POLLUTION POTENTIAL OF A NEW RAW SEWAGE STABILIZATION POND

by

Wayne Luick Clark, III

A Thesis Submitted to the Faculty of the

DEPARTMENT OF CIVIL ENGINEERING AND ENGINEERING MECHANICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN CIVIL ENGINEERING

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 7 7

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Wayne Luick Clark III

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

R. A. Phillips

R. A. PHILLIPS
Professor of Civil Engineering

April 28 1977
Date

ACKNOWLEDGMENTS

The author's thanks and appreciation are gratefully extended to Professor Q. M. Mees for making this academic experience possible and to Dr. R. A. Phillips for his advice and direction in preparation of this thesis.

The intellectual as well as physical assistance of Dr. L. G. Wilson, G. G. Small, and the staff of the Water Resources Research Center of The University of Arizona is also remembered and greatly appreciated.

The author wishes to also thank B. J. Joplin and others of the Pima County Department of Sanitation for their cooperation in this project.

The work upon which this thesis is based was supported by funds provided by The United States Department of the Interior, Office of Water Resources and Technology, as authorized under the Water Resources Research Act of 1964.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

LIST OF TABLES

ABSTRACT

In order to evaluate the groundwater pollution potential of a waste stabilization pond constructed and put into operation in 1971 by the Pima County Department of Sanitation, physical, chemical, and bacteriological analyses were performed on surface and subsurface water samples. Data were also gathered to monitor the water balance so that seepage losses could be estimated.

Analyses indicated that no deleterious effects on underlying groundwater were attributal to the new pond during initial filling. However, when wastewater was first introduced into the pond, a very high nitrate concentration was found in the infiltrate as nitrates already existing in the soil were apparently flushed through. This phenomenon quickly abated and infiltrate was found to contain primarily ammonia nitrogen throughout the balance of the study. Ammonia nitrogen concentration did not increase in well samples, indicating soil sorption was taking place.

Infiltration rates, estimated from the water balance data, were in the range of from 0.04 to 0.50 cm/hr.

CHAPTER 1

INTRODUCTION

General Considerations

Tucson, Arizona, is totally reliant on groundwater for its domestic, industrial, and agricultural water supply. This water normally contains on the order of 300 mg/l total dissolved solids (TDS) (Engineering-Science, Inc., and Marum and Marum, Inc., 1973).

Wastewater resulting from community water usage is generally found to contain about 700 mg/l TDS. An additional 200 to 250 mg/l of suspended solids (SS) is also present. Suspended solids are primarily organic materials which give the sewage its high biochemical oxygen demand (BOD) as well as its high microbial population.

A sewage treatment plant's function is to reduce the BOD, solids, and microbe levels to a point where the effluent can be disposed of with relative safety and reduced environmental impact. Raw sewage stabilization ponds can offer this treatment function where conventional primary-secondary treatment schemes are not economically feasible. Pond treatment of sewage is being employed by several thousand communities nationwide, as an operationally simple and inexpensive method of sewage treatment (Missouri Basin Engineering Health Council, 1971).

Successful operation of a pond depends on the fundamental concept that adequate oxygen must be supplied so as to satisfy the BOD of the waste being treated. Ponds can be relied upon to sustain a high BOD loading rate due to the large quantities of oxygen being supplied by algae. Aerobic microorganisms use the oxygen produced by the algae to oxidize the organic matter in sewage. These organisms in turn produce carbon dioxide from which the carbon is photosynthetically fixed by the algae while liberating oxygen.

The effective BOD reduction is thus the result of solids settling and biochemical oxidation of organic materials. Reduction of the enteric pathogens in sewage is also a result of settling but is primarily a function of exposure to an unfavorable environment and predation.

Clearly, the design of a pond system must be aimed at optimizing oxygen production and dispersion while providing an adequate detention time to complete biochemical reactions and effectively reduce the pathogen density. If the pond used suffers significant water loss through seepage, the lost effluent could potentially short circuit the pond system and with insufficient detention time for adequate reaction could result in untreated chemical and biological contaminants reaching the groundwater.

This situation would be unlikely in an area of alluvial fill, but it would develop when a fractured aquifer system existed under a pond, especially if the water table is shallow.

During construction of a pond, the bottom is often sealed with clay, an impermeable membrane, or is compacted in order to reduce the soil permeability. Clogging of the soil surface layer interstices by settled organics is generally expected to eventually restrict seepage to a low rate. The time required for self-sealing is a highly variable function which depends on the nature of the waste and soil classification.

During the pond start-up period, however, the hydraulic gradient is maximal across the soil-water interface, resulting in high infiltration.

Objectives and Scope of Thesis

This investigation sought to (1) evaluate qualitative effects of sewage stabilization pond infiltration on groundwater, and (2) to examine the bio-physiochemical transformations occurring during infiltreation through the soil.

The site of the research work was the Pima County Department of Sanitation's Ina Road Water Pollution Control Facility, located approximately twelve miles northwest of Tucson, Arizona, between Interstate 10 and the Santa Cruz

River (Figure 1). After construction of a new 9.8 acre pond (Pond No. 4, Figure 1) by Pima County in 1970-71, extensive sampling and monitoring facilties were installed for study. These facilities made possible a four-month program to establish background levels for the groundwater parameters to be investigated after filling of the pond began. Commencing with the introduction of water to the pond, surface water, tensiometer cup samples, and well samples were analyzed. This second phase of work lasted until Pond No. 4 began overflowing.

A companion study was performed by Small (1973), a graduate student in the Department of Hydrology and Water Resources Administration. The first phase of this work involved characterization of the pond soils and establishment of background levels for soil moisture and well levels. After pond filling began Small monitored the parameters needed to compute a hydrologic balance for the pond.

The two studies enabled an evaluation of potential groundwater contamination arising from a new raw sewage stabilization pond, built on a partially compacted unsealed soil base in the Santa Cruz River flood plain.

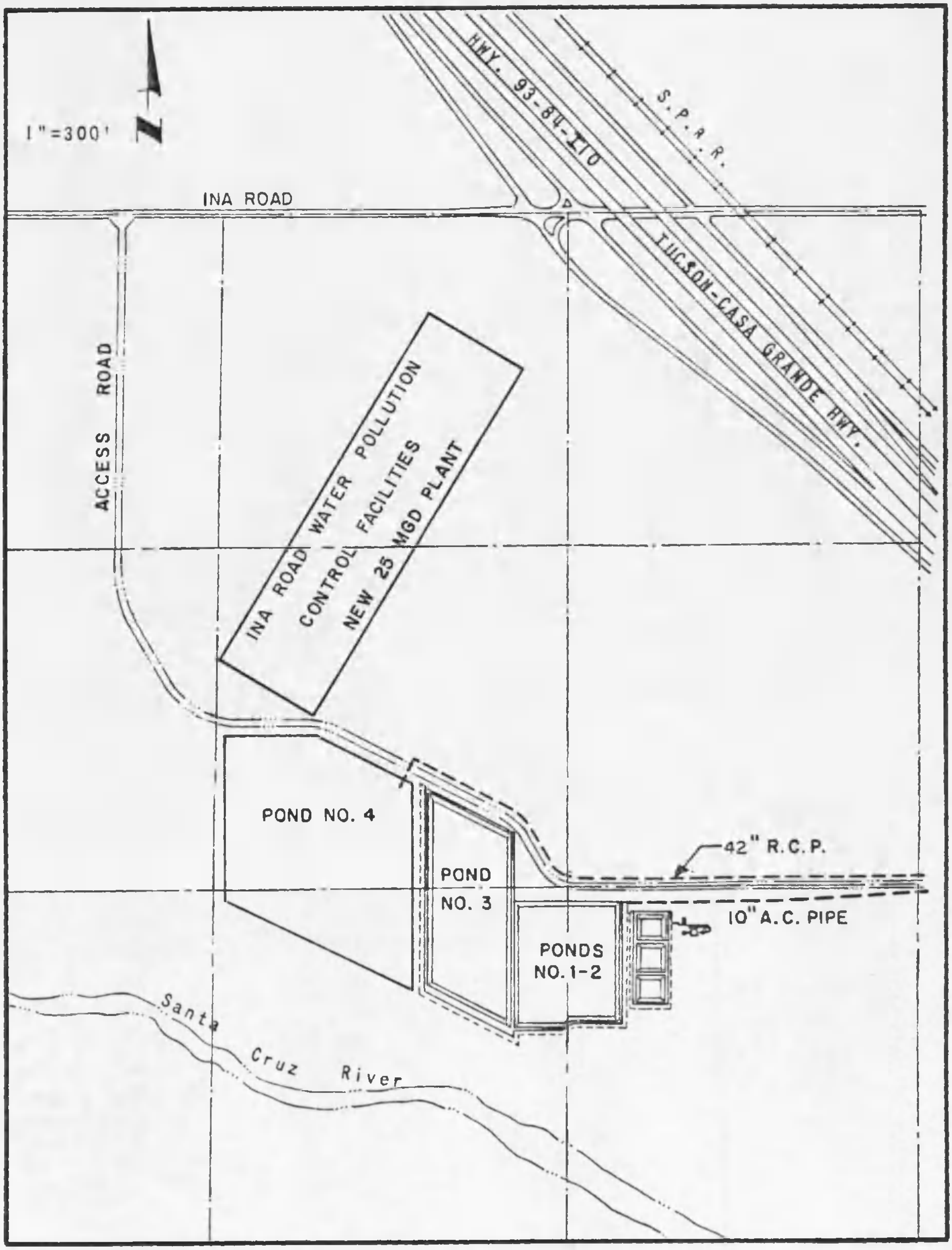

Figure 1. Map of Wastewater Pond Location

CHAPTER 2

REVIEW OF THE LITERATURE

Sewage stabilization pond seepage deserves serious attention due to the potential for deleterious effects on man and his environment. Wastewater can reach the groundwater and if the contaminants have not been adequately reduced or removed, public health hazards may exist. This problem is especially important in areas such as Tucson which are totally dependent on groundwater as the source of domestic water.

Most ponds are operated with no adverse effects on groundwater supplies; however, serious chemical and biological contamination can occur under certain conditions (Keeney, 1970; Fitzgerald and Rohlich, 1958; Bogan, 1961; Meyer, 1960).

Potential for Wastewater Infiltration

The rate of infiltration across the soil water interface in a sewage pond is a function of hydraulic head, structure of geological strata and character of the wastewater.

A reduction in the infiltration rate can occur when water tables are near the ground surface or where subsurface zones of lower permeability result in a perched zone of saturation. Under these circumstances the diminished hydraulic gradient results in somewhat lower infiltration rate. Ponding in any case provides conditions of a relatively large head. It is therefore important that the permeability of the soil underlying a pond be naturally or artificially suppressed to contain effluent recharge within acceptable limits.

Neel and Hopkins (1956) attempted to operate an experimental raw sewage stabilization pond built upon a sand and gravel base. Following a year's operation and testing, obvious degradation of groundwater quality indicated the desirability of impermeable pond bottoms in regions of domestic groundwater consumption.

Inadequate sealing can prevent proper operating levels from being reached, as was reported in the Joint Report of the North and South Dakota Departments of Health (1957). This report recommended selection of pond sites that avoid pervious soils, or use of a layer of packed clay to prevent sealing problems.

These two studies had partially relied upon ponds later being sealed by settled sewage solids during operation. Clogging of the soil surface undoubtedly occurred, but not before the undesirable effects of excess recharge appeared.

Sealing Effects of Sewage

Sealing mechanisms have been studied in detail by several authors who attempted to quantify changes in infiltration rates associated with sands and soils. Reduction of a soil's hydraulic conductivity, when filtering water containing suspended matter, is primarily a function of decreased intergranular pore space (Berend, 1966; Chang et al., 1974; de Vries, 1972; Krone, Orlob, and Hodygkinson, 1958).

Physical entrapment of suspended solids, colloids, and biological floc occurs initially but does not produce complete sealing. Secondary biological and chemical changes in the soil can result in nearly complete sealing. Chemical changes are relatively insignificant but the biological activity in the benthal layer can completely seal the soil surface (Chang et al., 1974). It was also shown that final sealing is related to the activity of slime-forming microorganisms and to the resultant increased polysaccharide content of the soil. Deming (1963) also found that volatile matter and moisture content decreased with depth while the permeability increased. This indicated that permeability is directly related to biological activity. Chemical dispersants can effect sealing and the natural presence of these agents in water can be related to the sodium adsorption ratio ($SAR = Na^{+}/((Ca^{++} + Mg^{++})/2)^{1/2}$). After studying the effects of the sodium adsorption ratio on permeability, Matthew and Harms (1969) concluded that as the SAR increases so does the probability that a stabilization pond will seal naturally.

In the ponds studied by Deming (1963), the organic matter had penetrated approximately 15 cm into the soil after several years' operation, whereas Chang et al. (1974) found the hydraulically restrictive layer to be 5 cm thick after about two months' operation.

Chang et al. (1974) noted that soil texture affected only the elapsed time required to reduce infiltration to experimentally immeasurable rates. Clay soil achieved this low level of seepage in 17 days, whereas sandy soil required 29 days. At 64 days, sand had a tested hydraulic conductivity of only 0.15 cm/hr. This compares to Deming's (1963) determination of a 0.0015 cm/hr rate for a lagoon in operation for three years in a clay-sealed sandy loam soil.

Robinson (1973), working with an unlined "cattle waste digestion pond," detected an initial seepage rate of 0.47 cm/hr. This rate declined to 0.023 cm/hr after three months and then to 0.013 cm/hr after six months of operation. Groundwater dilution around the pond was most rapid during the first three weeks of operation, indicating seepage was highest in this time interval. This pond was situated in an area of silty clay loam alluvial soil in which rapid sealing would be consistent with the tight soil structure.

It is evident from the studies reviewed herein that the first few weeks of sewage ponding can result in significant infiltration of wastewater. This effect apparently diminishes with time. However, some entrained pollutants such as trace metals, organic toxins, and nitrates are a persistent and mobil hazard (Middleton and Walton, 1961).

Pollutant Travel in Groundwater

Of the biological and chemical pollutants normally encountered in domestic sewage, pathogenic organisms and nitrate nitrogen (NO_3-N) have historically represented the most serious threat to public health. Waterborne pathogens as a disease vector have been extensively documented, and the poisonous effects of high NO_3-N consumption have more recently received close attention (Winton, Tradiff, and McCabe, 1971; Keeney, 1970; Pruel, 1966). In recent years, concern has also been given to the possible effects of various trace metals and organic compounds.

Because of the potential health hazard these contaminants pose, it is not only important to study the quantitative effects of pond effluent but also the areal extent of its influence. The information developed can be applied to properly locating ponds relative to well fields or other domestic water sources. Mallman and Mack (1961) summarized their study by noting that initial removals of bacteria are very high, with the rate of reduction decreasing with distances into the soil. Furthermore, bacteria seldom migrate more than 100 ft from the source. Viruses, they felt, would travel further, but no definitive evidence was found to assess the extent of viral travel. They also stated that some chemical pollutants traveled further than biological pollutants.

Virus travel appears to be less than 100 ft in soil according to the results reported by Gilbert et al. (1976). After applying secondary effluent to a land disposal system for 7 years, a virus testing program was begun and continued throughout 1964. Although they found high viral counts in the applied effluent, no viruses were detected in samples from several observation wells, all of which were perforated less than 30 feet below the land surface.

Krone et al. (1958) stated that the ultimate bacterial travel during the wet season was about 80 feet in sandy soil. They observed that chemical contamination appeared to arrive after bacteria, probably due to more sensitive analytical techniques for detecting bacteria rather than higher velocities for the bacteria.

Baars (1961) found that sand-based ponds reduced *E. coli* to very low concentrations within 9.75 ft of the sand surface. This supports the earlier work of Caldwell (1938) which indicated that 10 ft of fine sand could remove all bacteria.

Bacterial removals in the first 10 ft of soil travel result primarily from filtration. The absence of indicator bacteria at 100 ft from effluent sources is probably due to long bacterial residence time in a hostile environment (Meyer, 1960). Meyer, quoting Stead, states that more than 99 per cent die within two or three weeks. Therefore, due to normally low groundwater flow velocities, living bacteria seldom travel more than the generally accepted 100 ft before being entrapped or dying. This 100 ft value is used by the United States Public Health Service as "safe" minimum separation of drinking water supplies from sources of contamination (EPA, 1969). Unless some mechanism exists which allows short circuiting, 100 ft appears to be adequate to protect water resources from microbial contamination.

"Safe" separation distances for chemical pollutants are more difficult to ascertain, as chemicals often persist unaltered for long periods. Middleton and Walton (1961) presented data summarizing the apparent travel time and distance for several organic contaminants such as gasoline and picric acid which were found to travel up to three miles in 4 to 6 years. These nonbiodegradable types of organic chemicals seldom occur in domestic sewage and are generally a problem only where leakage from storage tanks or industrial waste ponds occurs.

Detergents in domestic sewage have yielded ABS which is not readily degradable and which, according to Middleton and Walton (1961), could possibly travel underground several thousand feet from the source. It was the discovery of ABS in local water supply wells which forced premature cessation of operations in ponds studied by Neel and Hopkins (1956).

Pruel (1968) found that 300 ft of travel through sandy or silty soil was necessary to reduce ABS and ammonia nitrogen levels to background concentrations.

Inorganic chemicals yielded by sewage ponds to groundwater are largely harmless in concentrations reaching water supply wells. Pond infiltrate can produce locally higher total dissolved solids in groundwaters which may be a nuisance, but is not generally a health hazard. Certain nitrogen compounds have previously been rated as potential hazards, especially nitrate nitrogen which is a relatively stable and mobile pollutant.

In general, stable chemical pollutants can travel much greater distances than bacterial. This is due to the dilution of the wastewater by groundwater and the long life of the chemical agents (Meyer, 1960). The direction and speed of pollutant travel is directly related to the bulk aquifer characteristics under a pond. Waste materials from a pond normally move with the groundwater they enter.

The local groundwater movements, however, can be altered by infiltrating wastewater. A localized mound can be created in the water table beneath the pond. This peak in the hydraulic gradient would induce a steeper velocity gradient away from the pond. With an increased gradient and head, groundwater movement will experience an increased velocity and could travel counter to the natural flow direction (Meyer, 1960). This counter current flow would be in the zone above the regional water table and it is doubtful if any measurable effect on the natural velocity would occur.

Well pumping in the vicinity of a pond may produce a cone of depression in the regional water table which would greatly increase the groundwater flow velocity toward the well, even if the well had been originally sited upgradient from a pond. This may explain the unexpected occurrence of detergents in wells upgradient from the ponds studied by Neel and Hopkins (1956).

Location of domestic wells to avoid the area influenced by a pond system requires careful aquifer modeling, even if the well is apparently upgradient from the source of contamination.

CHAPTER 3

EXPERIMENTAL METHODS AND PROCEDURES

Preexisting facilities for the project included two 2-in by 100-ft deep, steel access wells with screened well points. One well, located inside the pond, and one outside about 450 ft to the west are labeled 3I and 1E, respectively, in Figure 2. These wells were used in conjunction with a recording neutron probe, as sampling points for groundwater samples, and for measuring water table fluctuations.

Located near well 3I were two 4-in PVC wells, one extending to a depth of 40 ft and one to 60 ft. These are designated 1I and 2I, respectively. These PVC wells would not normally reach the water table but after pond filling began, they could be used for sampling from saturated regions of the vadose zone. An irrigation well (1F) existed 300 ft west of pond No. 4 and was an excellent source of regional groundwater samples when it was in operation.

Sampling Equipment

All four of the wells inside the pond had been capped below the finish grade of the bottom so as not to interfere with construction activities. It was therefore necessary to extend them all by 10 ft so the tops of the wells would be above the design water surface elevation.

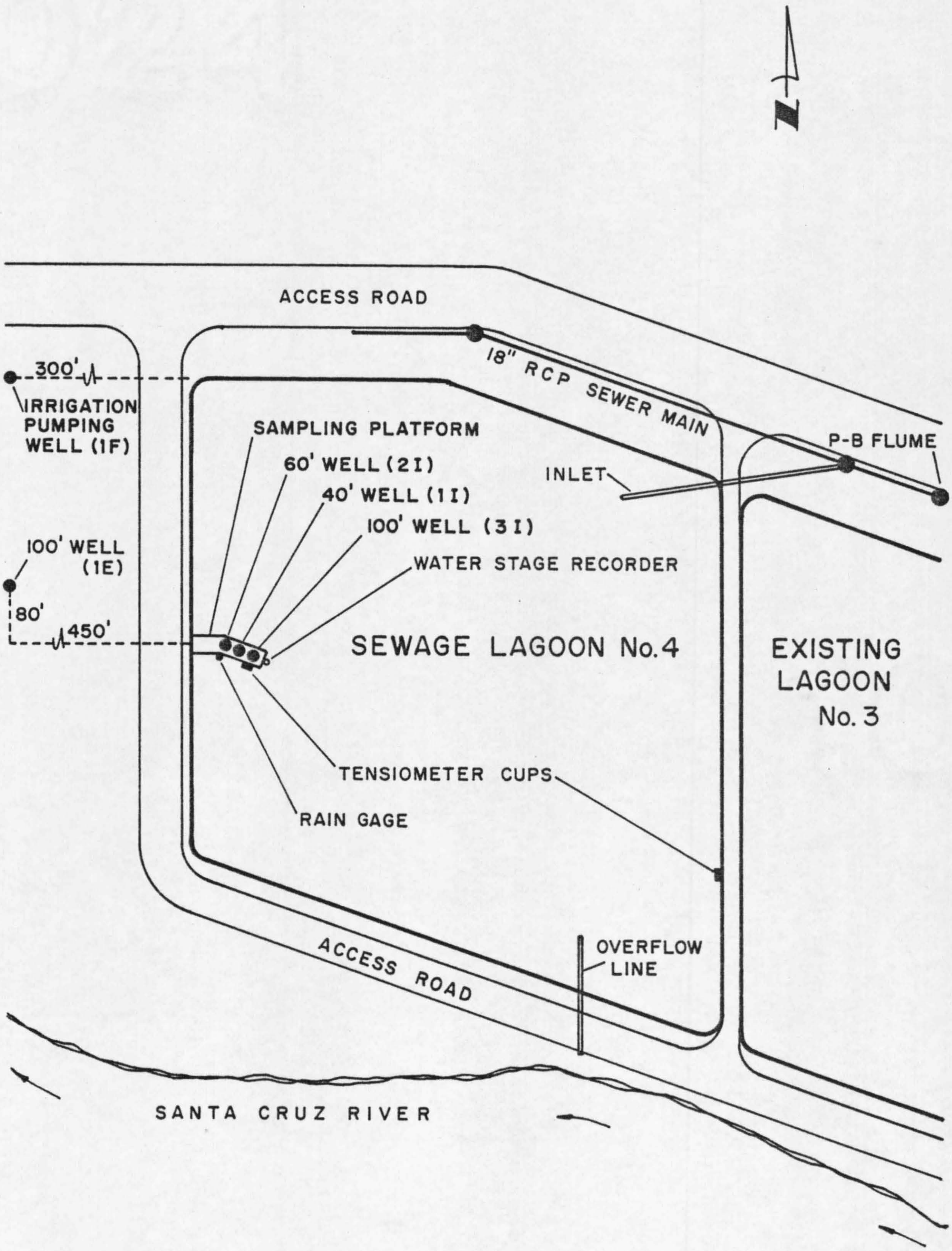

Figure 2. Schematic of Pond Sampling Locations

To facilitate the sampling of pond wells and provide a support for sampling and test equipment, a large platform was built from the embankment out over the wells. Equipment installed included a rain gauge, a water stage recorder, and a sampling apparatus employing a series of six tensiometer cups. These cups were at 3, 6, 26, 38, 45, and 60 in below the bond bottom, with tubing leading from each cup to a vacuum manifold where individual samples were collected (Figure 3). Sampling cup depths were located to correspond with observed soil strata. A similar series of five cups was established near the embankment on the east side of the pond as located in Figure 2. Using the wells and tensiometer cups, the desired samples could be obtained for analysis.

Four months before the pond began receiving water on August 5, 1971, background data gathering began. The access wells and the irrigation well were regularly analyzed for total coliform bacteria; chemical oxygen demand (COD); temperature; pH; alkalinity; total hardness; calcium; total phosphorus; chloride; and ammonia, organic, nitrate, and nitrite nitrogen. These tests were also performed on surface samples and samples from the PVC wells as each became available.

Analysis for organic-N, NH_3-N, NO_2-N, and NO_3-N were made on samples taken from the platform and the East pond sets of tensiometer cups. This phase of the study was of

Figure 3. Vacuum Sampling Apparatus -- Note attached vacuum pump.

about eight months duration (from August, 1971, to April, 1972).

From several locations on the pond bottom, soil samples were taken for classification. Soil samples were also obtained for more complex analysis by the Department of Soils, Water and Engineering, The University of Arizona.

Hydraulic Measurements

To measure the quantity of flow into the pond a Palmer-Bowlus flume was installed in the influent sewer interceptor line. This flume was calibrated during the first weeks of flow by trajectory methods. Personnel of the Water Resources Research Center were then able to determine the pond's water balance using flume, rain gauge, and evaporimeter data.

Before the pond was filled, well levels were monitored and a neutron logger was operated to establish background unsaturated soil moisture profiles (Wilson, Clark, and Small, 1973). These types of information were gathered until the pond had filled and begun to overflow.

Test Procedures

Analytical procedures followed were those presented in Standard Methods (APHA, AWWA, WPCF, 1971).

Sampling Procedure

Sampling of the observation wells was accomplished with a brass bailer which would take one liter of sample (Figure 4). This was lowered by polyethylene rope to about 6 ft below the water surface (when depth was sufficient).

Pond samples were obtained by lowering a simple tipping bailer below the surface and quickly raising the bailer to work level.

Well 1F (Figure 2) was a high volume irrigation well which was sampled at its discharge line adjacent to the pump house. Unfortunately, this excellent source is operated only part of the year, when irrigation is at a peak.

Samples of sewage infiltrate were obtained by the apparatus shown in Figure 3. A cylinder, serving as a vacuum reservoir, was connected via a manifold to tubes which extended to the bottom of the buried porous tensiometer cups. Samples were collected in a set of bottles acting as a trap between reservoir and tensiometer cups. Sample volume could be roughly adjusted by varying the pressure in the cylinder. A gauged hand pump was used to evacuate the cylinder, allowing the pressure to be varied by noting the pressure reading while pumping.

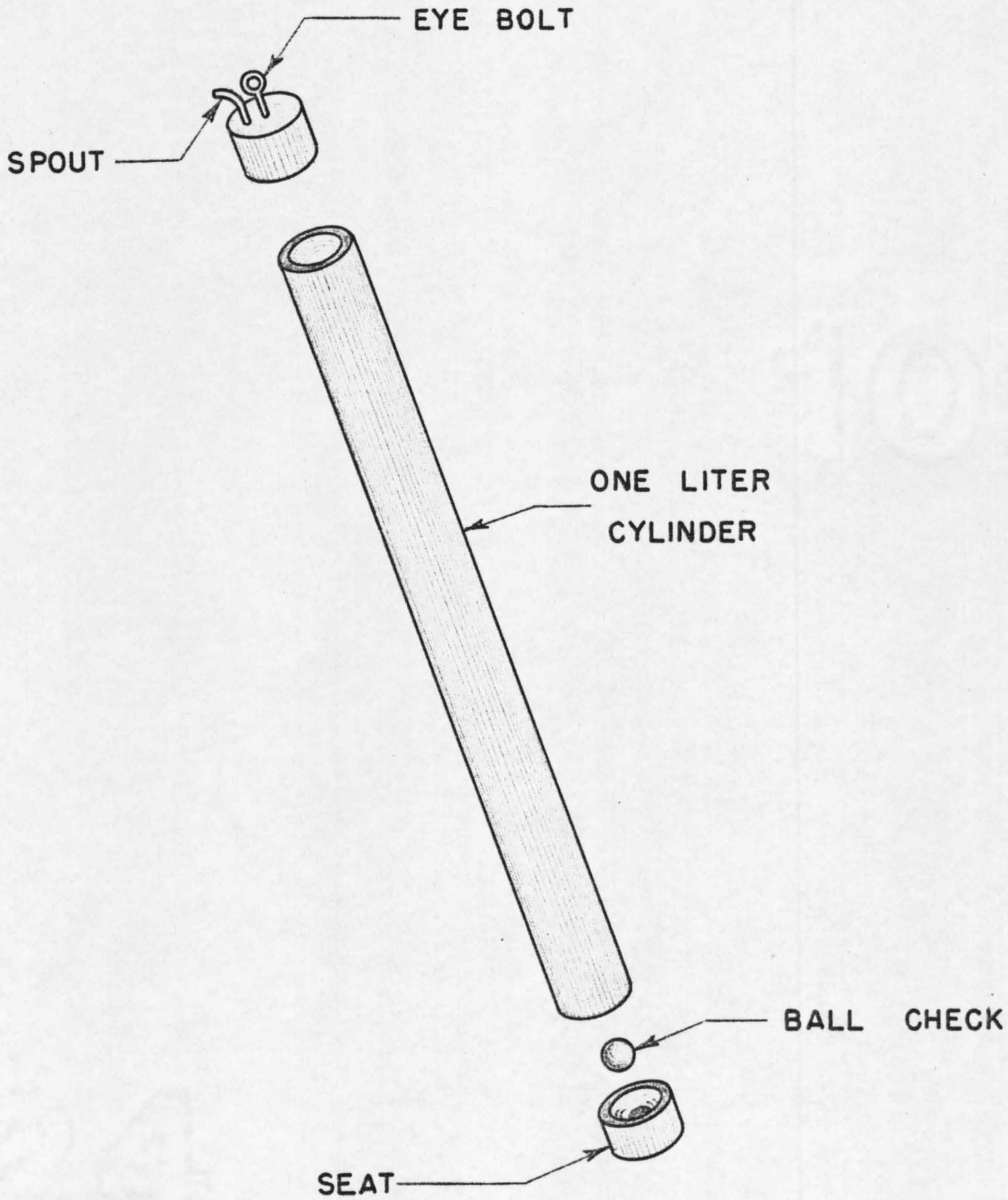

Figure 4. Sketch of Sampling Bailer

CHAPTER 4

RESULTS AND DISCUSSION

Gathering of background data commenced in March, 1971, and continued until August, 1971. During this time, samples of pond bottom soil were obtained for analysis, and testing was begun on samples of water from wells 1F, 1E, and 3I. Existing static water levels were measured and soil moisture profiles were determined with a recording neutron probe for wells 1E and 3I.

Soils Analyses

Analyses were performed on samples collected during the excavation and extension of wells 1I and 2I. These samples were subsequently evaluated by the Department of Soils, Water and Engineering, The University of Arizona. Table 1 summarizes these results and suggests several noteworthy relationships.

First, the surface strata contained a relatively large percentage of clay. This is consistent with the large cation exchange capacity (CEC) recorded, since clay materials often exhibit appreciable exchange capacity. Also, the exchangeable ion concentrations are also high in these strata, indicating the CEC is being at least partially utilized.

Table 1. Characteristics of Soils on the West Side of Pond No. 4

Sample Site	Depth[a] Inches	pH	NO_3-N (mg/l)	PO_4 (mg/l)	CEC (meq/ 100 gm)	Mechanical Analysis Sand %	Silt %	Clay %
40' PVC Well	0-30	7.2	136	5.0	23.4	52.5	31.5	16.0
40' PVC Well	31-49	7.9	368	7.1	5.9	94.5	3.0	2.5
40' PVC Well	49-52	7.5	208	22.5	10.5	80.5	14.5	5.0
60' PVC Well	0-30	7.4	106	5.3	16.7			
60' PVC Well	30-48	6.7	264	22.5	3.7			
60' PVC Well	48-51	7.5	288	21.7	7.6			

[a]Depth below pond bottom.

The clays present in this 30-in thick stratum have resulted from removal of surface soil from adjacent areas to fill and level the pond bottom. Gelderman (1972) described the area as consisting of Grabe Loam or Vinton Anthony sandy loam which means the soil series consisted of well-drained loams, gravelly loams, and silty clay loams. The thickness of this horizon is therefore the result of construction activity and the high clay portion is common to soils in the area. Farming has been carried on along the river for many years and this land use activity would generally result in finer grained soils.

Nitrate nitrogen (NO_3-N) derived from extract was very high on the west side soil samples, possibly due to farming and previous research work in the area. Lehman (1968) had used the immediate area for soil-grass sewage filtration studies and this combined with the past agricultural activity apparently has left a large NO_3-N residual in the soil.

Nitrates were relatively lower on the east side of the pond as shown in Table 2. Here the sample depths were chosen to correspond to the tensiometer sampling cups and do not indicate observed textural changes. Mechanical analysis of pond bottom samples indicated that textural changes occurred in the upper 12 in, between 12 and 24 in, between 24 and 36 in, and between 36 and 48 in.

Table 2. Characteristics of Soils on the East Side of Pond No. 4

Sample[a] Depth (Inches)	pH	NO_3-N (mg/l)	CEC (meq/ 100 gm)	Mechanical Analysis Sand %	Silt %	Clay %
0-6	8.0	133	7.8	62.5	27.5	10.0
6-12	8.0	75	8.2	65.0	25.0	10.0
12-24	8.0	63	9.8	73.0	19.0	8.0
24-36	8.1	39	12.6	34.0	55.1	10.9
36-48	8.0	38	9.0	57.0	33.0	10.0

[a]Depth below pond bottom.

Clay content in all east side strata was about 10 per cent. This is a lower value than the surface stratum of the west side, but higher than the lower west side soil strata. CEC values showed a trend similar to that of the clay analyses, again indicating a positive correlation between clay content and CEC. The highest east side CEC values occurred in samples from the 24-36 in depth. The greatest clay percentage did likewise.

Nitrate-N was 2 to 3 times higher in the 0 to 6 in east soil layer than in succeeding layers, and was nearly the same as the uppermost west side soil horizon. However, in comparing Tables 1 and 2 one can see that the NO_3-N increased 2- to 3-fold in samples from deeper horizons on the west side. Perhaps soils of approximately 135 mg/l NO_3-N predominate in surface soils and these surface soils were used for fill in the west pond sample area, and remain in place on the east side of the pond.

Groundwater and Surface Water Results

On March 18, 1971, groundwater sampling was initiated using the pond internal well 3I and the two wells external to the pond, designated 1E and 1F. Samples were obtained on a weekly basis to be analyzed for COD, total and fecal coliform bacteria, alkalinity, calcium, total hardness, chloride, total phosphate, ammonia nitrogen, organic nitrogen, nitrate nitrogen, and nitrite nitrogen. Measurements of pH and temperature were also made.

Beginning on August 5, 1971, when the wastewater pond came on line, the above determinations were begun on surface water samples as well as groundwater samples from well 1I and 2I. As flooding progressed across the pond bottom, the tensiometer cups began to respond and samples were collected. These were analyzed for the nitrogen species only. Results from the tensiometer cup analyses will be presented and discussed in a subsequent section.

Results from the many tests performed are generally presented graphically in order to simplify their interpretation and to clarify trends. Most of the basic data have also been tabulated and are presented in the appendices. Certain of the tests performed yielded relatively unvarying results and therefore will be discussed but not necessarily plotted or tabulated.

Chemical Oxygen Demand

COD values for wells 1I, 2I, 3I, and 1E varied principally as a function of elapsed settling time before analysis. COD values for samples from these wells were initially in the range of 100 mg/l but were reduced to 20 mg/l or less if the solids suspended by turbulence from the sampling were allowed to settle. By taking adequate precautions not to disturb slime growths on the inside of the well casing, the COD for both settled and unsettled samples decreased to 20 mg/l or less.

The COD for these wells was therefore quite low and apparently did not vary significantly over the study period of 13 months. Well 1F also showed a low COD, in the range of 10 mg/l, and was always very clear. This indicated that the gross aquifer has suffered little organic pollution from the pond.

Coliform Bacteria

Total and fecal coliform bacteria results also remained consistently low in wells 1I, 2I, 3I, 1E and 1F. While establishing background densities for this parameter, up to 1,000 ml of sample were filtered through 0.45 μm membrane and cultured. Less than one coliform per 100 ml was found is fecal coliform samples. Thereafter, only 100 ml of sample was gathered for fecal and 100 ml for total coliform testing due to difficulty in obtaining and processing larger samples. Results from coliform analyses did not significantly vary from a density of less than 1/100 ml for any of the wells, suggesting that no bacterial contamination of the pond's underlying aquifer has occurred.

Temperature, pH, and Alkalinity

Well and surface water pH measurements fluctuated only slightly. No meaningful trend was detected as readings generally ranged between pH 7 to 9. Groundwater temperatures were predictably constant, always registering 21°C. Alkalinity seemed to show more variable results than pH but the values were fairly constant with concentrations at the study's end very close to initial background concentrations (Figure 5). The decrease in alkalinity occurring in the deeper wells, 1E and 3I may be a result of stormwater penetration to the aquifer from the Santa Cruz River in October through January.

Total Hardness and Calcium

Figure 6 displays the results of the total hardness analyses. Deep wells 3I and 1E showed considerable variation from March, 1971, until pond filling in August, 1971, when concentrations leveled off. Well 1F was more consistent being 350 mg/l at the beginning and end of sampling with the concentration occasionally dropping to 250 mg/l for no discernible reason.

The hardness at well 2I quickly rose from approximately 200 mg/l soon after August 5, 1971, to 800 mg/l during September. The level abated until December 1, 1971, when the total hardness was down to nearly 250 mg/l, the approximate concentration prevailing until April 4, 1972, when sampling closed. This peak could have been the result of calcium being flushed from more shallow soils. However, no similar peak was detected in the more shallow well, 1I.

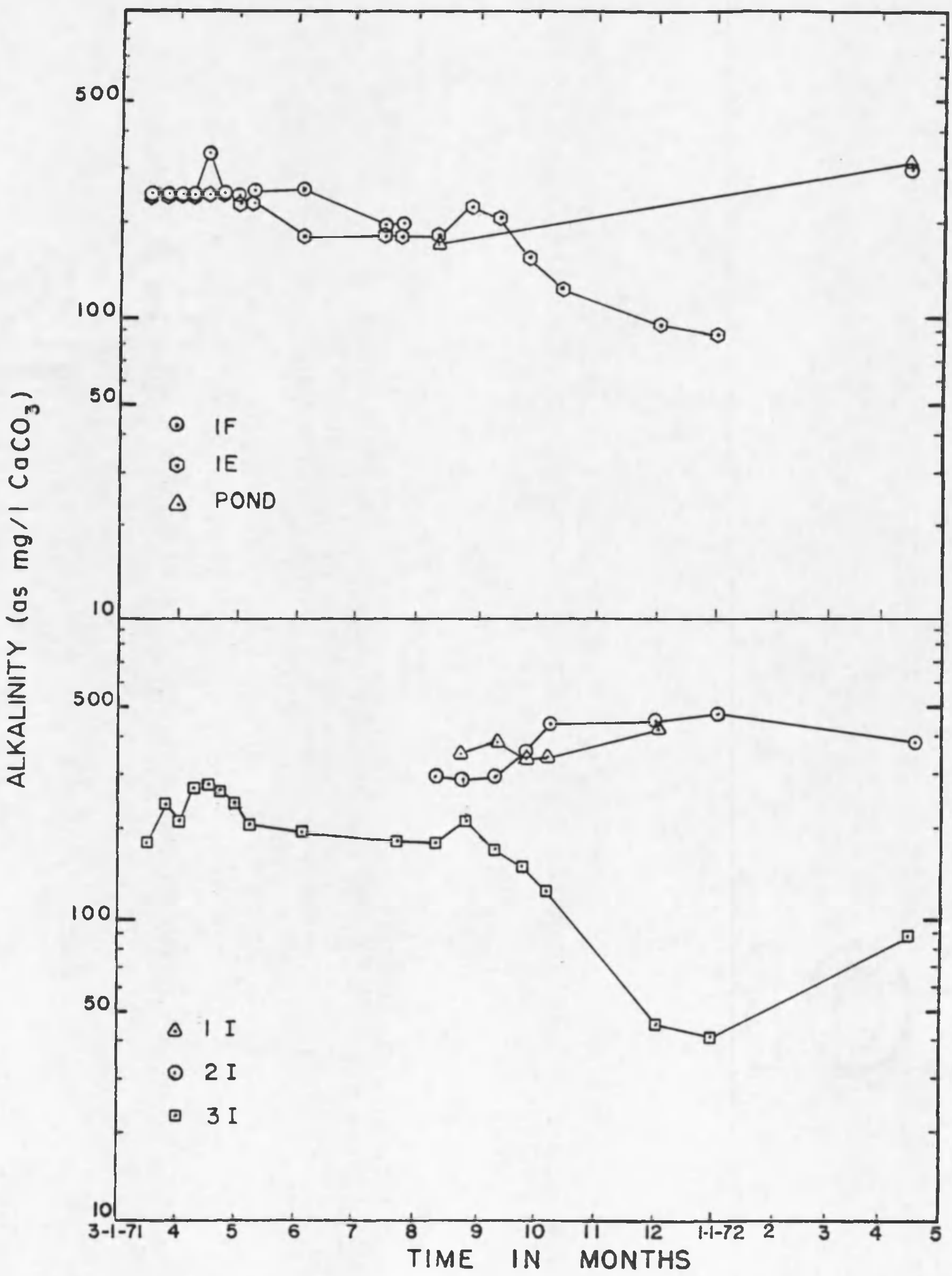

Figure 5. Alkalinity for Wells 1E, 1F, 1I, 2I, and 3I

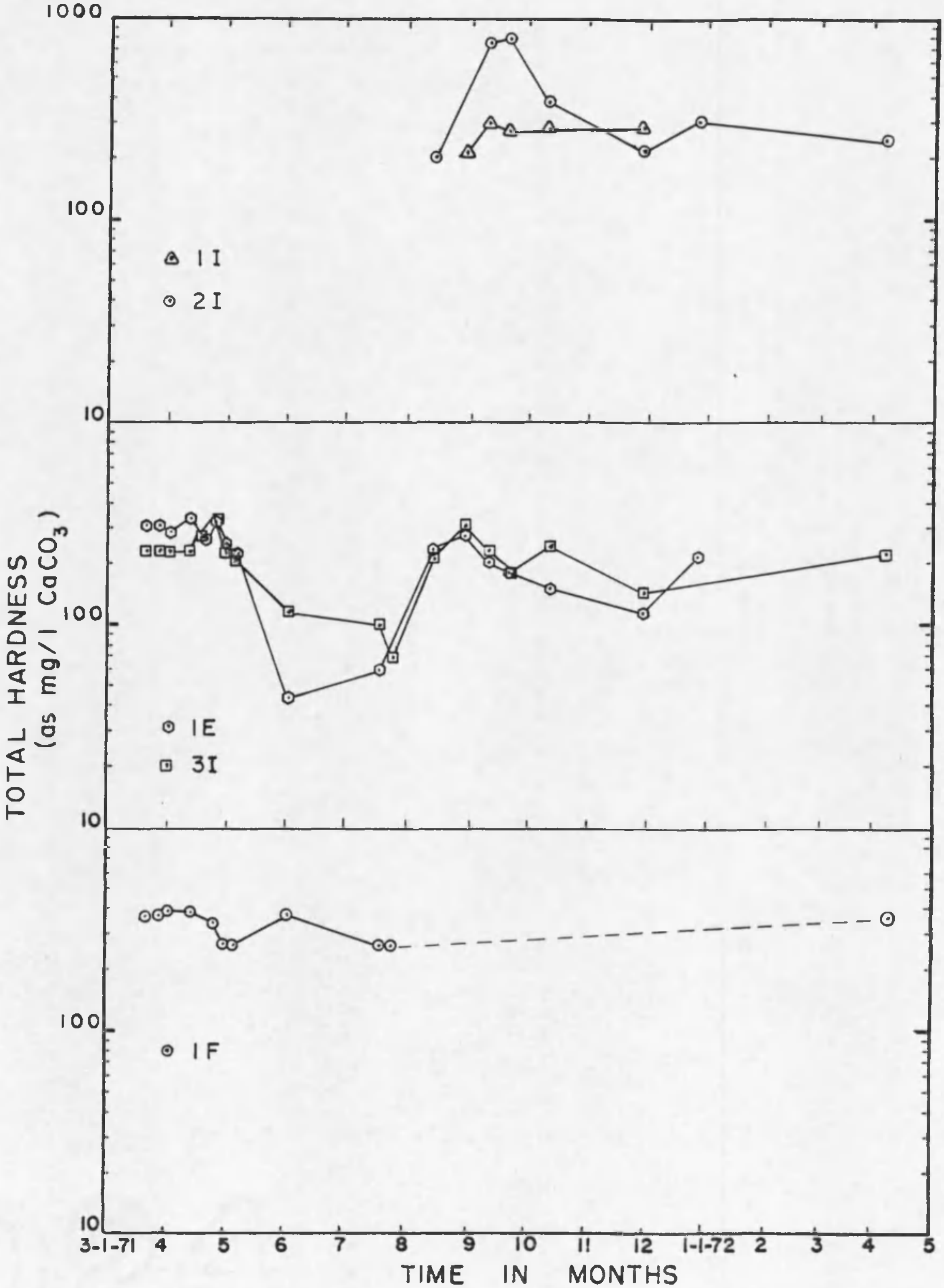

Figure 6. Total Hardness for Wells 1E, 1F, 1I, 2I, and 3I

This, the most shallow well, had very little water (0 to 3 ft) so it was often difficult or impossible to get an adequate sample for comparison.

Overall the calcium results resembled the total hardness curves as one would anticipate. Pond total hardness and calcium apparently increased although only two samples were analyzed.

Chloride

Chloride concentrations (Figure 7) varied widely in samples from all these sources. Well 2I again showed a very high chloride peak in September, 1971, and, to a lesser extent, did well 1I. In the graph one can see a small but clear peak subsequently occurring in the deep wels 1E and 3I. This peak lagged the shallow well peak by two weeks and was much less prominent. No peak at all was found in the deep irrigation well 1F.

It can be surmised that these peaks were related to a large runoff event in the Santa Cruz River on September 1 and September 2 (U.S. Geol. Survey, 1971), which leached soluble salts from a sanitary landfill located between the river and the test wells. The premise is supported by the fact that well 2I peaked at 459 mg/l chloride while the surface water chloride was never above 60 mg/l and further by the relative timing involved in the landfill flooding and subsequent high chloride measurements.

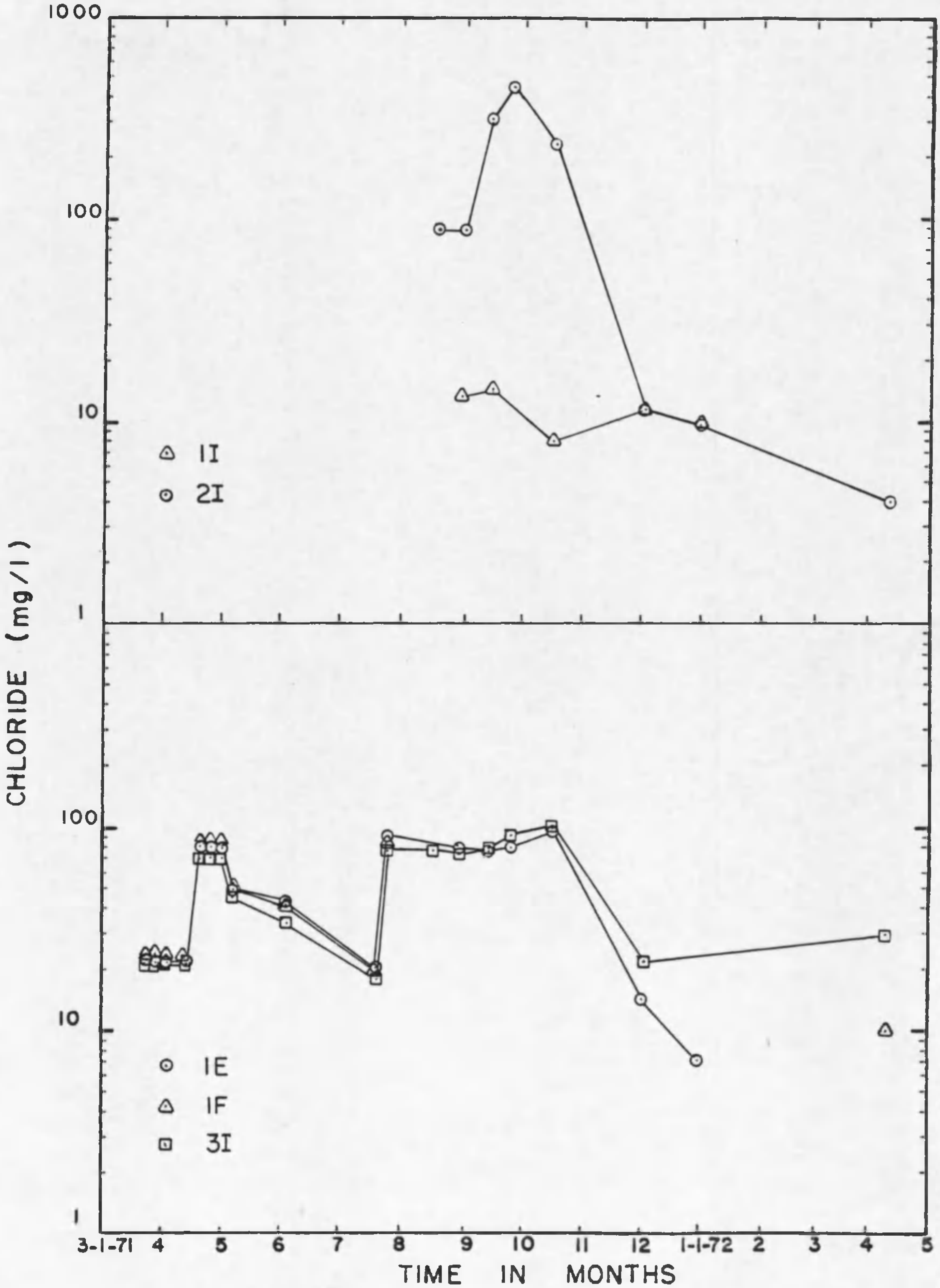

Figure 7. Chloride for Wells 1E, 1F, 1I, 2I, and 3I

If the chloride peaks which later occurred in wells 1E and 3I are also related to the landfill leachate, then the long time lag noted is perhaps due to the phenomenon that ground water moves much faster parallel to soil strata than perpendicular to them.

Total Phosphate

The variations in the total phosphate content of the wells as shown in Figure 8 are difficult to explain. Well 1F was most consistent, beginning at about 1 mg/l and ending at 2 mg/l. Well 3I had an initial phosphate concentration of approximately 0.13 mg/l and by May was nearly 0 mg/l. Although well 1E took until September to approach 0 mg/l total phosphate, both wells showed a very sharp rise in late September when well 3I reached 10 mg/l and well 1E recorded a 6 mg/l. With this peak occurring less than two months after the pond filling began, it could be postulated that phosphates were infiltrating for a short time, but this peak was probably related to the landfill flood, also.

More apparent trends are suggested by comparing the surface sample results to the shallow well results (wells 1I and 2I). A positive relationship was exhibited in the curves for these water analyses as the shallows began in range of 5 mg/l and the surface at 30 mg/l. Although the phosphate curve for the wells rose more rapidly than that of the surface water, both had nearly 50 mg/l total

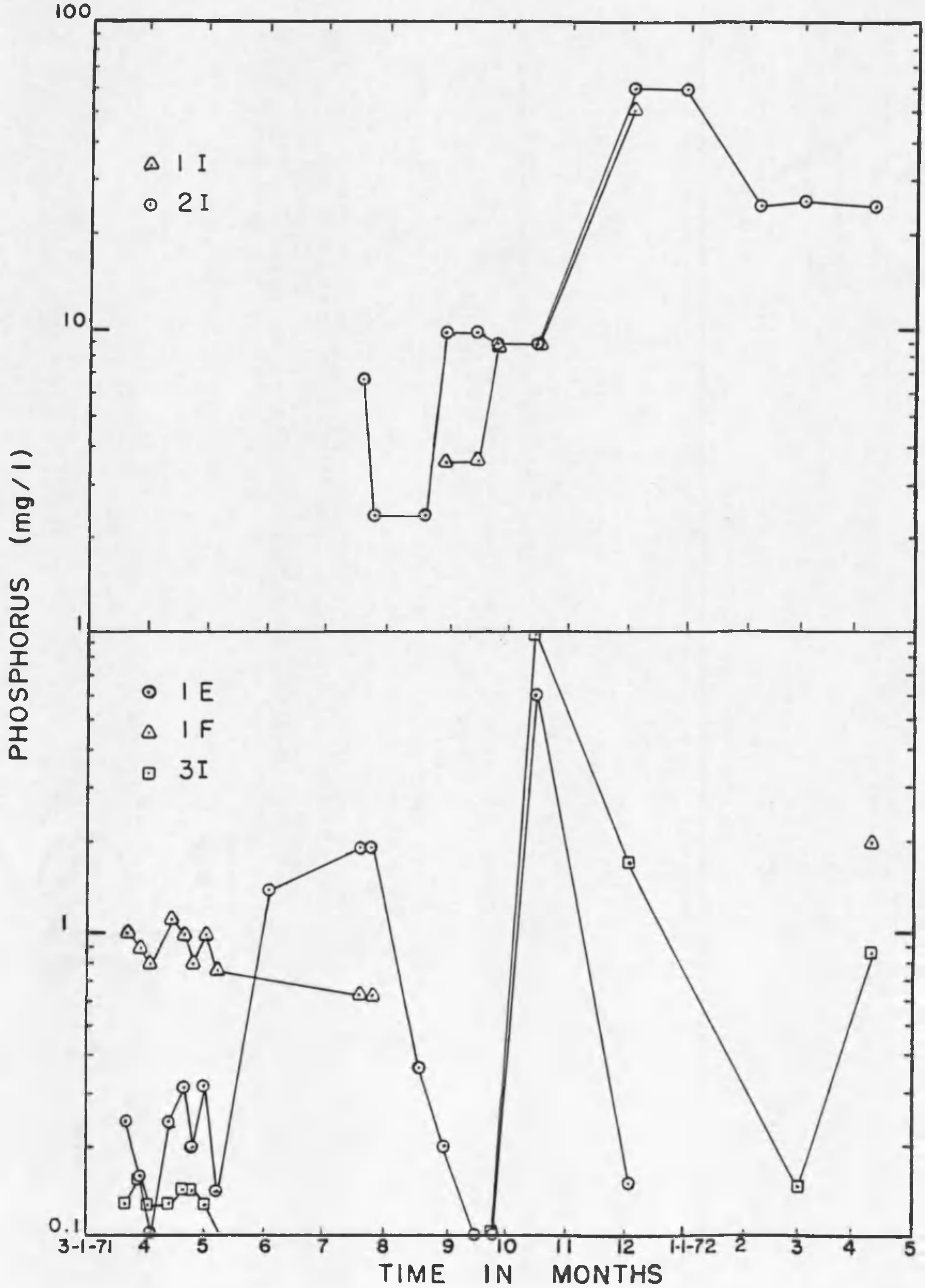

Figure 8. Total Phosphate for Wells 1E, 1F, 1I, 2I, and 3I

phosphate by late November, 1971. Surface water samples and shallow well samples remained in this range of concentration, and were much higher than were the deep wells, where total phosphates had declined to 2 mg/l or less.

Although surface water total phosphate appears to be related to that of the shallow wells, there apparently is no such relationship between surface water and the shallow groundwater and deeper groundwater regimes.

Nitrogen

The trends and relationships in nitrogen species are shown in the curves of Figures 9, 10, 11, and 12. Data for the total nitrogen content of the pond and wells are shown in Figure 9. Total-N is the sum of the NH_3-, organic-, NO_2-, and NO_3-N values for a given day's sampling.

Examination of Figure 9 reveals the overall trends in nitrogen concentration, and a comparison of all four figures serves to clarify the factors influencing those trends. Figure 9 indicates that the surface water and deep irrigation well were fairly constant in nitrogen content. The shallow wells experienced an overall decrease in nitrogen, whereas the deeper wells, 1E and 3I, appear to have increased in nitrogen content.

Surface water total-N was of a relatively constant at approximately 40 mg/l as the result of an increase in organic- and ammonia-N being offset by a decrease in NO_3-N

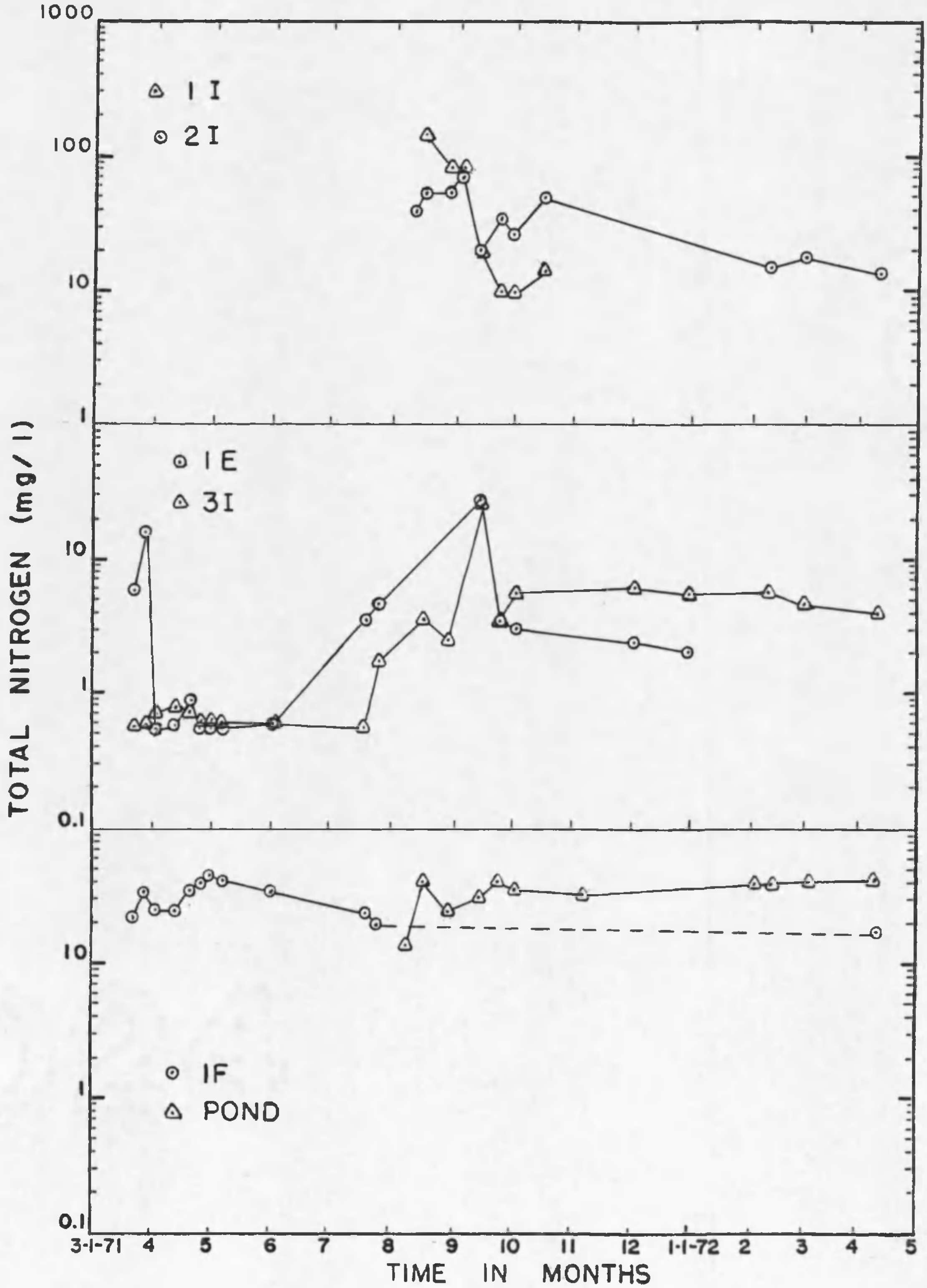

Figure 9. Total Nitrogen Results for Wells 1I, 2I, 3I, 1E, 1F, and Pond Samples

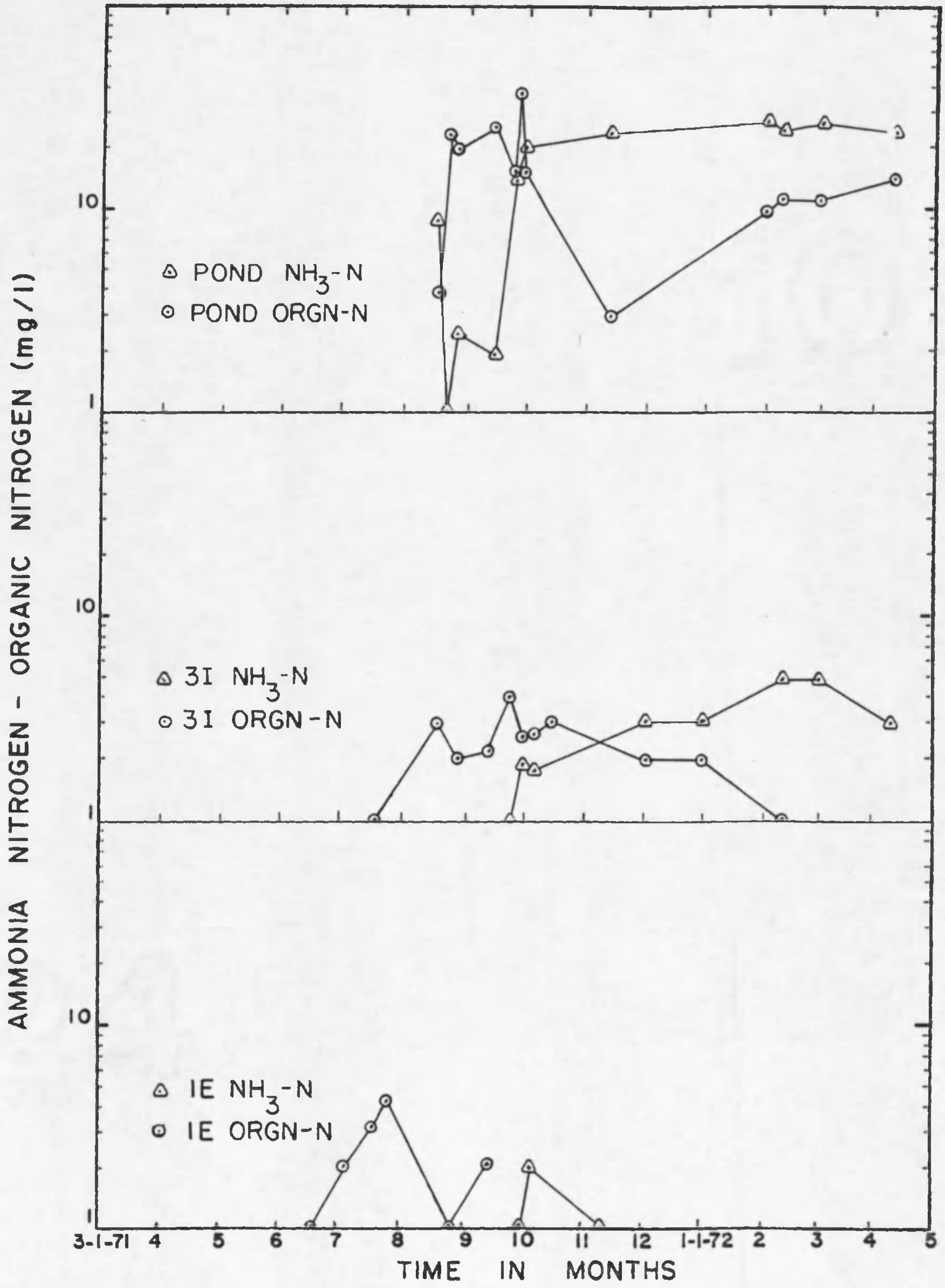

Figure 10. Ammonia and Organic Nitrogen for Wells 1E, 1F, 1I, 2I, 3I, and Pond Samples

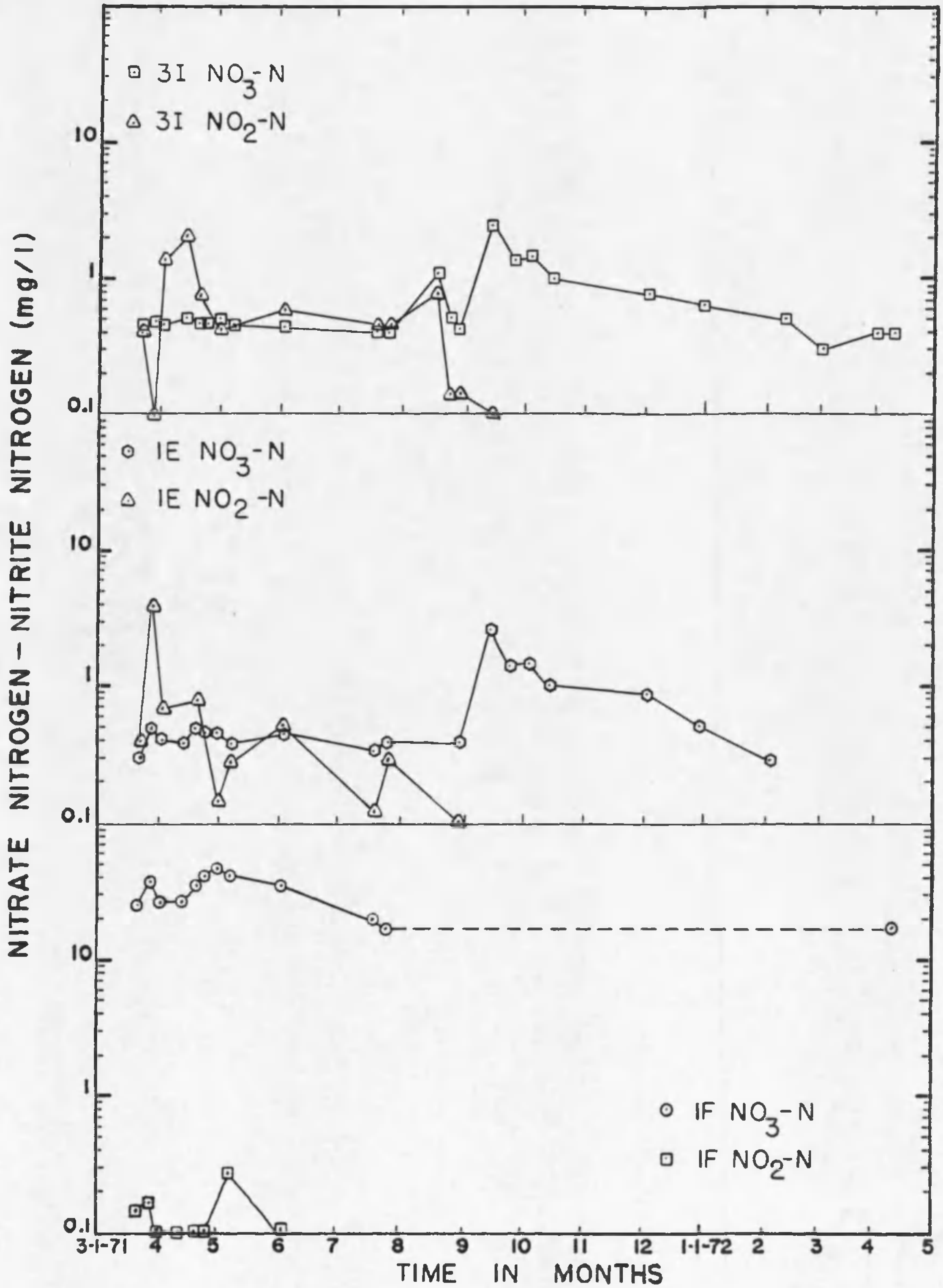

Figure 11. Nitrate and Nitrite Nitrogen for Wells 1E, 1F, and 3I

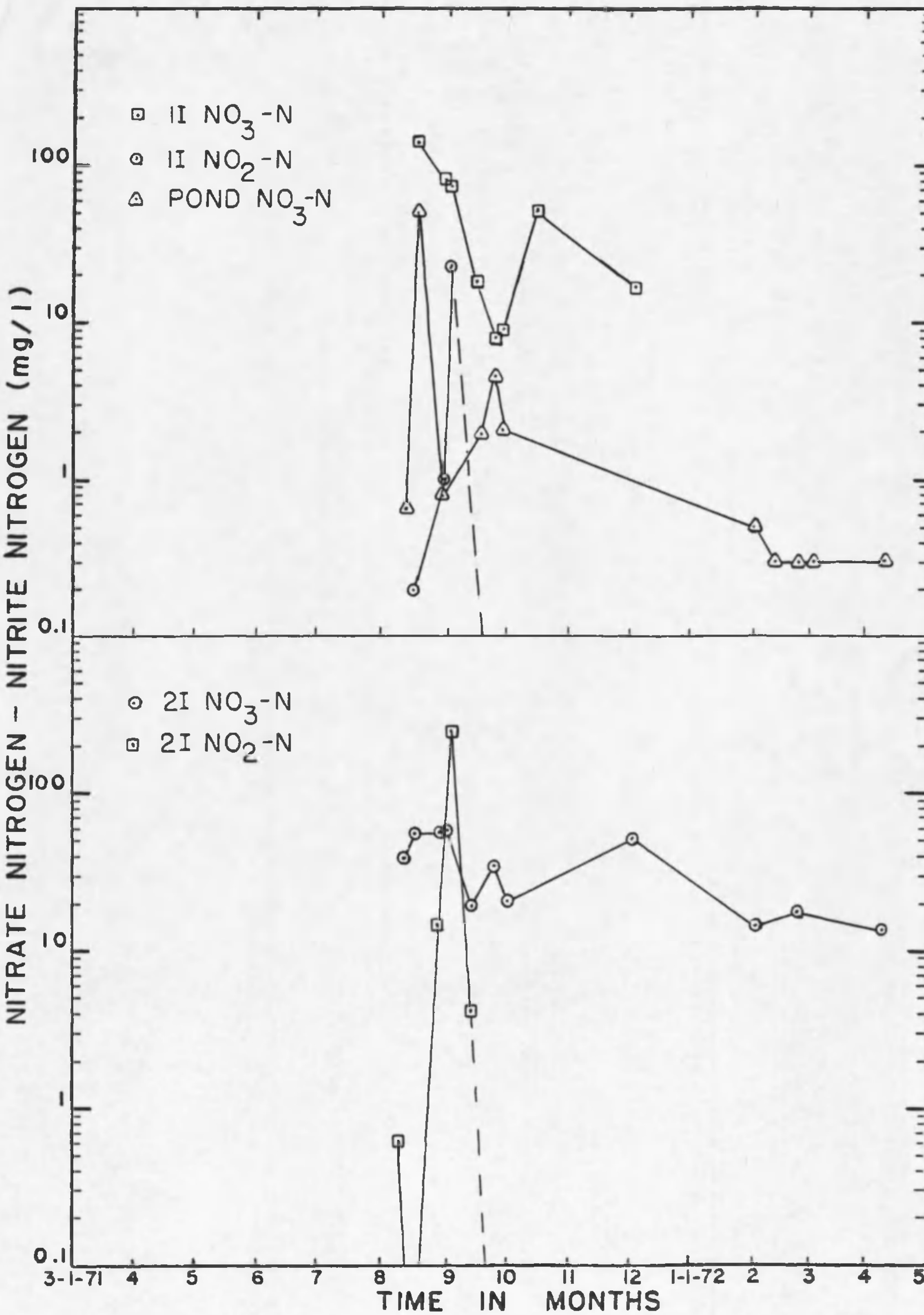

Figure 12. Nitrate and Nitrite Nitrogen for Wells 1I, 2I, and Pond Samples

(Figures 10, 11, and 12). Pond No. 4 was put into service by removing plugs from the sewer main which feeds the pond, allowing raw sewage to enter. Raw sewage generally contains little NO_3-N which makes the source of the initially high NO_3-N concentrations in surface samples a question. Pond bottom soil did have a high native NO_3 content and there were periods of rainfall during initial filling of the pond but these sources of NO_3-N would probably not account for concentrations as high as 40 mg/l.

The flat total-N curve of well 1F resulted from a flat NO_3-N curve which generally had about 20 mg/l NO_3-N, no organic-N or NH_3-N, and very little NO_2-N. Shallow wells also had little nitrogen other than NO_3-N and this species generally decreased during the study period.

More active nitrogen movements are reflected in the curves of the deep observation wells 1E and 3I. Beginning in March, 1971, the total-N curves hovered at about 0.5 mg/l and continued there until September, 1971, when there was a small but sharp increase in nitrate, peaking in mid-September near 2.5 mg/l. The NO_3-N peak was possibly related to the large seasonal runoff in the Santa Cruz River during August, 1971 (U.S. Geol. Survey, 1971), which could have altered normal groundwater flow patterns, bringing water of higher NO_3-N content into the area of the pond. In September, an increase in organic-N also began with NO_2-N and NH_3-N being insignificant. By late September, 1971, the nitrates were down to about 1 mg/l, but the total-N was sustained at higher levels by increased NH_3-N and organic-N activity. Nitrates then continued to decline in both deep wells toward the concentrations found during initial background analyses. Organic-N continued to be present in a concentration range of approximately 1 to 2 mg/l for both wells, while NH_3-N decreased to 0 mg/l in well 1E. However, the NH_3-N in well 3I maintained a slow rate of increase which resulted in a slight overall increase in NH_3-N concentration.

The results for the deep observation wells correlate poorly with those of the shallow wells. This is reasonable considering the dilution that probably occurs when the pond infiltrate interacts with the much larger groundwater mass. Surface water nitrates declined, probably due to assimilation, and shallow groundwater nitrates also decreased, probably due to its dilution by very low nitrate infiltrate. Denitrification was probably not a noticeable influence as COD values were low, indicating no energy source was available.

Nitrates showed dramatic peaks in deep well samples during this same period. Unfortunately well 1F was out of service from late July, 1971, until April, 1972. Therefore, no information was available for comparison during the September, 1971, NO_3-N peaks found in wells 3I and 1E.

Perhaps the flooding that influenced the chlorides in shallow wells simultaneously created enough additional hydraulic head to drive nitrate-rich effluent water laterally from the Santa Cruz River. The City of Tucson has discharged sewage effluent into the Santa Cruz River channel for many years. This effluent can become high nitrified before infiltrating causing excessive nitrate concentrations along the Santa Cruz (Laney, 1972; Schmidt, 1973; City of Tucson, 1970-71; Engineering-Science, Inc., and Marum and Marum, Inc., 1973).

Laney (1972) found nitrate to be a minor chemical constituent in most of the ground water in the basin, except in places along the Santa Cruz River where nitrate concentrations were more than 40 mg/l. Therefore, nitrate subflow which would normally be toward the river channel could be reversed subsequent to a river runoff event. Lateral dispersion of high nitrate groundwater would show up as a sharp rise in nitrates for wells affected by flow reversal. As the runoff abated in the channel, normal groundwater flow would be restored and affected wells would once again approach gross aquifer NO_3-N concentration.

The above hypothesis could explain NO_3-N behavior; however, the gradual increase in NH_3-N is more difficult to assess. Tensionmeter cup data indicate that the infiltrate became high in NH_3-N soon after the wastewater pond went anaerobic in late September, 1971 (Table 3). With the fairly

Table 3. Dissolved Oxygen Concentrations at Various Depths During Pond Filling, 1971 -- After Small (1973).

Date	Time	Top (mg/l)	1/2 Depth (mg/l)	Bottom (mg/l)
8-28-71	--	8.2	5.1	1.4
8-30-71	0845	7.1	5.7	1.4
8-30-71	1725	30.6	--	3.8
8-31-71	0830	4.3	--	2.1
9-1-71	0830	4.5	3.3	0.3
9-2-71	0830	2.7	1.9	1.4
9-2-71	1705	28.5	--	0.5
9-3-71	0850	4.7	--	3.9
9-4-71	0830	6.0	--	0.3
9-5-71	0820	3.5	--	0.3
9-7-71	0820	3.5	--	0.3
9-8-71	1000	19.5	11.7	2.8
9-9-71	0805	1.5	0.2	0.3
9-10-71	0930	2.2	--	1.5
9-13-71	1400	1.1	0.4	0.2
9-17-71	1400	0.5	--	0.3
9-20-71	1400	0.3	--	0.2
9-22-71	1400	0.3	--	0.1
10-6-71	1600	0.0	--	0.0

high infiltration rate, considerable NH_3-N was infiltrating, but was not detected in the shallow wells. It is difficult to perceive how the noted NH_3-N increase in deep well samples could arise from infiltrate without affecting shallow well samples.

Tensiometer Cup Results

These nitrogen data were consistent in showing clear trends in samples from both sampling locations. Because of the consistency from both locations they will be discussed simultaneously.

Ammonia Nitrogen

NH_3-N concentrations (Figures 13 and 14) were zero for about two months after the pond began filling. Then, at all levels but one, there was a rapid increase in NH_3-N which continued throughout the study, finally reaching 30 mg/l. In the west 26-in and east 24-in levels, NH_3-N remained near zero mg/l for an additional two months. The 24-in deep east sample then rose to 30 mg/l; however, the 26-in deep west samples never showed a significant increase in NH_3-N. This anomaly is probably related to the highest CEC being present in this soil horizon (Table 1), resulting in a continuous removal of ammonia ions from the infiltrating water through clay sorption mechanisms. Such a relationship is supported by the data in Table 4 which compares each soil horizon CEC to the mean of NH_3-N values

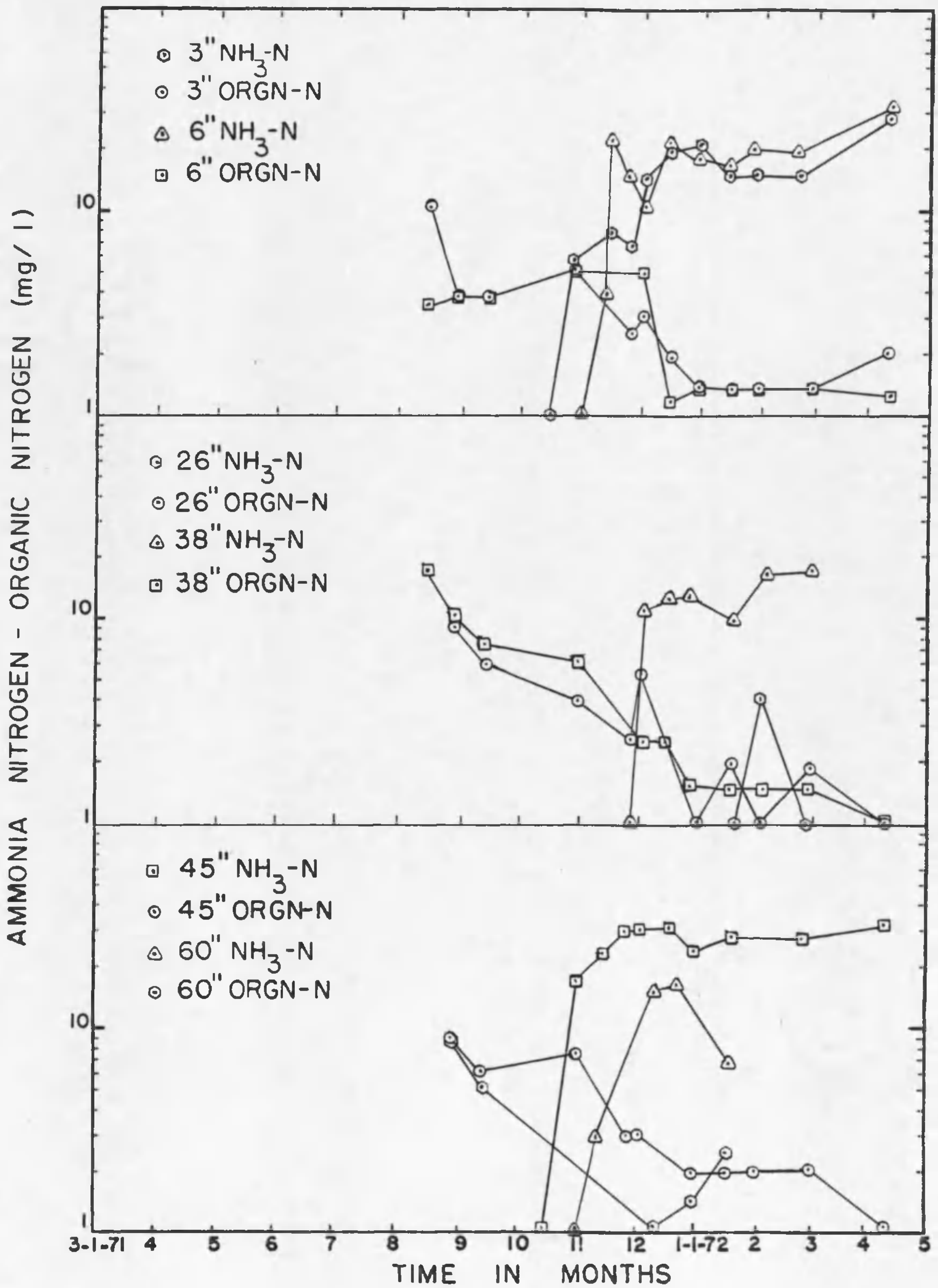

Figure 13. Percolating Ammonia and Organic Nitrogen Concentrations Under Pond on West Side

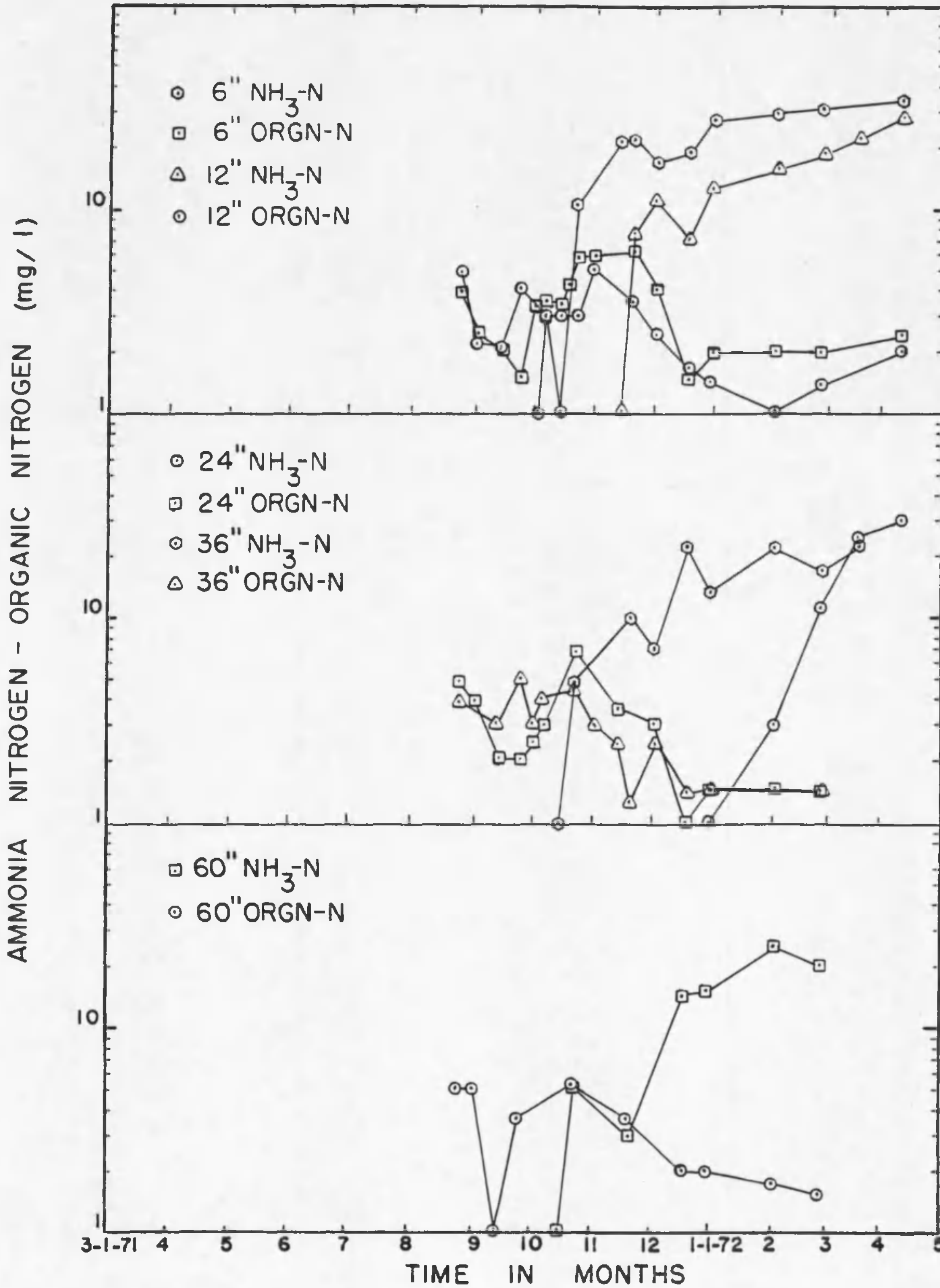

Figure 14. Percolating Ammonia and Organic Nitrogen Concentrations Under Pond on East Side

Table 4. Variations in Cation Exchange Capacity and Ammonia Nitrogen with Soil Depth

Soil Horizon Depth (in.)	CEC (meq/100 g)	East Side Mean NH_3-N (mg/l)	West Side Mean NH_3-N (mg/l)
0-6	7.8	--	15.8
6-12	8.2	21.1	21.2
12-24	9.8	11.32	--
24-36	12.6	5.43	1.25
36-48	9.0	14.54	8.99

found. That NH_3-N is affected by the CEC is shown by a correlation analysis whereby the west side of the pond showed r = -0.89 and the east side showed r = -0.94.

Nitrite Nitrogen

This form of nitrogen quickly diminished to insignificant concentrations and from September, 1971, on were not detected (Figures 15 and 16).

Organic Nitrogen

Organic-N had a mean concentration of about 8 mg/l initially on the west and about 5 mg/l on the east. These values were gradually reduced to about 2 mg/l. This indicates that organic compounds are being assimilated as benthic deposits develop, allowing only soluble constituents through (Figures 13 and 14).

Nitrate Nitrogen

When NO_3-N analyses were first performed, the results showed extremely high concentrations (100 mg/l), but these quickly dropped to 5 mg/l and leveled off for about a month. This level was then followed by a steady decline to less than 1 mg/l (Figures 15 and 16).

Initial loss of NO_3-N was due to a loss of residual nitrates, previously stored in the soil. The level mid-portion of the curves may represent an equilibrium period wherein the NO_3-N level of the pond (Figure 12) was

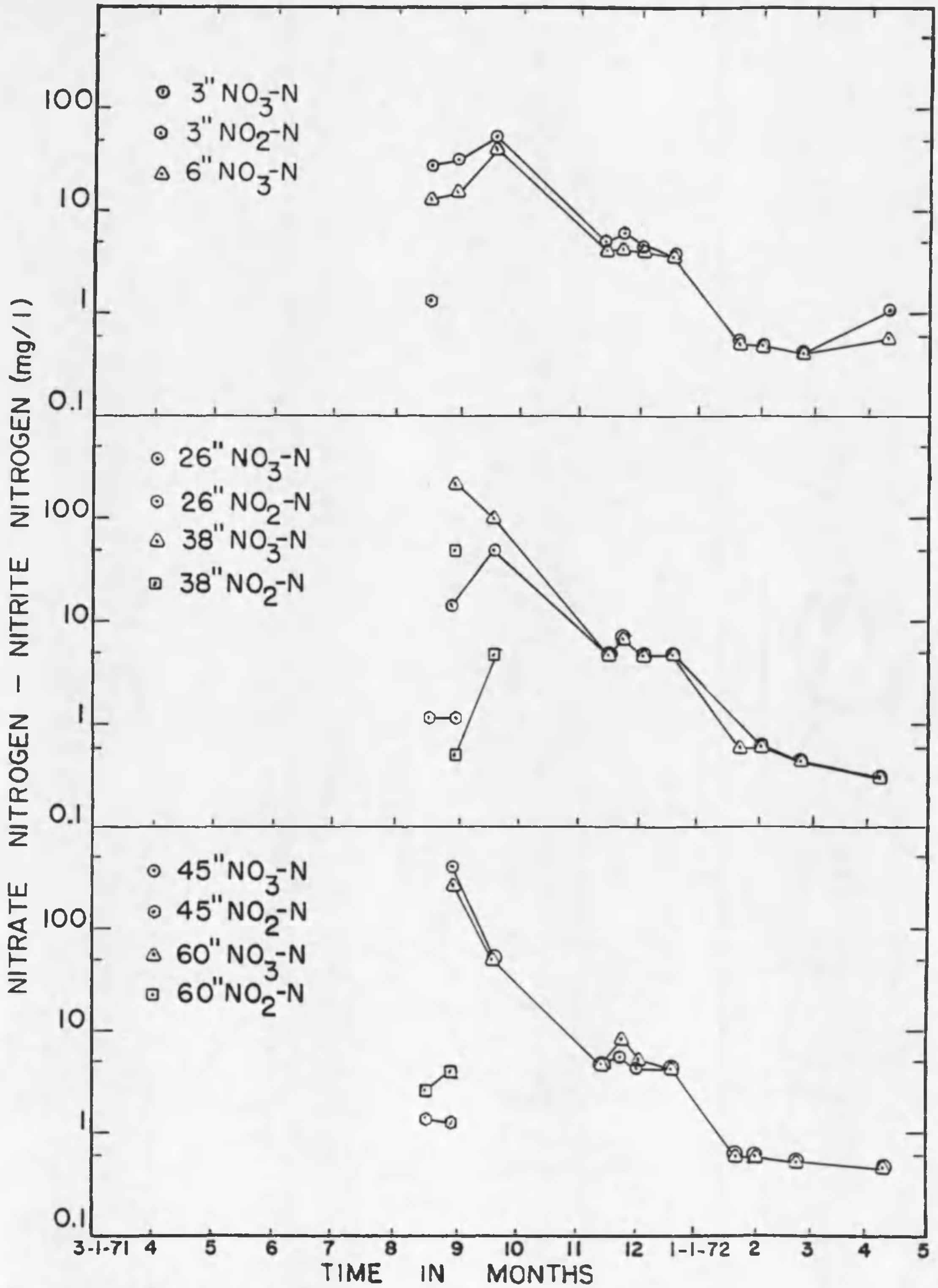

Figure 15. Percolating Nitrate and Nitrite Nitrogen Concentrations Under Pond on West Side

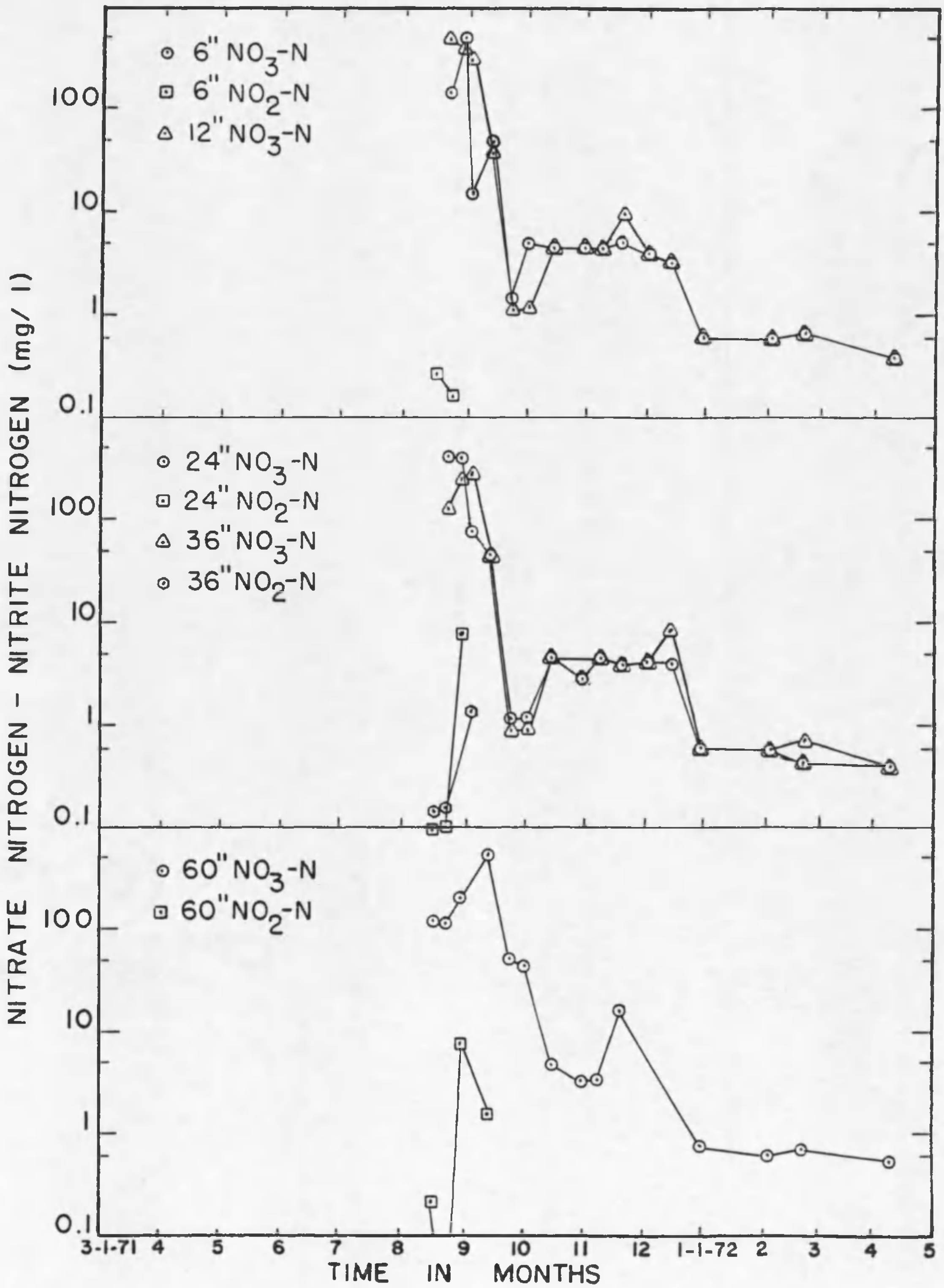

Figure 16. Percolating Nitrate and Nitrite Nitrogen Concentrations Under Pond on East Side

unaffected before infiltration. As the organic material accumulated at the pond bottom, denitrification was possible with the end products of anaerobic decomposition serving as the carbon source.

Total Nitrogen

Total-N data, as represented by the curves of Figures 17 and 18, can be interpreted in light of the component data curves. The total-N was initially very high due to the very high NO_3-N which subsequently declined as soil NO_3-N was depleted.

This decrease in NO_3-N resulted in a falling total nitrogen curve. Total nitrogen then recovered over the next six months due primarily to the steady increase in NH_3-N. Here again the anomaly of the 24-in and 26-in NH_3-N samples is clearly shown as the west side 24-in curve recovered only after the ammonia finally broke through near the study's end.

From Figure 9 it can be seen that total-N for surface water samples remained at about 40 mg/l while total-N detected in the tensiometer cups averaged approximately 25 mg/l. Much of this nitrogen reduction results from entrapment of organic-N at the soil-water interface. Additional nitrogen is removed from the infiltrate as the soil's CEC is exercised, and NH_3-N is adsorbed.

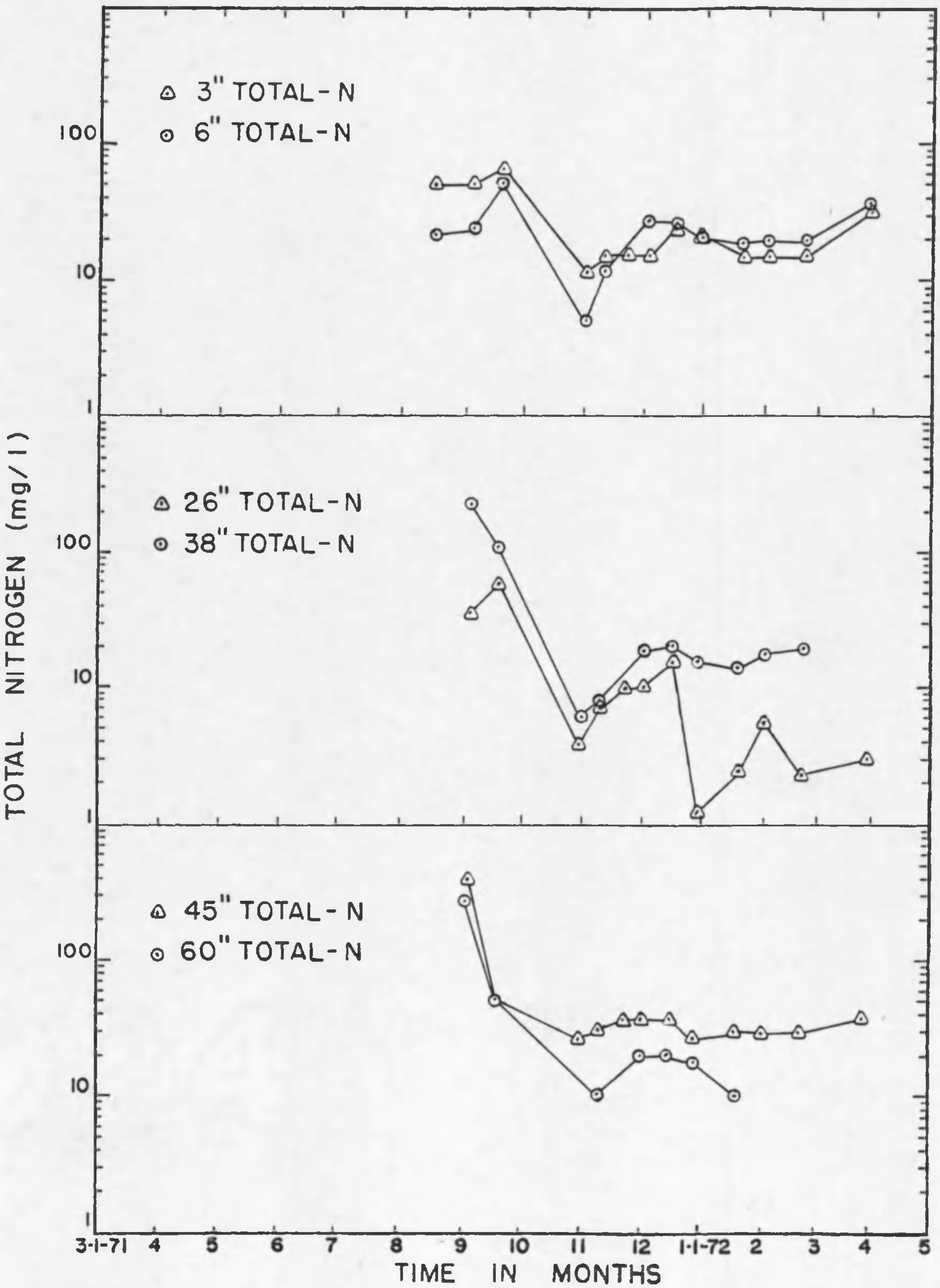

Figure 17. Percolating Total Nitrogen Concentration Under Pond on West Side

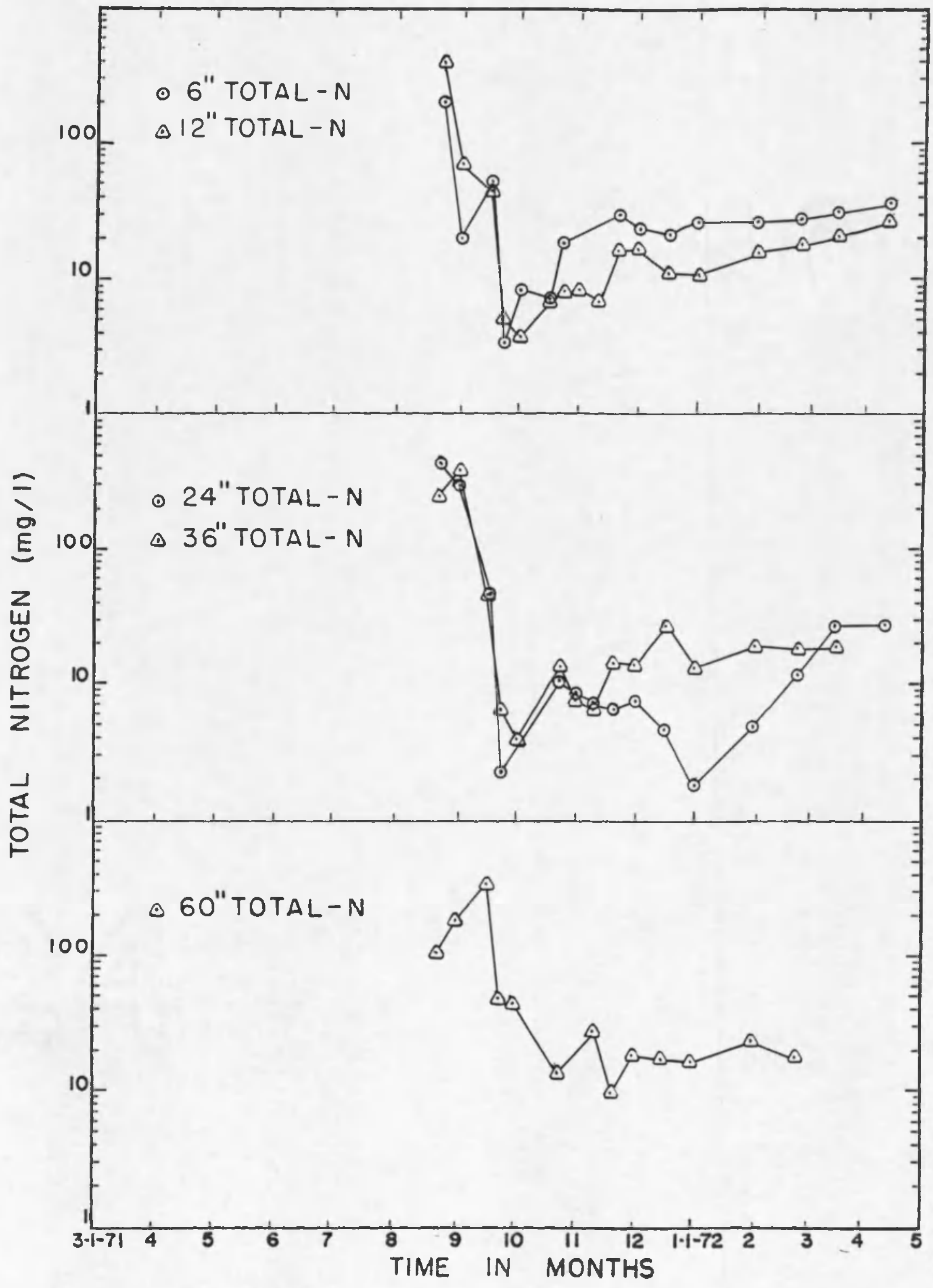

Figure 18. Percolating Total Nitrogen Concentration Under Pond on East Side

Infiltration and Groundwater Movement

With the sandy loam soil and lack of special action taken for sealing the pond bottom, there was initially high infiltration. Figure 19 depicts daily rates with the average infiltration rate being about 0.23 cm/hr. Deming (1963) found the rate to be 0.0015 cm/hr in wastewater pond No. 3 immediately east of the subject pond. Pond No. 3 was sealed with a clay blanket when constructed so seepage has probably always been relatively lower than in pond No. 4.

The rate of infiltration for pond No. 4 could eventually decrease to that of the neighboring pond if enough time were to elapse. From Figure 19, there is no apparent decline in the seepage rate during this short term evaluation. Furthermore, a slight positive slope was found in the linear regression curve for infiltration data. A value of 0.02 was computed for (r^2) which indicates that the infiltration rate was virtually unrelated to time over the period of study.

Water level and moisture logger studies were inconclusive. The influence of the Santa Cruz River flow and the cone of depression from well 1F negated the possibility of firm conclusions on lateral spreading of pond effluent.

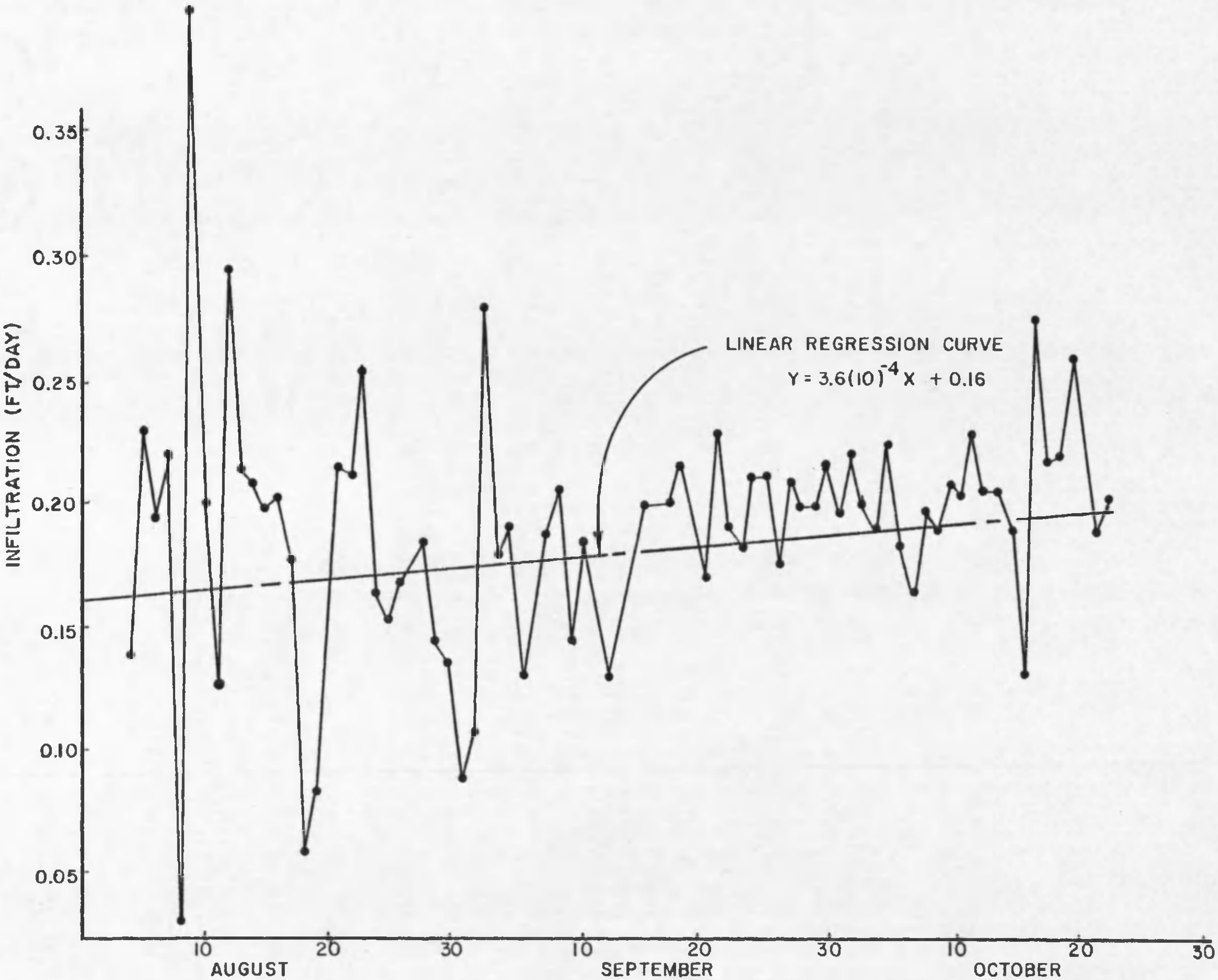

Figure 19. Pond Infiltration Rates -- After Small (1973).

CHAPTER 5

GENERAL DISCUSSION

Data from the observation wells were intended to indicate possible alterations in the groundwater, arising from the initiation of a sewage stabilization pond. Consideration of the deep well data indicates that the pond apparently had no adverse effect on groundwater quality. However, the quantity of wastewater infiltrating from the pond was so slight as to be inconsequential in comparison to the millions of gallons of secondary effluent which daily flow down the Santa Cruz River from the City of Tucson sewage treatment plant. Even the large initial pulse of NO_3^-, a mobile ion, was masked by dilution and went undetected in well water samples.

Pond start-up did result in some high infiltrate chemical concentrations but the early infiltration rate, which should diminish, appears to ameliorate the pond's effects on the groundwater mass.

The more shallow observations wells straddle the normal water table, with one ending below and the other above the saturated zone. Samples from these wells might have been expected to yield more direct evidence of the pond's polluting effects, but the data from wells 1I and 2I seem primarily related to rainfall runoff events in the nearby Santa Cruz River.

Results from well 1I are difficult to assess since the level was often too low to obtain any sample. Water levels in well 2I maintained a useful minimum level which rose coincident with Santa Cruz River runoff events. Also coincident was a peak in chlorides and hardness corresponding to the high levels present in runoff water. After the last runoff events, chlorides began to decline and this continued through the last sample run.

The shallow sampling cups were intended to give information on nitrogen transformations in the first 5 ft below the pond bottom from the time the pond was brought on line until it was operating in steady state.

Immediately after the introduction of sewage to the pond, there was a very high concentration of nitrate nitrogen in tensiometer cup samples. From the soil analysis it is evident that there is a large quantity of nitrate existing in the soil which may reach a concentration of over 300 mg/l. This resident nitrate was flushed out of the upper soil strata and eventually infiltrate NO_3-N concentrations reached the minimum detectable. Initially high nitrite concentrations dropped to undetectable levels almost immediately after pond filling began, presumably a result of NO_2-N reduction to N_2 or NH_3-N.

In the first few months of sampling, the ammonia levels remained near zero mg/l. Then as the pond sediments and deeper water became anaerobic, the ammonia concentration increased rapidly to relatively high levels as nitrification ceased. At about the 24-in sampling depth, an anomaly occurred on both sides of the pond. West side 26-in deep samples never indicated ammonia concentrations above initial minimum levels and east side 24-in concentrations lagged by four months, then displayed a sudden increase in ammonia which raised the concentration to the range of that from the other sampling depths. There was a very high correlation of mean ammonia concentration to CEC for the various sampling depths. This combined with the breakthrough evidenced by the rapid rise of the curves in Figures 14 and 15, indicates that cation exchange theory applies. Therefore, one might hypothesize that had the study continued, the west side 26-in level would have eventually shown a typical breakthrough.

At present rates (Figures 10 and 11), the total quantity of nitrogen infiltrating is quite small, about 26 kg/day (9.8 acre x 0.18 ft/day x 12 mg/l x 1.23 = 26 kg/day). This is about 2 per cent of the amount being pumped out of the ground when well 1F is being operated (10,000 gpm x 25 mg/l x 0.00558 = 1395 kg/day). Projections based on Deming's (1963) work indicate that the infiltration rate will continue to decline.

With the low NO_3-, NO_2-, and organic-N concentration, the primary source of potential nitrogen pollution of the ground water is NH_3-N. Introduction of NH_3-N to the groundwater will be delayed as the water table is deep and with infiltrate spreading horizontally, a large volume of soil is available for adsorption of this cation.

CHAPTER 6

CONCLUSIONS

Considering the data of wells 1E, 3I, and 1F, it is apparent that there has been no detectable biological or chemical alteration of the groundwater resulting from establishment of pond No. 4. Fecal coliform bacteria in the well samples remained less than one/100 ml throughout the entire study. COD was initially very low and apparently declined slightly over the period of the study, while pH and temperature remained nearly constant.

pH, fecal coliform, total hardness, total phosphate, chloride, and total nitrogen concentrations in the deep wells, 3I and 1F, varied by achieved values after a year nearly equal to initial values (Table 5).

Santa Cruz River runoff events and the influence of well 1F negated the possibility of a firm conclusion on lateral spreading of infiltrate from the pond. Chloride data, however, did indicate that in some strata the horizontal velocities may be as high as 200 ft/day.

Table 5. Initial and Final Water Sample Analysis Values

	Pond Surface[a]		Well 1I[b]		Well 2I[c]		Well 3I[d]		Well 1F[e]	
	Init.	Fin.	Init.	Fin.	Init.	Fin.	Init.	Fin.	Init.	Fin.
COD (mg/l)	150	--	12.2	9.7	40	0	9.5	20	9.5	9.5
Total Coliform (no/100 ml)	10^5	--	14.0	<1	<1	--	800	20	<1	<1
Fecal Coliform (no/100 ml)	10^5	--	<1.0	<1	<1	<1	<1	<1	<1	<1
pH	8.4	7.4	7.2	8.1	7.1	7.1	8.2	7.4	7.1	7.0
Alkalinity*	173.0	305.0	358.0	436.0	303.0	384.0	178.0	92.6	262.0	289.0
Total Hardness*	128.0	180.0	220.0	294.0	205.0	248.0	238.0	236.0	364.0	360.0
Calcium*	31.0	72.0	164.0	218.0	77.0	246.0	47.2	108.0	97.6	134.0
Chloride (mg/l)	59.0	9.0	13.0	12.0	90.0	4.0	21.5	29.0	22.2	10.0
Total Phosphate (mg/l)	29.0	42.5	3.7	52.0	6.7	24.3	0.13	0.9	1.05	2.0
Ammonia-N (mg/l)	9.0	24.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0
Organic-N (mg/l)	4.2	14.3	0.0	0.8	0.0	1.1	T	1.4	0.0	6.5
NO_2+NO_3-N (mg/l)	0.7	0.3	135.0	17.0	39.0	14.0	0.48	0.4	25.0	17.0
Total -N (mg/l)	14.1	38.6	135.0	17.8	39.0	15.1	0.48	4.5	25.0	23.5

Table 5.--Continued

*As mg/l $CaCO_3$

[a] Init. 8-12-71 Fin. 4-12-72

[b] Init. 8-26-71 Fin. 12-1-71

[c] Init. 8-12-71 Fin. 4-12-72

[d] Init. 3-18-71 Fin. 4-12-72

[e] Init. 3-18-71 Fin. 4-12-72

APPENDIX A

BASIC DATA FOR WELL AND POND WATER SAMPLES

Date: 3-18-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	9.5	9.5	19.0
Total Coliform (No./100ml)	--	--	--	800	<1	5,000
Fecal Coliform (No./100ml)	--	--	--	<1	<1	<1
pH	--	--	--	8.2	7.1	7.8
Alkalinity*	--	--	--	178.0	262.0	250.0
Total Hardness*	--	--	--	238.0	364.0	--
Calcium*	--	--	--	47.2	97.6	84.0
Chloride (mg/l)	--	--	--	21.5	22.2	22.5
Total Phosphate (mg/l)	--	--	--	0.13	1.05	0.25
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	T	0	0
Nitrate-N (mg/l)	--	--	--	0.48	25.0	0.35
Nitrite-N (µg/l)	--	--	--	40.0	14.0	38.0

*As mg/l $CaCO_3$

Date: 3-25-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	7.5	7.1	7.3
Alkalinity*	--	--	--	240.0	268.0	268.0
Total Hardness*	--	--	--	235.0	365.0	320.0
Calcium*	--	--	--	43.0	92.0	74.0
Chloride (mg/l)	--	--	--	21.5	22.5	22.5
Total Phosphate (mg/l)	--	--	--	0.17	0.90	0.70
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.50	37.0	0.50
Nitrite-N (μg/l)	--	--	--	10.0	16.0	104.0

*As mg/l $CaCO_3$

Date: 4-1-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	10.1	10.8	10.4
Total Coliform (No./100ml)	--	--	--	<10	<1	<10
Fecal Coliform (No./100ml)	--	--	--	<1	<1	<1
pH	--	--	--	7.8	7.1	7.7
Alkalinity*	--	--	--	220.0	270.0	260.0
Total Hardness*	--	--	--	240.0	380.0	285.0
Calcium*	--	--	--	56.0	76.0	67.0
Chloride (mg/l)	--	--	--	21.5	23.0	22.5
Total Phosphate (mg/l)	--	--	--	0.13	0.80	0.10
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.46	26.0	0.40
Nitrite-N (μg/l)	--	--	--	103.0	10.0	58.0

*As mg/l $CaCO_3$

Date: 4-8-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	9.7	11.0	9.3
Total Coliform (No./100ml)	--	--	--	<10	<10	<10
Fecal Coliform (No./100ml)	--	--	--	<1	<1	<1
pH	--	--	--	7.7	7.2	7.8
Alkalinity*	--	--	--	265.0	265.0	265.0
Total Hardness*	--	--	--	240.0	390.0	330.0
Calcium*	--	--	--	50.0	80.0	71.0
Chloride (mg/l)	--	--	--	21.5	21.5	23.5
Total Phosphate (mg/l)	--	--	--	0.13	1.20	0.25
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.52	26.0	0.38
Nitrite-N (µg/l)	--	--	--	200.0	10.0	--

*As mg/l $CaCO_3$

Date: 4-15-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	9.9	10.5	10.4
Total Coliform (No./100ml)	--	--	--	200	<1	720
Fecal Coliform (No./100ml)	--	--	--	<1	<1	<1
pH	--	--	--	7.9	7.4	7.9
Alkalinity*	--	--	--	270.0	350.0	260.0
Total Hardness*	--	--	--	270.0	--	260.0
Calcium*	--	--	--	23.0	56.0	70.0
Chloride (mg/l)	--	--	--	68.0	79.0	81.0
Total Phosphate (mg/l)	--	--	--	0.15	1.05	0.33
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.46	34.0	0.50
Nitrite-N (µg/l)	--	--	--	73.0	10.0	82.0

*As mg/l $CaCO_3$

Date: 4-22-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	10.6	10.8	10.6
Total Coliform (No./100ml)	--	--	--	<10	<10	<10
Fecal Coliform (No./100ml)	--	--	--	0	0	0
pH	--	--	--	7.5	7.1	7.8
Alkalinity*	--	--	--	260.0	270.0	270.0
Total Hardness*	--	--	--	305.0	320.0	320.0
Calcium*	--	--	--	47.0	92.0	70.0
Chloride (mg/l)	--	--	--	69.0	80.0	81.0
Total Phosphate (mg/l)	--	--	--	0.15	0.80	0.20
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.46	38.0	0.46
Nitrite-N (µg/l)	--	--	--	--	10.0	--

*As mg/l $CaCO_3$

Date: 4-29-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	9.8	10.0	9.8
Total Coliform (No./100ml)	--	--	--	<10	<10	<10
Fecal Coliform (No./100ml)	--	--	--	0	0	0
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	250.0	260.0	230.0
Total Hardness*	--	--	--	230.0	255.0	255.0
Calcium*	--	--	--	72.0	56.0	88.0
Chloride (mg/l)	--	--	--	67.0	82.0	82.0
Total Phosphate (mg/l)	--	--	--	0.13	1.05	0.33
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.50	44.0	0.44
Nitrite-N (µg/l)	--	--	--	40.0	--	14.0

*As mg/l $CaCO_3$

Date: 5-6-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	215.0	260.0	230.0
Total Hardness*	--	--	--	210.0	230.0	260.0
Calcium*	--	--	--	32.0	120.0	47.0
Chloride (mg/l)	--	--	--	45.0	47.0	47.0
Total Phosphate (mg/l)	--	--	--	TR	0.74	0.16
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.46	39.0	0.38
Nitrite-N (μg/l)	--	--	--	45.0	28.0	30.0

*As mg/l $CaCO_3$

Date: 6-3-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	<1	<1	<1
Fecal Coliform (No./100ml)	--	--	--	0	0	0
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	200.0	270.0	175.0
Total Hardness*	--	--	--	102.0	370.0	44.0
Calcium*	--	--	--	20.0	110.0	14.0
Chloride (mg/l)	--	--	--	34.5	42.0	43.0
Total Phosphate (mg/l)	--	--	--	TR	--	1.35
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	0	0	0
Nitrate-N (mg/l)	--	--	--	0.45	36.0	0.45
Nitrite-N (μg/l)	--	--	--	54.0	10.0	29.0

*As mg/l $CaCO_3$

Date: 7-19-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	8.8	7.4	9.5
Alkalinity*	--	--	--	185.0	202.0	172.0
Total Hardness*	--	--	--	99.0	265.0	70.0
Calcium*	--	--	--	41.0	170.0	38.0
Chloride (mg/l)	--	--	--	17.0	18.0	19.0
Total Phosphate (mg/l)	--	--	--	TR	0.64	--
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	1.0	0	3.0
Nitrate-N (mg/l)	--	--	--	0.40	20.0	0.38
Nitrite-N (µg/l)	--	--	--	45.0	0	12.0

*As mg/l $CaCO_3$

Date: 7-22-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	8.0	7.4	9.0
Alkalinity*	--	--	--	185.0	205.0	162.0
Total Hardness*	--	--	--	70.0	270.0	--
Calcium*	--	--	--	63.0	170.0	43.0
Chloride (mg/l)	--	--	--	78.0	89.0	91.0
Total Phosphate (mg/l)	--	--	--	TR	0.64	1.90
Ammonia-N (mg/l)	--	--	--	0	0	0
Organic-N (mg/l)	--	--	--	1.5	0	4.2
Nitrate-N (mg/l)	--	--	--	0.40	18	0.40
Nitrite-N (μg/l)	--	--	--	45.0	0	45.0

*As mg/l $CaCO_3$

Date: 8-12-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	150.0	--	40.0	--	--	--
Total Coliform (No./100ml)	10^5	--	<1	--	--	--
Fecal Coliform (No./100ml)	10^5	--	<1	--	--	--
pH	8.4	--	7.1	8.0	--	8.4
Alkalinity*	173.0	--	303.0	180.0	--	175.0
Total Hardness*	128.0	--	205.0	220.0	--	240.0
Calcium*	31.0	--	77.0	86.0	--	120.0
Chloride (mg/l)	59.0	--	90.0	79.0	76.0	--
Total Phosphate (mg/l)	29.0	--	6.7	TR	--	0.38
Ammonia-N (mg/l)	9.0	0	0	0	--	0
Organic-N (mg/l)	4.2	0	0	--	--	--
Nitrate-N (mg/l)	0.68	--	39.0	11.0	--	0.40
Nitrite-N (μg/l)	0	--	54.0	76.0	--	--

*As mg/l $CaCO_3$

Date: 8-19-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	--	--	--
Total Hardness*	--	--	--	--	--	--
Calcium*	--	--	--	--	--	--
Chloride (mg/l)	--	--	--	--	--	--
Total Phosphate (mg/l)	39.5	3.70	10.0	TR	--	--
Ammonia-N (mg/l)	0.50	0	0	0	--	0
Organic-N (mg/l)	24.5	0	0	3.0	--	--
Nitrate-N (mg/l)	15.0	104.0	55.0	0.50	--	0.40
Nitrite-N (µg/l)	0	20.5	2.0	14.0	--	--

*As mg/l $CaCO_3$

Date: 8-26-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	12.2	12.8	12.6	--	12.7
Total Coliform (No./100ml)	--	14	1	<1	--	2
Fecal Coliform (No./100ml)	--	<1	<1	<1	--	<1
pH	--	7.2	7.8	7.6	--	7.7
Alkalinity*	--	358.0	290.0	220.0	--	240.0
Total Hardness*	--	220.0	--	315.0	--	270.0
Calcium*	--	164.0	--	160.0	--	76.0
Chloride (mg/l)	--	13.0	88.0	75.0	--	78.0
Total Phosphate (mg/l)	--	3.70	10.0	TR	--	0.20
Ammonia-N (mg/l)	2.5	0	0	1.9	--	0
Organic-N (mg/l)	20.1	0	0	0	--	1.10
Nitrate-N (mg/l)	7.40	80.0	54.0	0.44	--	0.40
Nitrite-N (µg/l)	0	100.0	340.0	14.0	--	10.0

*As mg/l $CaCO_3$

Date: 9-2-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	8.7	13.9	13.1	13.6	--	14.2
Total Coliform (No./100ml)	--	--	--	<1	--	<1
Fecal Coliform (No./100ml)	--	--	--	<1	--	<1
pH	8.6	7.6	7.3	7.9	7.3	7.3
Alkalinity*	--	390.0	305.0	180.0	--	215.0
Total Hardness*	--	--	--	--	--	--
Calcium*	--	--	--	--	--	--
Chloride (mg/l)	--	15.0	325.0	81.0	--	79.0
Total Phosphate (mg/l)	--	3.70	10.0	TR	--	TR
Ammonia-N (mg/l)	1.4	0	0	0	--	0
Organic-N (mg/l)	27.3	0	0	2.2	--	1.8
Nitrate-N (mg/l)	--	75.0	57.0	--	--	--
Nitrite-N (µg/l)	--	2,200	12,500	--	--	--

*As mg/l $CaCO_3$

Date: 9-15-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	--	--	--
Total Hardness*	--	305.0	750.0	230.0	--	215.0
Calcium*	--	225.0	650.0	130.0	--	160.0
Chloride (mg/l)	--	--	--	--	--	--
Total Phosphate (mg/l)	--	--	--	--	--	--
Ammonia-N (mg/l)	12.8	0	0	0	--	0
Organic-N (mg/l)	15.5	0	0	4.0	--	1.8
Nitrate-N (mg/l)	1.90	18.0	18.0	25.0	--	25.0
Nitrite-N (µg/l)	0	10.0	10.0	10.0	--	0

*As mg/l $CaCO_3$

Date: 9-22-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	<1	--	<1
Fecal Coliform (No./100ml)	--	--	--	<1	--	<1
pH	--	7.5	7.0	8.2	--	8.2
Alkalinity*	--	370.0	380.0	150.0	--	155.0
Total Hardness*	--	280.0	800.0	180.0	--	180.0
Calcium*	--	220.0	650.0	100.0	--	102.0
Chloride (mg/l)	--	40.0	460.0	89.0	--	82.0
Total Phosphate (mg/l)	--	9.0	9.0	TR	--	TR
Ammonia-N (mg/l)	--	0	0	0	--	0
Organic-N (mg/l)	--	0	0	--	--	--
Nitrate-N (mg/l)	4.40	8.0	32.0	1.35	--	1.40
Nitrite-N (μg/l)	0	0	0	0	--	0

*As mg/l $CaCO_3$

Date: 9-29-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	--	--	--
Total Hardness*	--	--	--	--	--	--
Calcium*	--	--	--	--	--	--
Chloride (mg/l)	--	--	--	--	--	--
Total Phosphate (mg/l)	--	--	--	--	--	--
Ammonia-N (mg/l)	20.3	0	0	2.2	--	--
Organic-N (mg/l)	13.5	0	0	2.2	--	1.8
Nitrate-N (mg/l)	1.90	9.0	21.0	1.50	--	1.50
Nitrite-N (μg/l)	0	0	0	0	--	0

*As mg/l $CaCO_3$

Date: 10-6-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	9.7	10.2	9.5	--	9.7
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	7.8	7.0	8.1	--	8.4
Alkalinity*	--	375.0	450.0	130.0	--	135.0
Total Hardness*	--	290.0	380.0	250.0	--	165.0
Calcium*	--	220.0	250.0	100.0	--	77.0
Chloride (mg/l)	--	8.0	240.0	123.0	--	--
Total Phosphate (mg/l)	--	--	--	10.0	--	6.00
Ammonia-N (mg/l)	--	0	0	2.0	--	1.9
Organic-N (mg/l)	--	0	0	2.5	--	1.7
Nitrate-N (mg/l)	--	--	--	--	--	--
Nitrite-N (µg/l)	--	--	--	--	--	--

*As mg/l $CaCO_3$

Date: 10-15-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	--	--	--
Total Hardness*	--	--	--	--	--	--
Calcium*	--	--	--	--	--	--
Chloride (mg/l)	--	--	--	--	--	--
Total Phosphate (mg/l)	--	--	--	--	--	--
Ammonia-N (mg/l)	--	--	--	--	--	--
Organic-N (mg/l)	--	--	--	2.8	--	--
Nitrate-N (mg/l)	--	53.0	26.0	1.0	--	--
Nitrite-N (μg/l)	--	0	0	0	--	--

*As mg/l $CaCO_3$

Date: 12-1-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	9.7	10.0	9.7	--	9.2
Total Coliform (No./100ml)	--	<1	--	--	--	--
Fecal Coliform (No./100ml)	--	<1	--	--	--	--
pH	8.2	8.1	7.0	8.5	--	8.3
Alkalinity*	--	435.0	450.0	44.0	--	94.0
Total Hardness*	--	294.0	230.0	150.0	--	120.0
Calcium*	--	218.0	120.0	110.0	--	41.0
Chloride (mg/l)	--	12.0	12.0	23.0	--	--
Total Phosphate (mg/l)	48.0	52.0	60.0	1.70	--	0.17
Ammonia-N (mg/l)	22.5	0	0	2.8	--	0.3
Organic-N (mg/l)	3.0	0	0	2.0	--	1.4
Nitrate-N (mg/l)	--	17.0	52.0	0.80	--	0.88
Nitrite-N (µg/l)	--	0	0	0	--	0

*As mg/l $CaCO_3$

Date: 12-29-71

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	11.0	11.9	11.9	10.1	--	11.7
Total Coliform (No./100ml)	--	--	--	<1	--	<1
Fecal Coliform (No./100ml)	--	<1	<1	<1	<1	<1
pH	--	--	7.0	8.2	--	8.2
Alkalinity*	--	--	470.0	40.0	--	88.0
Total Hardness*	--	--	300.0	--	--	215.0
Calcium*	--	--	230.0	--	--	23.0
Chloride (mg/l)	--	10.0	10.0	17.0	--	7.0
Total Phosphate (mg/l)	--	--	60.0	--	--	--
Ammonia-N (mg/l)	--	0	0	3.4	--	0
Organic-N (mg/l)	--	0	0	1.8	--	1.8
Nitrate-N (mg/l)	--	--	--	--	--	0.50
Nitrite-N (µg/l)	--	--	--	--	--	0

*As mg/l $CaCO_3$

Date: 2-2-72

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	--	--	--
Total Hardness*	--	--	--	--	--	--
Calcium*	--	--	--	--	--	--
Chloride (mg/l)	--	--	--	--	--	--
Total Phosphate (mg/l)	48.0	--	--	--	--	--
Ammonia-N (mg/l)	27.5	0	0	--	--	--
Organic-N (mg/l)	10.3	0	0	--	--	--
Nitrate-N (mg/l)	0.5	--	--	--	--	--
Nitrite-N (μg/l)	0	--	--	--	--	--

*As mg/l $CaCO_3$

Date: 2-10-72

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	--	--	--
Total Hardness*	--	--	--	--	--	--
Calcium*	--	--	--	--	--	--
Chloride (mg/l)	--	--	--	--	--	--
Total Phosphate (mg/l)	29.0	--	25.0	--	--	--
Ammonia-N (mg/l)	24.6	0	0	4.9	--	--
Organic-N (mg/l)	11.0	0	0	1.0	--	--
Nitrate-N (mg/l)	0.30	--	15.0	0.50	--	0.30
Nitrite-N (µg/l)	0	--	0	0	--	0

*As mg/l $CaCO_3$

Date: 3-1-72

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	--	--	--	--
Total Coliform (No./100ml)	--	--	--	--	--	--
Fecal Coliform (No./100ml)	--	--	--	--	--	--
pH	--	--	--	--	--	--
Alkalinity*	--	--	--	--	--	--
Total Hardness*	--	--	--	--	--	--
Calcium*	--	--	--	--	--	--
Chloride (mg/l)	--	--	--	--	--	--
Total Phosphate (mg/l)	48.0	--	27.0	0.15	--	--
Ammonia-N (mg/l)	26.5	--	--	4.8	--	--
Organic-N (mg/l)	10.8	--	--	0.3	--	--
Nitrate-N (mg/l)	0.30	--	18.0	0.30	--	--
Nitrite-N (µg/l)	0	--	0	--	--	--

*As mg/l $CaCO_3$

Date: 4-12-72

	Surface	1I	2I	3I	1F	1E
COD (mg/l)	--	--	0	20	9.5	--
Total Coliform (No./100ml)	--	--	--	20	<1	--
Fecal Coliform (No./100ml)	--	--	--	<1	<1	--
pH	7.4	--	7.1	7.4	7.0	--
Alkalinity*	305.0	--	384.0	92.6	289.0	--
Total Hardness*	180.0	--	248.0	236.0	360.0	--
Calcium*	72.0	--	246.0	108.0	134.0	--
Chloride (mg/l)	9.0	--	4.0	29.0	10.0	--
Total Phosphate (mg/l)	42.5	--	24.3	0.9	2.0	--
Ammonia-N (mg/l)	24.0	--	0.0	2.7	0.0	--
Organic-N (mg/l)	14.3	--	1.1	1.4	6.5	--
Nitrate-N (mg/l)	0.30	--	14.0	0.40	17.0	--
Nitrite-N (μg/l)	0	--	0	0	0	--

*As mg/l $CaCO_3$

APPENDIX B

BASIC DATA FOR TENSIOMETER CUP DATA

Date: 8-12-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	0	10.5	39.0	2,200
6	0	3.5	18.0	1,500
26	0	--	--	1,200
38	0	18.5	--	--
45	0	--	--	1,800
60	0	--	--	2,500
East side tensiometer cups (in. deep)				
6	--	--	--	--
12	--	--	--	--
24	--	--	--	--
36	--	--	--	--
60	--	--	--	--

Date: 8-19-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	--	--	210.0	145.0
12	--	--	420.0	340.0
24	--	--	420.0	240.0
36	--	--	240.0	110.0
60	--	--	120.0	340.0

Date: 8-26-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	0	4.1	450.0	25.0
12	0	4.75	400.0	220.0
24	0	4.75	400.0	240.0
36	0	4.1	340.0	125.0
60	0	5.0	110.0	28.0

Date: 9-2-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	0	4.0	44.0	0
6	0	4.0	24.0	0
26	0	9.0	24.0	1200
38	0	10.0	210.0	500
45	0	9.0	360.0	1350
60	0	9.0	260.0	3400
East side tensiometer cups (in. deep)				
6	--	--	20.0	40.0
12	--	--	300.0	820.0
24	--	--	72.0	1500.0
36	--	--	380.0	640.0
60	--	--	180.0	8800.0

Date: 9-15-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	0	4.2	60.0	0
6	0	4.5	54.0	0
26	0	6.0	50.0	0
38	0	7.5	100.0	4000
45	0	6.2	46.0	28.0
60	0	5.0	48.0	100.0
East side tensiometer cups (in. deep)				
6	0	2.2	54.0	560.0
12	0	2.2	45.0	--
24	0	2.2	45.0	--
36	0	2.9	45.0	--
60	0	0	360.0	2600

Date: 9-22-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	0	1.75	2.0	0
12	0	4.0	1.4	0
24	0	2.0	1.5	0
36	0	4.9	1.3	0
60	0	3.0	50.0	0

Date: 9-29-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	0	3.4	5.4	0
12	0	2.9	1.4	0
24	0	2.5	1.6	0
36	0	2.5	1.6	0
60	0	--	44.0	0

Date: 10-6-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	2.75	3.25	--	--
12	0	2.75	--	--
24	0	2.75	--	--
36	0	4.25	--	--
60	0	--	--	--

Date: 10-15-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	0	3.5	4.5	0
12	0	3.0	4.5	0
24	0	--	4.5	0
36	0	--	4.5	0
60	0	--	4.5	0

Date: 10-20-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	10.8	5.6	--	--
12	0	0	--	--
24	0.8	6.5	--	--
36	4.5	4.5	--	--
60	5.5	5.3	3.5	0

Date: 11-1-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	6.0	5.5	--	--
6	0	5.5	--	--
26	0	4.0	--	--
38	0	6.2	--	--
45	17.0	7.5	--	--
60	0	--	--	--
East side tensiometer cups (in. deep)				
6	--	5.5	4.5	0
12	0	--	4.5	0
24	0	--	3.8	0
36	--	3.2	4.5	0
60	--	--	3.4	0

Date: 11-10-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	8.2	--	5.4	0
6	6.3	--	4.4	0
26	0	--	3.8	0
38	0	--	4.6	0
45	24.0	--	4.2	0
60	2.8	--	4.6	0
East side tensiometer cups (in. deep)				
6	22.0	3.5	4.5	0
12	0	3.5	4.5	0
24	0	3.5	5.0	0
36	--	2.5	4.6	0
60	--	--	24.0	0

Date: 11-17-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	22	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	21.0	5.9	5.0	0
12	7.6	1.7	8.4	0
24	0	2.9	4.5	0
36	9.9	1.4	4.5	0
60	3.2	2.5	--	--

Date: 11-24-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	7.5	2.5	7.3	0
6	14.0	--	5.0	0
26	0	2.5	6.9	0
38	0	--	7.3	0
45	27.0	3	5.4	0
60	--	2	8.6	0
East side tensiometer cups (in. deep)				
6	--	--	--	--
12	--	--	--	--
24	--	--	--	--
36	--	--	--	--
60	--	--	--	--

Date: 12-1-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	15.5	3.3	5.4	0
6	11.0	5.5	4.8	0
26	0	5.5	4.5	0
38	12.0	2.5	4.5	0
45	29.0	3.2	4.0	0
60	--	--	4.2	0
East side tensiometer cups (in. deep)				
6	16.5	4.0	4.5	0
12	11.0	2.5	4.5	0
24	0.8	2.9	4.5	0
36	7.0	2.5	5.0	0
60	--	--	--	--

Date: 12-15-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	18.5	2.0	4.0	0
6	20.0	1.5	4.0	0
26	0	--	4.5	0
38	12.5	2.0	4.0	0
45	29.0	--	4.0	0
60	15.0	1.5	4.0	0
East side tensiometer cups (in. deep)				
6	17.9	1.5	3.8	0
12	7.0	1.8	4.0	0
24	0	1.0	4.4	0
36	21.5	1.2	7.9	0
60	14.6	2.0	--	--

Date: 12-29-71

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	26.5	2.0	0.05	0
12	13.0	1.5	0.05	0
24	0	1.5	0.05	0
36	13.0	1.5	0.05	0
60	16.0	2.0	0.07	0

Date: 1-19-72

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	14.0	1.5	0.5	0
6	18.0	1.5	0.5	0
26	0	1.0	--	--
38	10.5	1.5	0.5	0
45	27.5	2.0	0.5	0
60	6.5	1.5	0.5	0
East side tensiometer cups (in. deep)				
6	--	--	--	--
12	--	--	--	--
24	--	--	--	--
36	--	--	--	--
60	--	--	--	--

Date: 2-2-72

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	16.0	1.5	0.5	0
6	21.0	1.5	0.5	0
26	4.8	1.0	0.5	0
38	16.5	1.5	0.5	0
45	27.5	1.75	0.5	0
60	--	--	0.5	0
East side tensiometer cups (in. deep)				
6	30.0	1.9	.05	0
12	15.5	1.0	.05	0
24	3.0	1.6	.05	0
36	21.0	1.5	.05	0
60	24.5	1.6	.05	0

Date: 2-23-72

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	16.0	1.5	0.4	0
6	20.5	1.5	0.4	0
26	0.4	1.5	0.4	0
38	7.5	1.5	0.4	0
45	27.3	2.0	0.4	0
60	--	--	0.4	0
East side tensiometer cups (in. deep)				
6	30.5	1.9	.06	0
12	18.5	1.5	.06	0
24	12.2	1.5	.04	0
36	17.5	1.5	.06	0
60	19.2	1.5	.06	0

Date: 3-15-72

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (μg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	33.7	--	--	--
12	21.0	--	--	--
24	22.5	--	--	--
36	21.5	--	--	--
60	--	--	--	--

Date: 3-29-72

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	29.0	2.75	1.20	0
6	32.5	1.4	0.60	0
26	0.5	1.0	0.35	0
38	--	0.5	--	--
45	31.5	1.0	0.35	0
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	--	--	--	--
12	--	--	--	--
24	--	--	--	--
36	--	--	--	--
60	--	--	--	--

Date: 4-12-72

	Ammonia-N (mg/l)	Organic-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (µg/l)
West side tensiometer cups (in. deep)				
3	--	--	--	--
6	--	--	--	--
26	--	--	--	--
38	--	--	--	--
45	--	--	--	--
60	--	--	--	--
East side tensiometer cups (in. deep)				
6	33.5	2.5	0.35	0
12	27.5	2.0	0.35	0
24	30.25	--	0.35	0
36	--	--	0.35	0
60	--	--	0.35	0

REFERENCES

APHA, AWWA, AND WPCF. Standard Methods for the Examination of Water and Wastewater. 13th ed. American Public Health Association, New York (1971).

Baars, J. K. "Experiences in the Netherlands with Contamination of Ground Water." Proceedings of 1961 Symposium, Ground Water Contamination, Robert A. Taft, Sanitary Engineering Center, USPHS Technical Report W61-5 (1961).

Berend, J. E. "An Analytical Approach to the Clogging Effect of Suspended Matter." Tahal, Water Planning for Israel LTD. Tel Aviv (1966).

Bogan, R. H. "Problems Arising from Ground Water Contamination by Sewage Lagoons at Tieton, Washington." Proceedings of 1961 Symposium, Ground Water Contamination, Robert A. Taft, Sanitary Engineering Center, USPHS Technical Report W61-5 (1961).

Caldwell, E. "Studies of Subsoil Pollution in Relation to Possible Contamination of the Groundwater from Human Excretia Deposited in Experimental Latrines." Jour. of Infect. Dis., 62, 272 (1938).

Chang, A. C., W. R. Olmstead, J. B. Johanson, and G. Tamashita. "The Sealing Effects of Wastewater Ponds." Jour. Water Poll. Control Fed. 46, 1715 (1974).

City of Tucson. "Annual Report by the Department of Water and Sewers" (1970-71).

Deming, S. A. "Natural Sealing Potential of Raw Sewage Stabilization Lagoons." Unpublished M.S. thesis, Department of Civil Engineering & Engineering Mechanics, University of Arizona, Tucson (1963).

de Vries, J. "Infiltration of Wastewater and the Mechanism of Pore Clogging." Jour. Water Poll. Control Fed. 44, 565 (1972).

Engineering-Science, Inc. and Marum and Marum, Inc. "Groundwater Occurrence and Quality Variations." A Regional Plan for Water, Sewerage and Solid Waste Management Pima Association of Governments, Vol. III (September, 1973).

EPA. "Manual for Evaluating Public Drinking Water Supplies." United States Public Health Service Publication 1820 (1969).

Fitzgerald, G. P., and G. A. Rohlich. "An Evaluation of Stabilization Pond Literature." Sew. and Ind. Wastes, 30, 1213 (1958).

Gelderman, F. W. "Soil Survey of the Tucson-Avra Valley Area, Arizona." Soil Conservation Service, United States Department of Agriculture (April, 1972).

Gilbert, R. G., R. C. Rice, H. Bouwer, C. P. Gerba, C. Wallis, and J. L. Melnick. "Wastewater Renovation and Reuse: Virus Removal by Soil Filtration." Sci., 192, 1004 (1976).

Joint Report of the North and South Dakota Departments of Health. "Sewage Stabilization Ponds in the Dakotas." U.S. Department of Health, Education and Welfare, Robert A. Taft, Sanitary Engineering Center, Cincinnati, Ohio, Vol. 1, pp. 54-60 (1957).

Keeney, D. R. "Nitrates in Plants and Waters." Jour. of Milk and Food Technol. 33, 425 (1970).

Krone, R. B., G. T. Orlob, and Carl Hodygkinson. "Movement of Coliform Bacteria Through Porous Media." Sew. and Ind. Wastes, 30, 22a (1958).

Laney, R. L. "Chemical Quality of the Water in the Tucson Basin, Arizona." United States Geological Survey, Water-Supply Paper 1939-D (1972).

Lehman, G. S. "Soil and Grass Filtration of Domestic Sewage Effluent for the Removal of Trace Elements." Unpublished dissertation, University of Arizona, Tucson (1968).

Mallman, W. L., and W. N. Mack. "Biological Contamination of Ground Water." Proceedings of 1961 Symposium, Ground Water Contamination, Robert A. Taft, Sanitary Engineering Center, United States Public Health Service Technical Report W61-5 (1961).

Matthew, F. L., and L. L. Harms. "Sodium Adsorption Ratio Influence on Stabilization Pond Sealing." Jour. Water Poll. Control Fed. 41, 11, part 2, 109r (1969).

Meyer, Gerald. "Geologic and Hydrologic Aspects of Stabilization Ponds." Jour. Water Poll. Control Fed. 32, 820 (1960).

Middleton, M., and G. Walton. "Organic Chemical Contamination of Ground Water." Proceedings of 1961 Symposium, Ground Water Contamination, Robert A. Taft, Sanitary Engineering Center, United States Public Health Service Technical Report W61-5 (1961).

Missouri Basin Engineering Health Council. "Waste Treatment Lagoon-State of the Art." Water Pollution Control Research Series, Environmental Protection Agency (1971).

Neel, J. K., and G. J. Hopkins. "Experimental Lagooning of Raw Sewage." Sew. and Ind. Wastes 28, 1326 (1956).

Pruel, H. C. "Underground Movement of Nitrogen." Advances in Water Pollution Research, Proceedings of the Third International Conference, Munich, Germany 1, 309-329 (September, 1966).

Pruel, H. C. "Contaminants in Groundwater Near Waste Stabilization Ponds." Jour. Water Poll. Control Fed. 40, 659 (1968).

Robinson, P. G. "Changes in Seepage Rate from an Unlined Cattle Waste Digestion Pond." Trans. of Amer. Soc. of Agri. Eng. 16, 95 (1973).

Schmidt, K. D. "Groundwater Contamination in the Cortaro Area, Pima County, Arizona." Hydrology and Water Resources in Arizona and the Southwest, II, Arizona Section of the Amer. Water Res. Assoc. (1973).

Small, G. G. "Groundwater Recharge and Quality Trans-Formations During the Iniations and Management of a New Stabilization Lagoon." Unpublished M.S. thesis, Department of Hydrology and Water Resources, University of Arizona, Tucson (1973).

U.S. Geol. Survey. "Water Resources Data for Arizona." Part 1, Surface Water Records (1971).

Wilson, L. G., W. L. Clark, III, and G. G. Small. "Subsurface Quality Transformations During the Initiation of a New Stabilization Lagoon." Water Res. Bul. 9, 2 (April, 1973).

Winton, E. F., R. G. Tradiff, and L. J. McCabe. "Nitrate in Drinking Water." Jour. Amer. Water Works Assn. 63, 951 (1971).