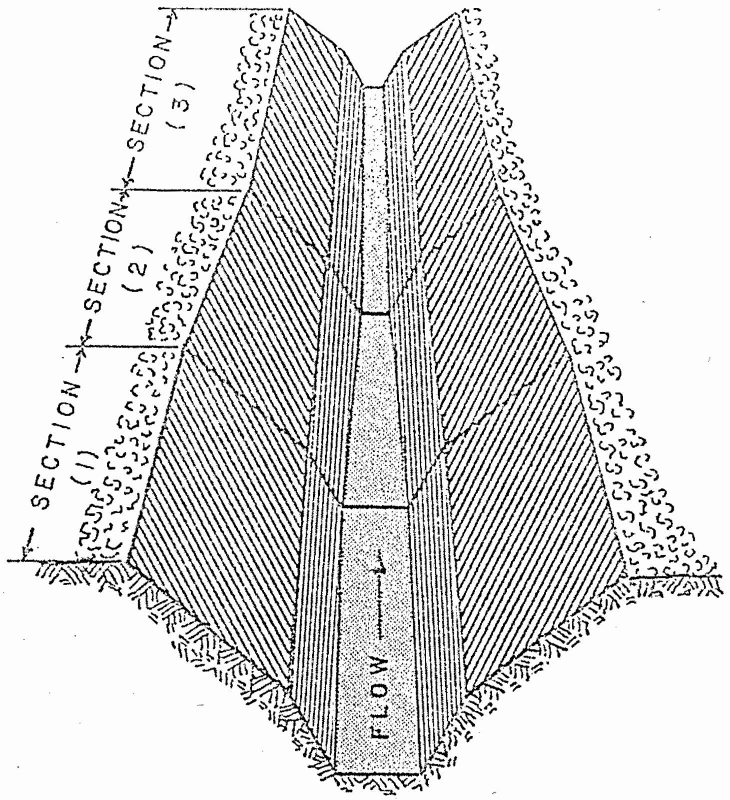


Figure 1: General, complex-shaped, critical-flow flume.

TITLE: DEPTH DETECTION IN CRITICAL DEPTH FLUMES

CRIS WORK UNIT: 5402-12260-004 CODE NO.: Ariz.-WCL-72-3

The project was initiated to evaluate effective methods to economically detect flow depth in flumes. Since most of our recorder systems depend on floats in stilling wells, means of keeping stilling-well pipelines open during runoff events containing suspended and bedload materials are necessary. Air bubbling systems were tried in conjunction with 12-inch diameter stilling wells connected in U-tube manometer fashion. One side of this large U-tube was fitted with an air-tight cap. The stilling-well pipe was then connected to the top of the closed side. An air tank also was connected to the top of the closed side. Air bubbled slowly backwards through the stilling-well pipe into the flume, resisted by the backpressure of the flow depth in the flume. This backpressure consequently altered the water levels in the two stilling-well legs that were interconnected in U-tube fashion. This level was detected on a standard strip-chart, water-stage recorder. Lag time was a serious disadvantage with the air-bubble system. Newer commercial systems of different recorder design apparently are adequate, but to switch to them would require abandonment of large existing inventories of standard water-stage recorders.

A method that delays plugging had been observed in flume installations made by the University of Arizona at Tucson. The method involved construction of a large cavity in the floor of the flume astride the desired point of depth detection. The size may be on the order of several cubic feet. The cavity is covered with a slotted grill coincident with the flume floor over which the flow, with most of the sediment bedload, passes. The stilling-well pipe then enters this cavity and is fitted with a pipe elbow. The elbow is turned down so that sediment cannot fall directly into it. The cavity must fill with sediment before the pipeline can be obstructed.

We constructed similar cavity and grill devices for use on the flumes in Hawaii. Several questions arose concerning effects of openings. In general, if slots are used perpendicular to the flow, all the bedload has opportunity to drop into the cavity. If the slots are parallel to the flow, only that portion passing directly over a slot will fall in. However, the requirement usually recognized for good manometer-tap practice, that of having 2-hole diameters of plate thickness, cannot be readily maintained in the direction of flow. The transverse direction could easily meet the requirement. Considering the probable increased bedload trapping of the transverse slots and the low quality pressure detection likely with the parallel slots, we decided to use a battery of holes 3/16" in diameter drilled into the 1/4-inch grating plate. This approximated both requirements adequately. Laboratory use shows no pressure-detection anomolies and field use shows no sedimentation-plugging problems, although periodic grating and cavity cleaning is necessary. The technique is planned for future installations.

Additional schemes to be evaluated include positive, low-rate injection of clean water into the stilling well. This technique is used with waste-water flows where city water supplies are available. The detection error is low since the friction loss is usually insignificant for the clean water to flow through the stilling-well pipe connected to the flume. In remote areas, this technique may require a gravel filter upstream from the flume in the bottom of the channel to provide a low-rate clean flow to connect to the stilling well. Low cost methods of controlling the flow rate so that it is neither too low nor too high need consideration.

SUMMARY AND CONCLUSIONS:

A survey of usable techniques for keeping stilling-well connecting pipes to flumes clear of sediment deposits was made. The more promising were laboratory tested and modified. Air injection, or bubbler, systems respond too slowly when used with equipment designed to adapt standard water-stage recorders for sensing bubble pressure changes. Newer commercial equipment is apparently adequate but is of different design, and would require abandonment of a large inventory of standard water-stage recorders.

Sediment-collection cavities below the flume floor, covered with a slotted grating have been previously used by several weir and flume users. Questions concerning the proper direction for installing grating slots, transverse to the flow or parallel to the flow, were considered. All the bedload would have an opportunity to fall through a transverse slot, but the pressure detection through a thick grating plate should meet the requirements of good piezometer taps. Slots, parallel to the flow would miss a proportion of the bedload, but would possibly provide poor pressure detection, since the slots would likely be several times longer than the grating thickness, and would fail to meet recognized piezometer-dimension standards. A compromise was to drill a battery of holes through the grating plate. Laboratory use shows no pressure-detection anomolies and field experience has been satisfactory. The technique is planned for future installations.

PERSONNEL: John A. Reploge and Gary Frasier

TITLE: EVALUATING TRICKLE IRRIGATION FOR GRAPE PRODUCTION

CRIS WORK UNIT: 5402-12260-004 Code No. Ariz-WCL 73-1

INTRODUCTION:

A successful trickle irrigation system depends upon proper design, management, and maintenance. The three-fold objectives of this investigation on the use of trickle irrigation for grapes are: (1) To determine the effects of quantity and frequency of trickle and furrow irrigation on yield and fruit quality; (2) To determine design requirements in terms of number, discharge rate, and placement of trickle irrigation emitters; and (3) To determine soil moisture and salt distribution patterns for specific irrigation treatments.

FIELD PROCEDURE:

A 3-year study is being conducted on a 3-acre vineyard near Litchfield Park, Arizona, owned by J. C. Boswell, Inc. The manager of the ranch is providing assistance in pruning, fertilizing, controlling insects, harvesting, and general farming operations. The vines are 11 years old, of the Perlette variety of table-grapes, and the soil texture is sandy loam.

Trickle and furrow irrigation treatments for the first year (1973) included: three varying quantities, based on ratios of past consumptive-use data; three irrigation frequencies -- daily, 3-day, and 6-day; and a variation of one or two trickle irrigation emitters per vine. The furrow irrigation treatments included the same three seasonal quantities used for the trickle irrigation, applied in two or three furrows per vine, with the irrigation frequency based on the consumptive-use curve. These 18 treatment combinations were replicated four times in a split-plot design. Each plot was 3 rows wide, with 6 vines per row. Vine spacing is 7 ft along the row, and 11 ft between rows. Figure 1 shows the randomization of the different treatment combinations.

The different quantities of water to be applied were determined by multiplying 0.75, 1.00, and 1.25 times an estimated consumptive-use rate, and then converting this to an application quantity based on the entire surface area between vines. This estimated consumptive-use rate was taken from a 4-year mean curve (1962-65), determined from soil-moisture sampling near Litchfield Park. Residual stored moisture and precipitation were also considered in computation of these different water applications. In addition, consumptive use was measured during 1973 by extensive soil-moisture sampling on a separate 18-vine plot. This plot was entirely dead-level and enclosed by border dikes, where the water management was identical to the 1.00 furrow-irrigation treatments.

The trickle irrigation system used was a 1-gph Drip-Eze, with emitter-type system. With two emitters per vine, the emitters were 3.5 ft apart, and with a single emitter per vine, the emitter was placed 6 inches from the vine. Final filtration for the trickle irrigation system was through a 10-micron filter bag, and water applications for the different trickle and furrow irrigation treatments were measured with turbine-vane, household-type water meters.

New growth began about February 15, and canes were 2 inches long by March 1st. Because of plentiful early-season rainfall totaling over 4 inches between January 1st and March 30th, furrow irrigation treatments were not started until April 30th. The 1.0 furrow irrigation amounts given, by dates during the growing season, were: 4 inches on April 30, 4 inches on May 30, and 3 inches on June 18. Trickle irrigation treatments commenced on May 1.

Data obtained included salinity, tensiometer readings, evaporation pan, atmograph, yield and quality measurements, as well as amount of water applied on all treatments and soil-moisture measurements on the consumptive-use plot. Salinity distribution patterns were determined, first on April 16 after the major rainfall had ended, and again on August 6 after harvest was over. Salinity samples were taken perpendicularly to emitters in a southerly direction on two adjacent vines at 1-foot intervals from the emitter to the midpoint between vine rows at depths of 0-6, 6-12, 12-24, 24-36, and 36-48 inches. The selected irrigation treatments were: 1.25 consumptive use, daily trickle irrigations, 1 emitter per vine; 1.00 consumptive use, daily trickle irrigations, 1 emitter per vine; 1.00 consumptive use, daily trickle irrigations, 2 emitters per vine; 1.00 consumptive use, 6-day trickle irrigations, 2 emitters per vine; 0.75 consumptive use, daily trickle irrigations, 1 emitter per vine; and 1.00 consumptive use, 3 furrows per vine.

Tensiometers were installed on the same selected treatments at a 1-ft distance from the emitters at depths of 1, 2, and 4 ft. Tensiometer readings were made at least 3 times each week, starting on May 1st, between 9:00 and 10:00 A.M. To obtain a comparison of consumptive use with evaporation, a standard Young screen evaporation pan was buried between vine rows with the free water surface at ground level and a second modified-Young screen evaporation pan was placed above ground with the water surface level just above the crop. Also, Piche atmographs, using porous evaporation pads, were placed both within and above the crop canopy.

A single harvest on June 30 was used for this first year. Since there was variability between vines, seven of the better vines were selected from each plot, and the Mexican-American harvesters were asked to pick only marketable grape clusters, and to trim only rotten berries from these clusters. From each box of grapes harvested, 15 to 20 were randomly selected, to total between 200 and 300 berries from each plot from which berry size and sugar content were determined.

RESULTS AND DISCUSSION: Because of extensive rainfall early in the season and precise scheduling of different irrigation quantities for both trickle and furrow irrigation, treatments did not begin until May 1st. The amount of water made available for consumptive use from each treatment was calculated by adding the measured consumptive use before May 1st to the water applied, rainfall, and residual moisture used from the 1.0 consumptive-use treatment after May 1. Table 1 shows total available moisture and adjusted irrigation quantities for trickle and furrow irrigation treatments.

The weed control requirement appeared to be less for trickle than for furrow irrigation. In 1973, weed control on the trickle irrigation consisted of one disking and one spraying with weed-oil near the vines and emitters. Weeds were removed from the furrow irrigation by disking three times. The conventional practice is to disk and replace furrows before every furrow irrigation. It appears that the cost and labor required with two or three chemical sprayings should be less than six to eight diskings and furrowings.

The 1973 measured consumptive use of 19.1 inches is shown in Figure 2. This compares closely with the mean seasonal consumptive use of 1962-65, upon which the different irrigation treatments were based. Notice an earlier, sharp decline in water use due to an earlier girdling date, on the Perlette variety. Figure 3 depicts the relationship between pan and atmograph evaporation to the 1973 measured consumptive use. Semi-monthly correction factors are given, indicating that evaporation measurements are not directly related to consumptive use under these field conditions, but vary with time of growing season and instrument location.

Soil salinity distribution patterns were determined for the various treatments from saturated extracts of samples taken at various depth-distance combinations from the vine row. After one year of trickle irrigation, soil salinity would not generally be considered very high. The average of dissolved salts in the irrigation water was about 0.39 mmhos/cm (250 ppm), which is good quality water for Central Arizona. The initial soil conductivity, after early-season rainfall, was predominately below 2.5 mmhos/cm throughout the top four feet of the soil profile. Also, there was a definite leaching of salts every two feet between the vine rows, which corresponded to the chiseling distance. As expected, the salt distribution patterns were different after harvest for the trickle compared to the furrow irrigation plots. The salts in the trickle irrigation areas were moved 3 to 4 feet away from the trickle emitters and appeared near the soil surface. Conductivity values at this point were between 4 and 5 mmhos/cm. At the end of the season, the salts in the furrow irrigation area remained essentially below 2.5 mmhos/cm.

Tensiometer readings at a 1-ft distance from trickle irrigation emitters are presented in Figure 4. These readings indicate: (1) The soil-moisture levels at the 0.85 consumptive-use treatment became drier in late May and continued throughout June; (2) The soil-moisture levels at the 1.00 consumptive-use treatment were about the same for either one or two emitters and for either a daily or a 6-day irrigation frequency; and (3) The soil-moisture levels were slightly wetter for the 1.15 consumptive use over the 1.00 consumptive-use treatment.

Before discussing production results in terms of total yield and fruit quality, three conditions should be stressed. First, extensive rainfall early in the season may have negated possible differences from the application of different quantities of irrigation water. Second, there was no uniformity in the methods by which different harvestors discarded rotten or poorer quality fruit. Third, there was some nonuniformity between grape vines, themselves, which may have affected the results.

Table 2 shows the mean grape yields for the various trickle and furrow irrigation treatment This weight was a 13% increase in yield for the trickle irrigated plots with two emitters per vine as compared to plots which were irrigated by two or three furrows. There was a 9% greater yield for plots using two trickle irrigation emitters as compared to one trickle irrigation emitter per vine. Also, there was a slight indication of increased yield for the trickle-irrigated plots when the irrigation water quantity was increased. There was little difference in yield between plots given trickle irrigation at frequencies of 1 day, 3 days, and 6 days. As for furrow irrigation, there was little difference in yield between plots having three or two per vine, and little difference in yield between plots having water applications of different quantities. The analysis of variance showed yield differences to be significant between replications, due mostly to a 22% larger yield from one replication than the other three.

Berry sizes for the trickle and furrow irrigation methods are presented in Table 3. The most notable result was a 6% increase in berry size for the trickle-irrigated plots as compared to the furrow-irrigated plots. The increased berry size may explain the small increase in yield for the trickle over furrow irrigated plots. Table 4 shows there was little variation in sugar content from all plots, regardless of various irrigation methods or treatments. The analysis of variance indicated that differences between replications for berry size and sugar content were not significant.

SUMMARY AND CONCLUSIONS:

A 3-year field investigation is being conducted to determine irrigation management and design requirements for Perlette grape production. Trickle irrigation treatments include three irrigation quantities, based on ratios of a consumptive-use estimate; three irrigation frequencies -- daily, 3-day, and 6-day; and a variation of one or two trickle irrigation emitters per vine. Furrow irrigation treatments include the same three seasonal quantities used for the trickle irrigation applied in two or three furrows per vine; however, the irrigation frequency is varied, based on the consumptive use.

First-year results provide only an indication of possible benefits or problems with trickle irrigation; however, the results do emphasize the importance of proper management and system design. Weed control problems appeared to be reduced with trickle irrigation; however, the results do emphasize the importance of proper management and system design. Weed control problems appeared to be reduced with trickle irrigation, by using chemical treatment near emitters and vines, rather than using mechanical disking with furrow irrigation. Salts under trickle irrigation were moved 3 to 4 feet away from the trickle emitters, whereas salt concentrations under furrow irrigation remained unchanged. First-year production results were as follows: there was a small increase in yield for trickle irrigation with two emitters per vine over one emitter per vine; a slightly greater yield with two trickle irrigation emitters over furrow irrigation; a small increase in berry size for trickle-irrigated fruit over furrow-irrigated; little difference in sugar content between irrigation treatments; and little difference in yield between trickle irrigation frequencies. Two additional years of research should provide more pronounced information on the effects of quantity and frequency of trickle and furrow irrigation on yield and fruit quality.

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

TABLE 1. Available Moisture and Adjusted Irrigation Quantities for Trickle and Furrow Irrigation of Grapes, 1973.

Irrigation Quantity Consumptive-Use Ratio	Measured Consumptive-Use March 1--May 1 (inches)	Water Applied May 1--July 1 (inches)	Rainfall May 1--July 1 (inches)	Residual Moisture Used May 1--July 1 (inches)	Total Available Moisture for Consumptive Use (inches)	Adjusted Irrigation Quantity Consumptive-Use Ratio *
TRICKLE:						
1.25	4.8	14.4	0.6	2.7	22.5	1.15
1.00	4.8	11.7	0.6	2.7	19.8	1.00
0.75	4.8	8.9	0.6	2.7	17.0	0.85
FURROW:						
1.25	4.8	13.8	0.6	2.7	21.9	1.15
1.00	4.8	11.0	0.6	2.7	19.1	1.00
0.75	4.8	8.3	0.6	2.7	16.4	0.85

* Measured Seasonal Consumptive Use = 19.1 inches, 1973.

TABLE 2. Grape Production Using Trickle and Furrow Irrigation, 1973.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.15	1.00	0.85	
	(pounds per plot)			
TRICKLE:				
Daily / 1 emitter	210*	188	181	193 bc**
Daily / 2 emitters	222	195	205	207 ab
3-day / 2 emitters	218	219	225	221 a
6-day / 2 emitters	201	225	182	202 abc
MEAN	213 a	207 a	198 a	
FURROW:				
3 Furrows per vine	185	183	185	184 c
2 Furrows per vine	187	183	191	187 bc
MEAN	186 a	183 a	188 a	

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

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

TABLE 3. Berry Size for Trickle and Furrow Irrigation of Grapes, 1973.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.15	1.00	0.85	
	(pounds per 100 berries)			
TRICKLE:				
Daily / 1 emitter	0.66*	0.69	0.67	0.67 ab**
Daily / 2 emitters	0.65	0.65	0.69	0.66 abc
3-day / 2 emitters	0.69	0.69	0.66	0.68 a
6-day / 2 emitters	0.68	0.68	0.70	0.69 a
MEAN	0.67 a	0.68 a	0.68 a	
FURROW:				
3 Furrows per vine	0.65	0.60	0.66	0.64 bc
2 Furrows per vine	0.63	0.61	0.66	0.63 c
MEAN	0.64 a	0.61 a	0.66 a	

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

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

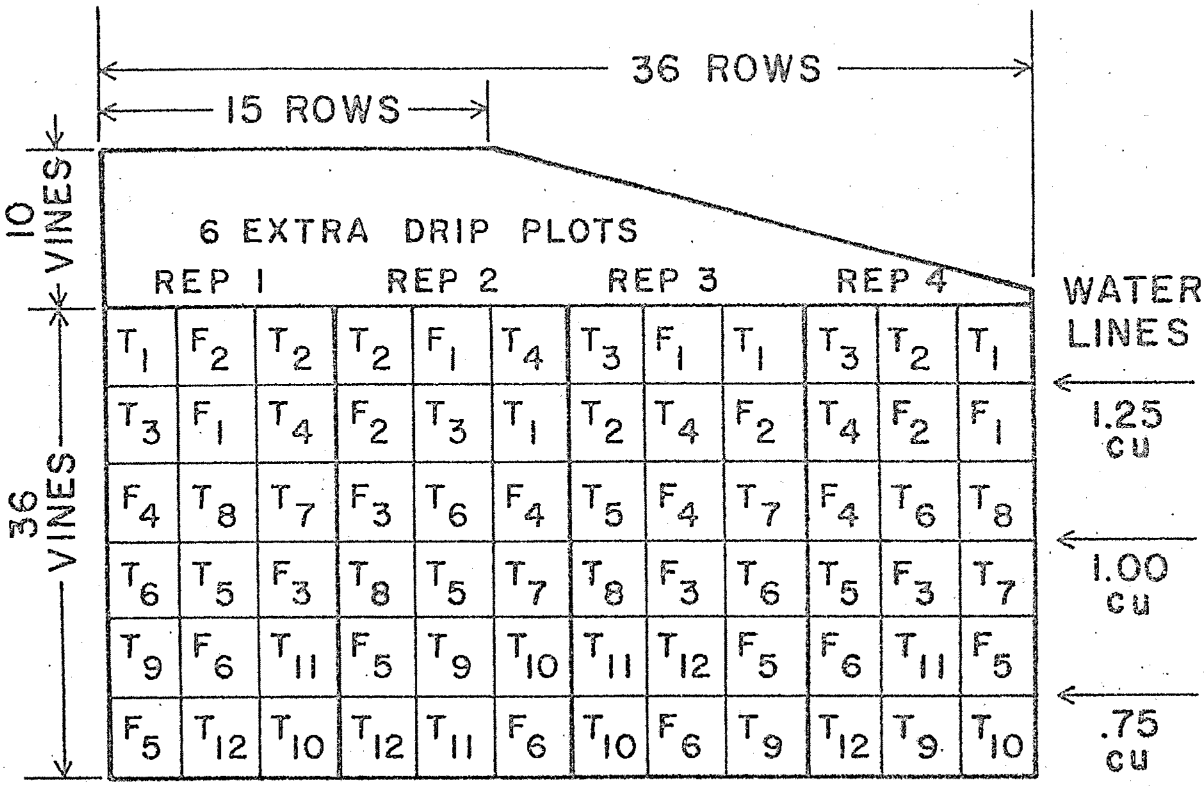
TABLE 4. Sugar Content for Trickle and Furrow Irrigation of Grapes, 1973.

Irrigation Treatment	Irrigation Quantity			Mean
	Consumptive-Use Ratio			
	1.15	1.00	0.85	
	(percent sugar)			
TRICKLE:				
Daily / 1 emitter	15.3*	15.8	16.6	15.9 a**
Daily / 2 emitters	15.6	15.5	15.7	15.6 a
3-day / 2 emitters	15.5	15.7	15.6	15.6 a
6-day / 2 emitters	15.4	15.6	16.5	15.8 a
MEAN	15.4 a	15.6 a	16.1 a	
FURROW:				
3 Furrows per vine	15.6	16.5	16.0	16.0 a
2 Furrows per vine	16.2	15.3	15.8	15.8 a
MEAN	15.9 a	15.9 a	15.9 a	

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

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

Fig. 1 RANDOMIZED TREATMENTS FOR GRAPE STUDY



TREATMENT COMBINATIONS *

T - Trickle

T_1 - 1.25 x CU,** Daily, 1 Emitter/vine
T_2 - 1.25 x CU, Daily, 2 Emitters/vine
T_3 - 1.25 x CU, 3-day, 2 Emitters/vine
T_4 - 1.25 x CU, 6-day, 2 Emitters/vine

T_5 - 1.00 x CU, Daily, 1 Emitter/vine
T_6 - 1.00 x CU, Daily, 2 Emitters/vine
T_7 - 1.00 x CU, 3-day, 2 Emitters/vine
T_8 - 1.00 x CU, 6-day, 2 Emitters/vine

T_9 - 0.75 x CU, Daily, 1 Emitter/vine
T_{10} - 0.75 x CU, Daily, 2 Emitters/vine
T_{11} - 0.75 x CU, 3-day, 2 Emitters/vine
T_{12} - 0.75 x CU, 6-day, 2 Emitters/vine

F - Furrow

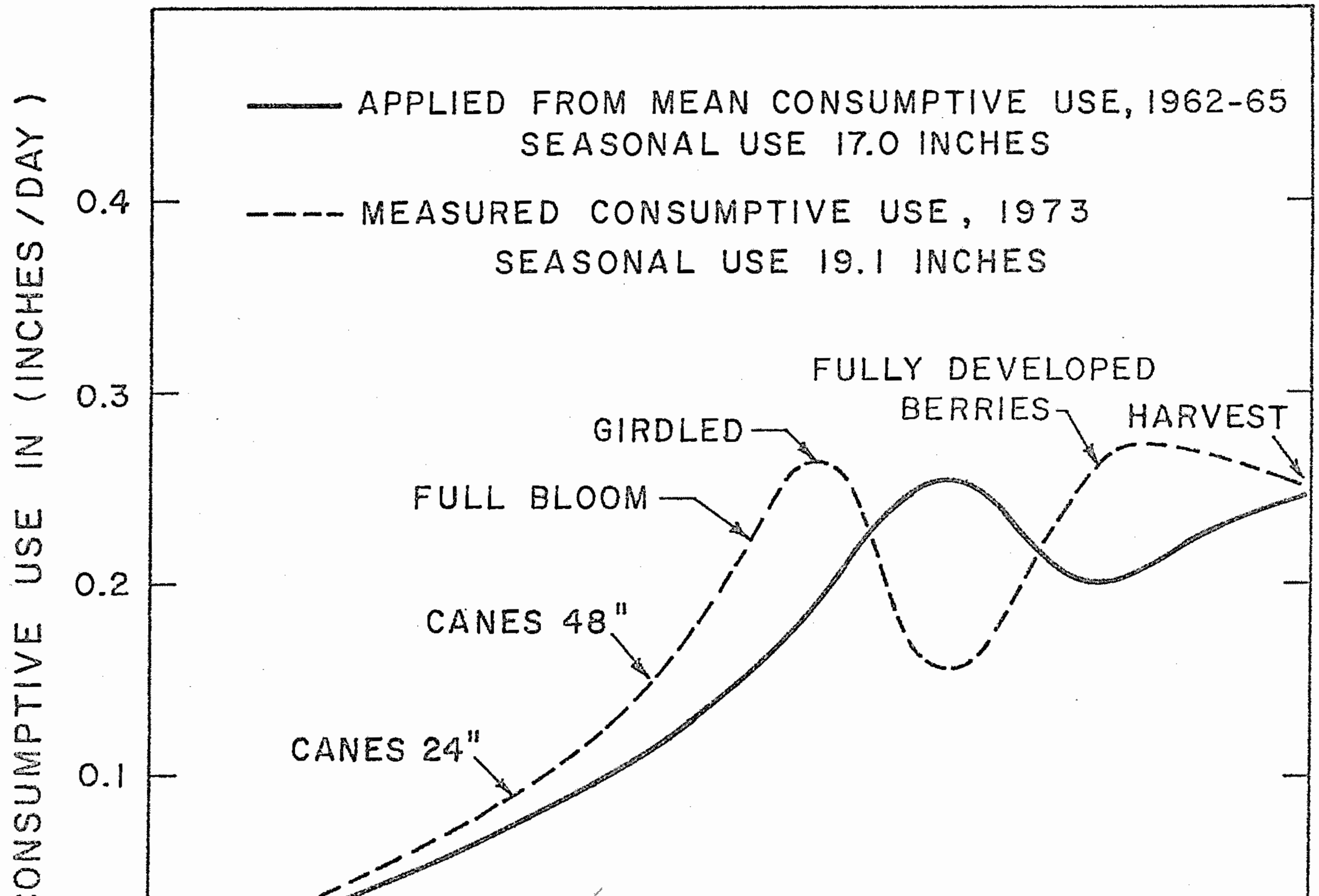
F_1 - 1.25 x CU, 3 Furrows/vine
F_2 - 1.25 x CU, 2 Furrows/vine

F_3 - 1.00 x CU, 3 Furrows/vine
F_4 - 1.00 x CU, 2 Furrows/vine

F_5 - 0.75 x CU, 3 Furrows/vine
F_6 - 0.75 x CU, 2 Furrows/vine

* Each plot - 33' x 42' (3 rows wide x 6 vines long)

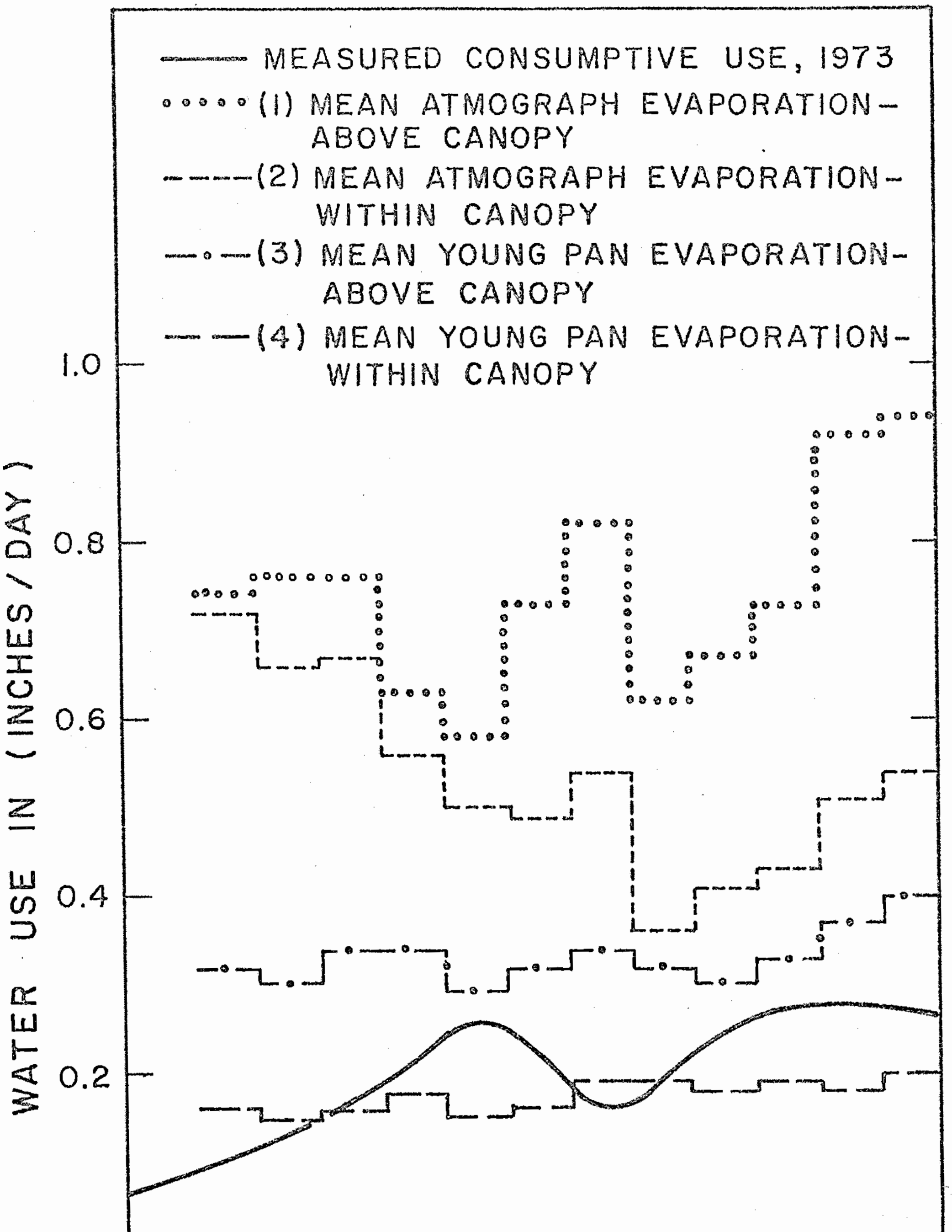
** Consumptive use



SEMIMONTHLY USE IN INCHES

	MARCH		APRIL		MAY		JUNE	
APPLIED	0.18	0.61	1.11	1.76	2.73	4.10	5.03	3.51
MEASURED	0.24	0.78	1.38	2.36	3.95	2.51	3.95	3.96

Figure 2. Applied and Measured Consumptive Use for Grapes, 1973.



K, FACTORS

(1)	0.14	0.21	0.38	0.29	0.38	0.30
(2)	0.15	0.24	0.43	0.41	0.62	0.52
(3)	0.30	0.49	0.83	0.48	0.86	0.69
(4)	0.65	1.00	0.65	1.00	0.70	0.70
	APRIL		MAY		JUNE	

Figure 3. Relationships of Evaporation Measurements from a Young Screen Pan and a Piche Atmograph to the 1973 Measured Consumptive Use for Grapes.

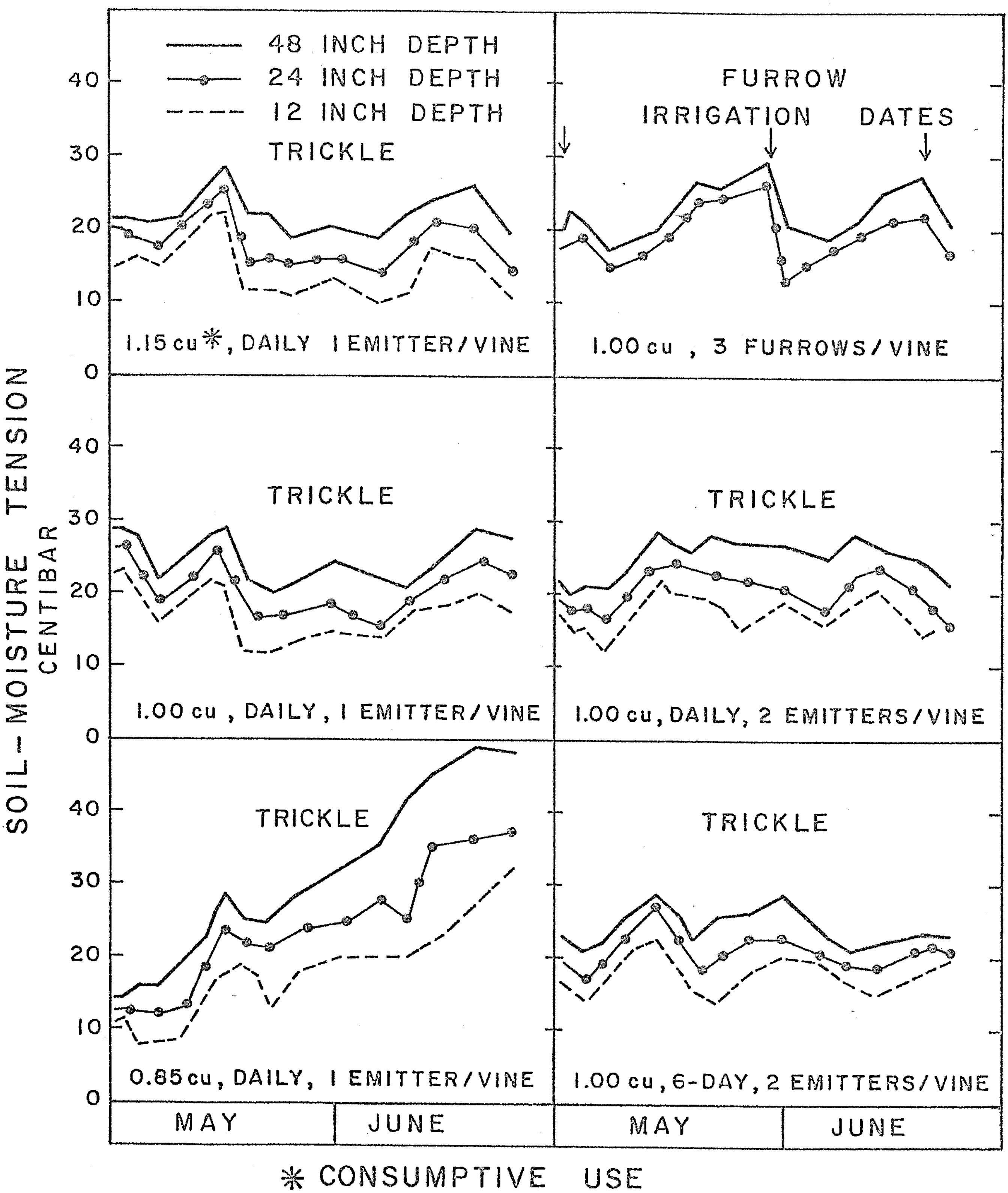


Figure 4. Tensiometer Readings on Grapes in 1973.

TITLE: EROSION-PREVENTIVE STRUCTURES TO DISTRIBUTE WATER INTO IRRIGATED FIELDS.

CRIS WORK UNIT: 5402-12260-004 CODE No.: USWCL 73-5

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

Recently, outlets in the form of jack-gates have become popular. From these, 10 to 30 cfs may be discharged, thus necessitating additional erosion-preventive structure design. Some have been modified in the field, others have been newly constructed, and all are being observed. Plans are being made to study the jack-gate problem in our laboratory's modeling facility.

A request from the Blythe area for a structure to prevent erosion from single outlets emitting up to 45 cfs has been received. This is associated with our irrigated automation project. A new outlet has been planned which will utilize some of the basic criteria from the original smaller structures. The large structure is being planned with the farm owner, and will be implemented in 1974.

PERSONNEL: <u>Leonard J. Erie,</u> Howard R. Haise, John Replogle Dale A. Bucks, Orrin F. French, and Bud Payne.

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

CRIS WORK UNIT: 5402-12260-004 CODE No.: USWCL 73-6

Because of water shortage, and shortage of labor, which is of poor quality and very costly, farm owners have requested the assistance of automated irrigation systems aimed at reducing labor requirements, cutting down operating costs and improving irrigation efficiency. As a result, 10 acres of citrus near Mesa, Arizona, which are irrigated by an underground supply system, and 40 acres near Blythe, California, which are irrigated by a surface conveyance system, have been converted to automation. These systems consist principally of rubber pillows installed on outlet tile and automatic gates from open ditches or subsurface distribution systems, energized pneumatically by a compressor and controlled by a time clock.

The 10-acre automated system near Mesa operated without problems during 1973. The 40-acre automated system near Blythe was supplemented with 64 permanent concrete erosion-preventive structures, after we had designed and installed one pilot structure. The farmer is interested in a structure that is less vulnerable to breakage by machinery. He has also completely accepted 40-acre dead-level fields, where he formerly would accept no more than 10 acres to a field. These larger fields make it easier and more economical to design the automatic system.

Additional changes in plans and design are being implemented, in an attempt to further increase efficiency of operation of the automated system.

PERSONNEL: Leonard J. Erie, Howard Haise, Dale A. Bucks, Bud Payne and Orrin F. French.

APPENDIX I

SUMMATION OF IMPORTANT FINDINGS

5402-12260-002 WATER TRANSFER IN THE SOIL-PLANT-ATMOSPHERE SYSTEMS AS RELATED TO WATER CONSERVATION

A new method for calculating soil heat flux using temperature and water content measurements only was developed. The method utilizes calorimetry in the upper 20 cm of soil and aligns the point of zero flux with the point of zero temperature gradient which occurs during the morning and evening temperature reversals. (WCL 68-1)

The black-eyed pea (Vigna sinensis) required as much water per unit of photosynthate under drought as when soil water was freely available. Since a suitable species for improving water-use efficiency should require less water, black-eyed pea does not appear to be the right crop for increasing the efficiency of water use in arid regions. (WCL 71-1)

It was discovered that algal blooms in a small pond of reclaimed wastewater could increase the absorption of solar radiation near the water surface to such a degree that surface water temperature would rise high enough to increase the water-air vapor pressure difference by 25%, indicating that phytoplanktonic growth may increase evaporation. (WCL 71-3)

A rapid and accurate method for analyzing sulfate in various types of waters was developed. Ionic association modeling improved the estimation of exchange constants of soils in mixed salt systems. (WCL 71-11)

Greater storage of soil water occurred near jojoba plants (Simmondsia chinensis) below two types of treated 20-m^2 catchments than in control plots following 71 mm of rainfall from November 1973 to January 1974. This augmented storage of water ultimately may promote higher yields of the seed containing a valuable wax. (WCL 73-4)

5402-12260-003 MANAGEMENT OF SUBSURFACE WATER MOVEMENT SYSTEMS FOR RENOVATION AND CONSERVATION OF WATER

Nitrogen removal from sewage water during soil filtration in laboratory columns was shown to increase exponentially as infiltration rate decreased, with 80% removal occurring at 15 cm/day infiltration. Tracer experiments showed that decreasing the infiltration rate resulted in more mixing of nitrate formed in the soil during drying with incoming sewage water. Growing barley or bermudagrass in soil columns flooded with sewage water increased N removal from the sewage by 9 to 10% after the plants became well established. This could result in an increase in N removal of 2,000 kg/ha. (WCL 68-3)

Reducing water depths in the rapid-infiltration basins at the Flushing Meadows Project for renovating secondary sewage effluent by groundwater recharge increased the nitrogen removal to 74%. This was caused by increased denitrification due to lower infiltration rates. The loading rate, however, was still 20 ft/month, which is very much high-rate. Previously, nitrogen removal was 25% at a loading rate of 30 ft/month. Thus, a slight reduction in loading rate resulted in a threefold increase in nitrogen removal. This shows that significant nitrogen removal can be obtained in high-rate land treatment systems, where the nitrogen load may be 100 times as much as nitrogen uptake by crops. (WCL 67-4)

A procedure was developed to calculate the reduction in seepage from a stream by removing phreatophytes in a floodplain. The seepage calculations are based on the relations between water use and water table depth before and after removal of the phreatophytes. The procedure makes it possible to estimate water savings and economic aspects of phreatophyte control projects without the need for extensive investigations.

5402-12260-004 INCREASING AND MANAGING SURFACE WATER SUPPLIES FOR AGRICULTURAL USE

Laboratory studies on potential soil treatments for harvesting precipitation showed that common paraffin wax and an experimental dust suppressant produced highly water-repellent soils. Preliminary field testing shows that the wax continues to yield approximately 90% runoff nearly 2 years after installation, and the dust suppressant about 90% runoff for the several months since installation. (WCL 67-2)

Sediment accumulation in flow-metering flumes was greatly reduced by simple angle-iron vanes installed on the sides of the flumes. These vanes cause a vortex action that keeps sediment in suspension. This development will be of great value in watershed hydrology, irrigation, and other areas where flow measurement has often been inaccurate because of sediment accumulation in flumes. (WCL 72-2)

To obtain maximum benefits from any irrigation method, proper management and scheduling procedures must be used. First-year results of a 3-year trickle and furrow irrigation study on grapes indicated that yield and quality were maintained and possibly increased with trickle over furrow irrigation; that yields were increased with two trickle emitters per vine over one emitter per vine; and that increasing the frequency of trickle irrigations did not increase yields. (WCL 73-1)

APPENDIX II

LIST OF PUBLICATIONS PUBLISHED AND MANUSCRIPTS PREPARED IN 1973

MS No.

5402-12260-002 Water transfer in the soil-plant-atmosphere system as related to water conservation.

Published: Ehrler, Wm. L. Additions to 'Transpiration Data Tables', IN "Biology Data Book", 2nd Edition, Vol. II, Sect. VII, 'Environment and Survival', Part 106, 'Factors Affecting Transpiration Rates: Magnoliophytes', Editors: Philip L. Altman and Dorothy S. Dittmer. Published by the Federation of American Societies for Experimental Biology, Bethesda, Maryland. 1973. Pp. 904-906. 374

Ehrler, Wm. L. Cotton leaf temperatures as related to soil water depletion and meteorological factors. Agron. Jour. 65(3):404-409. May-June 1973. 394

Idso, Sherwood B. On the concept of lake stability. Limnol. and Oceanog. 18(4):681-683. July 1973. 402

Idso, Sherwood B. Thermal radiation from a tropospheric dust suspension. Nature 241(5390): 448-449. Feb. 16, 1973. 414

Idso, Sherwood B., and Cole, Gerald A. Studies on a Kentucky Knobs Lake. V. Some aspects of the vertical transport of heat in the hypolimnion. Jour. of Ecol. (England) 61(2):413-420. July 1973. 401

Jackson, Ray D. Diurnal Changes in Soil-Water Content During Drying. Chap. 3 in "Field Soil Water Regime", Edited by R. R. Bruce, et al. Soil Sci. Soc. Amer. Spec. Publ. No. 5, Pp. 37-55. (Soil Sci. Soc. Amer., Madison, Wisc.) 1973. 370

Jackson, Ray D., and Kimball, B. A. Book Review: "Advanced Soil Physics", by Don Kirkham and W. L. Powers. Soil Sci. Soc. Amer. Proc. 37(1):vi. Jan-Feb 1973. 412

	MS No.
Jackson, R. D., Kimball, B. A., Reginato, R. J., and Nakayama, F. S. Diurnal soil-water evaporation: Time-depth-flux patterns. Soil Sci. Soc. Amer. Proc. 37(4):505-509. July-Aug 1973.	410
Kimball, Bruce A. Water vapor movement through mulches under field conditions. Soil Sci. Soc. Amer. Proc. 37(6):813-818. Nov-Dec 1973.	411
Mitchell, S. T., Kimball, B. A., and Ehrler, W. L. A miniature gravity-fed thermocouple psychrometer. Agron. Jour. 65(2):238-239. Mar-Apr 1973.	391
Nakayama, F. S. On solubility and solubility product constants. Soil Sci. Soc. Amer. Proc. (Letters to the Editor) 37(4):661-662. 1973.	417
Nakayama, F. S., Jackson, R. D., Kimball, B. A., and Reginato, R. J. Diurnal soil-water evaporation: Chloride movement and accumulation near the soil surface. Soil Sci. Soc. Amer. Proc. 37(4):509-513. July-Aug 1973.	418
Rasnick, B. A., and Nakayama, F. S. Nitrochromeazo titrimetric determination of sulfate in irrigation and other saline waters. Commun. in Soil Sci. and Plant Anal. 4(3):171-174. 1973.	426
Reginato, R. J., Nakayama, F. S., and Miller, J. B. Reducing seepage from stock tanks with uncompacted sodium-treated soils. Jour. Soil and Water Conserv. 28(5):214-215. Sept-Oct 1973.	434

Prepared:

	MS No.
Idso, Sherwood B. Low-level aerosol effects on earth's surface energy balance. Jour. Meteorol. Soc. Japan. (Submitted for publication).	442
Idso, Sherwood B. The calibration and use of net radiometers. Chap. in "Advances in Agronomy", Vol. 26. (In press).	448
Idso, Sherwood B. Climatic effects of increased industrial activity on the world's established agro-ecosystems. Agro-Ecosystems. (In press).	455

MS No.

Idso, Sherwood B., and Foster, Joyce M. Light and temperature relations in a small desert pond as influenced by phytoplanktonic density variations. Water Resources Res. (In press) 445

Kimball, B. A. Smoothing data with Fourier transformations. Agron. Jour. (In press). 443

Nakayama, F. S. Evaluation of the sodium-calcium exchange constants in chloride- and sulfate-soil systems by the associated and non-associated models. Soil Science. (Accepted for publication). 419

Ozment, A., Reginato, R. J., and Jackson, R. D. A programmable controller for automatic incremental positioning of source and detector probes. (Approved for publication). 436

Reginato, R. J. Count-rate instability in gamma-ray transmission equipment. Soil Sci. Soc. Amer. Proc. (NOTE). (In press). 428

Reginato, R. J. Gamma radiation measurement of bulk density changes in a soil pedon following irrigation. Soil Sci. Soc. Amer. Proc. (In press). 431

Reginato, R. J. Water content and bulk density changes in a soil pedon measured with two gamma-ray sources. Canadian Jour. Soil Sci. (Accepted for publication). 447

MS No.

5402-12260-
003 Management of subsurface water movement systems for renovation and conservation of water.

Published: Bouwer, Herman. Design and operation of land treatment systems for minimum contamination of ground water. Proc., Intl. Symp. on Underground Waste Management and Artificial Recharge, New Orleans, La., Sept. 26-30, 1973. Pp. 23-33. 433

Bouwer, Herman. Land treatment of liquid waste: The hydrologic system. Proc., Joint Conf. on Recycling Municipal Sludges and Effluents on Land, Champaign, Ill., July 9-13, 1973. Pp. 103-111. 435

Lance, J. C., Whisler, F. D., and Bouwer, H. Oxygen utilization in soils flooded with sewage water. Jour. Environ. Quality 2(3):345-350. July-Sept 1973. 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 63(3):359-362. March 1973. 404

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