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SEPARATION OF ALGAL CELLS FROM WASTEWATER LAGOON EFFLUENTS

Volume III:
Soil Mantle Treatment of Wastewater Stabilization Pond Effluent - Sprinkler Irrigation

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

As part of these activities, this report was prepared to make available to the sanitary engineering community the results of laboratory and field tests of the effectiveness of land application of wastewater lagoon effluents for the removal of algae, bacteria, and chemical components from lagoon effluent.

Francis T. Mayo
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ABSTRACT

To evaluate the soil mantle as a means of polishing lagoon effluent, a two-phase study was undertaken. A series of lysimeters was employed to evaluate the impact of soil treatment on removal of total and fecal coliform and fecal streptococcal organisms. The second phase consisted of a two-year field study to evaluate the efficiency of the sprinkler irrigation soil mantle wastewater treatment system when used to further treat wastewater stabilization pond effluent.

All four Utah soils evaluated provided good removal of the three indicator organisms, but the Utah State University Drainage Farm soil with a high clay content produced the best bacterial removal. Nitrate-N concentrations in the lysimeter effluents in excess of that expected from the soils was observed. This was attributed to leaching of nitrate-N originally present in the soils before placing them in the lysimeters.

The four soils were effective in removing organic carbon with the more clay-like soils providing better removals than the sand or silty loam soils. The finer textured soil, Drainage Farm soil, was the most efficient in removing suspended and volatile suspended solids; however, all of the soils were effective in removing suspended and volatile suspended solids with a minimum removal of 85 percent of the applied solids.

Adsorption and precipitation of phosphorus compounds was observed. Again, the higher clay content soils were the most efficient in removing phosphorus.

In the field experiments, the solid set sprinkler irrigation system provided trouble-free operation. However, the center pivot or self-propelled systems are considered the better alternatives for sprinkler irrigation.

Leaching of salts from the soils on the Drainage Farm occurred, and specific conductance and sodium adsorption ratio values were high in the drainage water from the underdrain system. These values were high enough to indicate that the re-use of the soil mantle treated water would be hazardous to the growth of most plants. However, continued application of a reasonably good quality water will eventually leach a considerable amount of the material from the soils and the effluent may be acceptable after leaching is completed.

Phosphorus removal was high when the water passed through the soil system; removal exceeded 80 percent. Some leaching of phosphorus at the lower sampling depth was indicated by an increase in phosphorus concentration. Again, as water is applied equilibrium will develop and a fairly constant removal of phosphorus should occur. Direct nutrient uptake of phosphorus by

the vegetation appeared to be negligible. The rate of application of irrigation water made no significant difference in the phosphorus removal rate. After two years of service, no observable change in the cation exchange capacity of the soil occurred, indicating that phosphorus removal should remain high in subsequent years of use.

Evidence of nitrate leaching was seen, and continued high rate irrigation should lower the nitrate levels of the soil. The application rate of irrigation water was shown to have an insignificant effect on the concentration of nitrate in the water samples from vegetated sites. On the bare sites where nitrate concentrations in the soil were initially higher than the vegetated sites, generally lower nitrate concentrations were observed in the water samples as the application rate increased.

Ammonia stripping was found to be an important ammonia removal mechanism when sprinkler irrigation was used and pH values of the irrigation water were high. Thirty-five percent removal of the ammonia was obtained through the stripping process when the pH value was approximately 9. The concentration of ammonia in the treated water samples was not affected by the concentration of ammonia in the irrigation water, the presence of vegetation or no vegetation nor the rate of application of irrigation water. The total organic carbon (TOC) concentrations observed in the treated water samples generally increased over those of the irrigation water. The properties of the soil system determined the TOC concentrations of the treated water sample rather than other factors such as TOC concentrations in the irrigation water, the vegetation, or the application rate of irrigation water.

The soil mantle treatment system was efficient in removing suspended solids from the percolating irrigation water. The mean concentration of the suspended solids in the drainage water from the 4 ft. deep mole drain contained an average of 2 mg/l of suspended solids and 1 mg/l of volatile suspended solids, while the mean values in the stabilization pond effluent were 13 mg/l suspended solids and 10 mg/l volatile suspended solids.

Vegetation yield was not significantly different between sites receiving different application rates of stabilization pond effluent, between sites receiving irrigation waters of differing nutrient content, or between sites with and without irrigation. The pH value, percent C, percent N, Ca, K, Na, and P concentrations in the soil samples were not observed to change over the two irrigation seasons. The NO_3-N concentrations in the soil samples declined over the two-season period in 19 of the 24 sample sites observed, indicating nitrate leaching. In most cases specific conductance of the soil sample extracts were unchanged over the two seasons except in some cases where initially high values were found.

This report was submitted in partial fulfillment of Contract No. 68-03-0281 by the Utah Water Research Laboratory, Utah State University, under the sponsorship of the U.S. Environmental Protection Agency.

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ACKNOWLEDGMENTS

The cooperation and assistance of the Logan City Engineer, Mr. Ray Hugie, is greatly appreciated. Assistance in the operation of the Logan City Waste Stabilization Lagoon System was provided by Logan City personnel. We wish to express our appreciation to the many land owners that granted permission to cross their property with the wastewater transport pipe.

SECTION 1

INTRODUCTION

Many wastewater treatment facilities now in existence cannot meet the effluent quality standards which will be required by new laws (PL 92-500). Municipalities and industries with facilities unable to meet the standards will receive ''cease and desist'' orders from the courts. Failure to comply with such orders will result in fines. Therefore, existing facilities must be improved to an extent that the effluent standards can be met, or a better method of treatment must be developed.

Upgrading facilities can be a difficult problem, especially for municipalities with a small tax base. Costs for wastewater collection and treatment in certain locations have exceeded the assessed value of the real property in the community served by the system. This creates a severe burden on the citizens of a municipality and the logic of imposing such a burden is questionable.

Wastewater stabilization pond effluent can often be improved to an acceptable level via soil mantle treatment by spray irrigation. Wastewaters in general have been used for years as irrigation water, but limited study has been made concerning wastewater stabilization pond effluent for such use (EPA, 1973). Soil mantle treatment by spray irrigation is an economically attractive and physically viable alternative to other biological or physical-chemical treatment methods.

To evaluate the soil mantle as a means of polishing lagoon effluent, a two phase study was undertaken. A series of lysimeters was employed to evaluate the impact of soil treatment on the removal of total and fecal coliform and fecal streptococcal organisms. The second phase consisted of a two year field study to evaluate the efficiency of the sprinkler irrigation soil mantle wastewater treatment system when used to further treat stabilization pond effluent. The aim of this study was to determine the effectiveness and economy of upgrading wastewater stabilization pond effluent using soil mantle treatment via spray irrigation.

Specific objectives were as follows:

1. To correlate soil characteristics with the efficiency of removal and the survival of enteric organisms found in wastewater stabilization pond effluents using lysimeters.

2. To evaluate the effectiveness of four Utah soils, with different characteristics, in removing organic and inorganic constituents found in wastewater stabilization pond effluents.

3. To determine changes in the characteristics of the four soils after use as a soil mantle wastewater treatment system.

4. Operate and maintain a field scale spray irrigation soil mantle treatment system using municipal wastewater stabilization pond effluent.

5. Operate the field treatment system for two successive irrigation seasons to assess trends in treatment efficiency and soil characteristics.

6. Monitor water quality parameters of the stabilization pond effluent and the effluent from the soil mantle treatment system.

7. Monitor soil parameters which may affect water quality.

8. Compare the treatment efficiencies of soil vegetated with naturally occurring weeds and grasses with soil barren of vegetation.

9. Determine the soil mantle treatment system efficiency in removing algal cells and other pollutants from the stabilization pond effluent.

10. Examine the soil mantle treatment process at different depths in the soil profile and with different stabilization pond effluent application rates.

11. Estimate the capital, operation, and maintenance costs of a spray irrigation system and compare with costs of alternative methods of upgrading wastewater stabilization pond effluent.

SECTION 2

CONCLUSIONS

LYSIMETER EXPERIMENTS

1. All soils provided good removal of total coliforms, fecal coliforms, and fecal streptococci, with the Drainage Farm soil producing the best bacterial removal followed by the Draper, Nibley, and Parleys soils in order of decreasing removal.

2. Bacterial removal by the Drainage Farm soil was enhanced by the dense texture which provided removal by the three mechanisms of straining, bridging, and straining and sedimentation.

3. Decomposition of organics present in the lagoon effluent and initially in the soils and the oxidation of ammonia present in the effluent from the oxidation ponds produced nitrate concentrations in the lysimeter effluents in excess of that present in the lagoon effluents.

4. Leaching of nitrate-N from the soils occurred.

5. Nibley (silty clay loam) soils showed the highest concentrations of nitrate-N in the lysimeter effluents with Drainage Farm (clay) soil next, then Parleys (silty loam) and finally Draper (sandy loam) soils showing the lowest concentrations.

6. All four soils were effective in removing organic carbon, but clay-like soils (Drainage Farm and Nibley) provided better removal than the sandy or silt loam soils.

7. Suspended and volatile suspended solids removals were approximately equivalent for all four soil types studied, and approximately 85 percent removal was obtained.

8. A combination of adsorption of phosphate and precipitation of compounds of phosphorus accounted for the reductions in phosphorus with Drainage Farm soil the most effective followed by Parleys, Draper, and Nibley soils.

FIELD EXPERIMENTS

9. The aluminum pipes, valves, rotating ‘‘Rainbird’’ type sprinkler and the centrifugal pump used in the solid-set irrigation system gave good service.

10. Where farm machinery must operate on the land, buried solid-set or center-pivot or self-propelled sprinkler systems would be desirable.

11. The specific conductance and sodium adsorption ratio (SAR) values observed in the drainage water were of such magnitude that reuse of the soil mantle treated water would be hazardous to soils, especially those containing clay, and to the growth of most plants especially under conditions of restricted drainage.

12. The specific conductance and SAR properties of the stabilization pond effluent indicated that the effluent was suitable for use as irrigation water under most conditions.

13. Phosphorus removal was high using the soil mantle treatment system, and removals exceeding 80 percent were obtained at a depth of 91.4 cm (3 ft.) in the soil profile. The removal observed at shallower depths in the soil was higher and averaged 95 percent removal at the 10.2 cm (4 in.) depth.

14. Adsorption appeared to be the major phosphorus removal mechanism with uptake of phosphorus by the vegetation apparently negligible.

15. The rate of application of irrigation water made no significant difference in the phosphorus removal.

16. After two years of applying lagoon effluent, no observable change in the cation exchange capacity of the soil occurred, indicating that phosphorus removal should remain high in subsequent years of use.

17. The nitrate-N observed in the treated water samples taken during this study originated from nitrate-N present in the soil before the start of irrigation.

18. Evidence of nitrate-N leaching was seen and continued high rate irrigation should lower the nitrate-N levels in the soils.

19. The nitrate-N concentrations in the water samples were determined by the characteristics of the soil rather than those of the irrigation water.

20. The application rate of irrigation water was shown to have an insignificant effect on the concentration of nitrate-N in the water samples from vegetated sites.

21. On the bare sites where nitrate-N concentrations in the soil were initially higher than the vegetated sites, generally lower nitrate-N concentrations were observed in the water samples as the application rate increased.

22. Concentrations of nitrate-N observed in the water samples ranged on the average from less than 20 μg/l to over 30 mg/l. Observed concentrations were primarily dependent upon the initial concentration of nitrate-N present in the soil for a given sample site.

23. Ammonia stripping was found to be an important ammonia removal mechanism when sprinkler irrigation was used and pH values of the irrigation water were high. Thirty-five percent removal of ammonia-N was obtained from the stripping process in this study.

24. Total system ammonia-N removal exceeding 90 percent was observed through the top 61.0 cm (2 ft.) of the soil profile. Overall removal dropped considerably to 67 percent at the 91.4 cm (3 ft.) depth.

25. The concentration of ammonia in the water samples was not significantly affected at the 95 percent confidence level by the concentration of ammonia in the irrigation water, the vegetation or lack thereof, or the rate of application of irrigation water.

26. The total organic carbon concentrations observed in the water samples generally increased over those of the irrigation water.

27. The properties of the soil system determined the TOC concentrations in the water samples rather than other factors such as the TOC of the irrigation water, the vegetation, or the application rate of irrigation water.

28. The soil mantle treated water appeared to be of lower quality than the applied irrigation water on the basis of organic content. This increase in organics is attributable to leaching of organics from the soil by the lagoon effluent.

29. The mean concentration of suspended solids in the drainage water from the 1.2 m (4 ft.) deep mole drain contained an average of 2 mg/l SS and 1 mg/l VSS while the mean values in the stabilization pond effluent were 13 mg/l SS and 10 mg/l VSS for the second irrigation season. Similar results were observed during the first irrigation season.

30. The vegetation yield was not significantly different at the 95 percent confidence level between sites receiving different application rates of stabilization pond effluent, between sites receiving irrigation waters of differing nutrient content, or between sites receiving no irrigation, and sites receiving irrigation.

31. The pH value, percent C, percent N, Ca, K, Na, and P concentrations in the soil samples were not observed to change over the two irrigation seasons.

32. The NO_3-N concentrations in the soil samples declined over the two season period in 19 of the 24 sample sites observed, indicating nitrate leaching.

33. In most cases the specific conductances (EC_e) of the soil sample extracts were unchanged over the two seasons except where initially higher values were found. In these cases a decline in specific conductance was seen, suggesting salt leaching.

34. The propagation of mosquitoes was a problem with the soil mantle treatment system.

35. Ponding of irrigation water on the soil surface due to excessively high irrigation rates must be avoided.

36. Only the 5.1 cm (2 in.) per week rate applied to vegetated soil did not pond and produce a mosquito problem.

37. Because most of the chemical parameters examined were unaffected by the irrigation application rate, the control of mosquito breeding may be the limiting factor in deciding the acceptable application rate.

38. Effluents from the soil wastewater treatment system consistently contained suspended solids concentrations less than 3 mg/l which easily meets discharge standards of 30 mg/l or less.

39. Organic carbon concentrations in the effluent from the soil wastewater treatment system were frequently higher than those measured in the lagoon effluent applied to the soil. This indicates leaching of organics by the lagoon effluents, and once equilibrium is established, the effluents from the soil system should easily meet the effluent standard of a BOD_5 concentration of 30 mg/l or less.

SECTION 3

RECOMMENDATIONS

1. Long term effects of the application of wastewaters to soil-plant systems should be evaluated.

2. An evaluation of full-scale soil-plant wastewater treatment systems should be undertaken.

3. Operational procedures for soil-plant wastewater treatment systems should be developed.

4. Current design criteria and design procedures should be evaluated and design methods and procedures developed to reflect geographic conditions and wastewater characteristics.

SECTION 4

LITERATURE REVIEW

A review of the history of sewage treatment indicates that wastewater irrigation was originally developed in the early nineteenth century as a system of both treatment and disposal (Rafter, 1897; Rudolfs, 1933; Mitchell, 1931). In recent years, other forms of waste treatment have replaced most irrigation wastewater treatment systems. Increasing energy costs and the need for less complicated treatment systems has resulted in re-examining the treatment possibilities of certain industrial, agricultural, and domestic wastewaters through the application of irrigation techniques (Riney, 1928; Mitchell, 1930; Goudey, 1931; McQueen, 1934; DeTurk, 1935).

Land application of wastewater treatment plant effluents in the United States dates back to the 1870's (EPA, 1973). The cities of Tucson and Phoenix, Arizona; Lubbock, Texas; Denver, Colorado; Pomona, Whittier and Riverside, California have used wastewater for irrigation (Wilcox, 1948). Merz (1956) reported Bakersfield, Fresno, Wasco, and Tulare, California; Abilene, Kingsville, and San Antonio, Texas as having obtained favorable results with land application. As of 1966, California had a total of 199 sewage treatment plants that applied effluent to the land, Texas had 40, Arizona 20, and New Mexico 21 (Eastman, 1967).

Recently, the U.S. Environmental Protection Agency has designated land application of wastewater as a viable alternative to traditional treatment discharge systems (Ward, 1975). When any project is to be considered for federal funding under best practicable designation, land treatment must be evaluated as one of the alternatives before funds may be granted. In assigning Best Practicable Technology (BPT) status to land treatment, the EPA has expressed the need to protect the environment. According to the EPA's BPT document (EPA, 1974),

> land application practices should not further degrade the air, land, or navigable waters; should not interfere with the attainment or maintenance of public water supplies, agricultural and industrial water uses, propagation of a balanced population of aquatic and land flora and fauna, and recreational activities in the area.

If primary drinking water standards are met by land treatment methods, most of the above objectives should be achieved. Due to the mobility of nitrate-N in soil systems, the drinking water standard of 10 mg/l of nitrate-N (EPA, 1975) may be the most difficult to meet with land treatment leachates.

In most cases the practice of irrigation with wastewater has resulted in improvement of water quality. At the Pennsylvania State University wastewater renovation project, effluents from trickling filters and activated sludge systems were applied to cropland and fruitland using spray irrigation (Myers, 1975). Removal of 93 percent for nitrogen and 35 percent for phosphorus were obtained when effluent was applied to a reed canary grass crop. On a hardwood forestland, 90 percent phosphorus removal was obtained. The forest biosystem was not consistent in lowering nitrogen concentrations.

Near Melbourne, Australia, raw sewage has been applied to the land for over 70 years. A flooding technique is used to irrigate pastures. Drainage effluents reportedly contain less nitrogen and phosphorus than generally found in secondary biological treatment plant effluent. Organic nitrogen and ammonia nitrogen removal were 93 percent and 91 percent, respectively. Total phosphorus removal was 91 percent. Perennial rye grass dominates most of the irrigated land (Seabrook, 1975).

The Muskegon County wastewater system is a spray irrigation land treatment scheme with approximately 6,000 acres of land under irrigation. Corn is grown for cattle feed as a part of the treatment system. Supplemental fertilizer is added to the irrigation water before application to the field. Treatment of the wastewater before irrigation is achieved with aerated lagoons. Storage ponds are used to hold wastewater when irrigation is not practiced. Reported phosphate removal was as high as 99 percent for the overall treatment process during 1974. The nitrogen content of the leachate sometimes exceeded that of the irrigation water during the same period (Demirjian, 1975).

The City of Tallahassee, Florida, applies trickling filter effluent to the land by spray irrigation. Scrub oak and other natural vegetation cover the irrigation site. Laboratory analyses indicated that the concentration of orthophosphate decreased from 25 mg/l at the surface to 0.04 mg/l at the depth of 3 m (10 feet) (Overman, 1975).

In west central Florida the General Electric Company operates a wastewater spray irrigation site consisting of combined industrial and sanitary waste. A subsurface drainage system collects percolating water and directs it to a sump where the water is then pumped to an onsite lake. The resulting effluent from the overall system exceeds the Florida State water quality standards (Applegate, 1975).

Although good results have been obtained, irrigation with wastewater is not a panacea for the economical treatment and disposal of wastes. Sanitary, aesthetic, economic, ecological, and other practical and technical considerations must be carefully balanced for a sound wastewater irrigation system (Gearheart and Middlebrooks, 1974).

The effect of sewage effluent on the yield of agronomic crops in most cases has been found to be beneficial (Hill et al., 1964; Herzik, 1956; Merz, 1965; Wilcox, 1949). Henry et al. (1954) obtained a significant increase in the yield of reed canary grass. Heukelekian (1957) obtained excellent crop yields in Israel. Wachs et al. (1970) observed yield increases with Satarea and Avena plants. Stokes et al. (1930) obtained yield increases in Florida amounting to 240 percent for both Napier grass and Japanese cane, when compared with the non-irrigated crops, or the same crops irrigated with well water. Day and Tucker (1960a,b) and Day et al. (1962) in Arizona, obtained beneficial yield effects on small grains which were harvested as pasture forage, as hay, or as grain.

More than 100 kinds of viruses are known to be excreted by man and approximately 70 of these have been found in sewage (Clarke and Chang, 1959; Clarke et al., 1962). Viruses that appear to be transmitted through wastewater are the entero-viruses, poliomyelitis (Paul and Trask, 1942a,b; Little, 1954; Kelley et al., 1957; Bancroft et al., 1957), coxsachie (Clark et al., 1971), and infectious hepatitis (Hayward, 1946; Dennis, 1959; Yogt, 1961). There are a limited number of studies on the movement of viruses through granular media (Merell et al., 1963). These studies showed that rapid sand filtration preceded by coagulation and sedimentation only partially remove virus. The removal of virus from percolating water is largely due to adsorption on the soil particles. Soils having a higher clay content adsorb viruses more readily than those with less clay (Eliassen et al., 1967; Drewry and Eliassen, 1968). Virus adsorption by soils generally increases with increased ion-exchange capacity, silt content, and glycerol-retention capacity (Drewry and Eliassen, 1968). The pH of the water soil system affects virus adsorption. At pH values of 7.0 to 7.5 and below, virus adsorption is more effective than at higher pH values (Drewry and Eliassen, 1968). Changes in water quality can cause viruses attached to soil particles to de-adsorb resulting in subsurface travel (Gerba et al., 1975).

It is feared that land disposal of domestic wastes may contaminate groundwater if viruses travel deeply into the soil. Between 1946 and 1961, 61 percent of all waterborne disease outbreaks in this country were caused by contaminated groundwater (Gerba et al., 1975).

Studies of bacteria removal by land treatment have shown that soil is an effective medium for treating sewage. Removal of bacteria from sewage effluents during percolation through the soil is accomplished largely at the soil surface by straining, sedimentation, and adsorption (Gerba et al., 1975). Using radioactive phosphorus to label coliform bacteria, tests at the Tulza collective farm in Rumania showed that 92 to 97 percent were retained in the uppermost 1.cm of the soil, with 3 to 5 percent retained in the 1 to 5 cm layer (Malculeseu and Drucan, 1967).

Reports from 69 communities in California using wastewater for irrigation indicate no groundwater pollution or disease transmission (Sepp, 1975).

Krone (1968) stated that, ''The utilization of wastewaters ... has been demonstrated to be feasible and reasonable safeguards are easily achieved.'' Krone suggests at least primary treatment with secondary treatment and chlorination recommended (Krone, 1968). ''From a communicable disease viewpoint, land disposal is far less hazardous than disposal into rivers and streams,'' (Bernarde, 1973).

Considerable concern has been voiced over the danger of aerosols which are generated when sewage effluents are applied to the land by sprinkler irrigation. Aerosol droplets may contain active pathogenic viruses or bacteria which might then be inhaled by workers on the irrigation site or nearby residents.

Bacteria and virus contamination of aerosols have been shown to exist near spray irrigation sites. In Israel, a study showed the presence of coliform bacteria as far as 350 meters downwind from a municipal spray irrigation site. In one case, a Salmonella bacterium was isolated 60 meters from the source. Initial concentrations of coliform bacteria ranged from 10^4 to 10^6/ml (Katzenelson and Teltch, 1976).

In another study, bacterial aerosols were observed significantly above background levels 190 meters downwind from a spray irrigation site (Sorber and Bausum, 1976). The aerosols emitted from a spray irrigation system using chlorinated effluent contained biological aerosols of the same order of magnitude as nonchlorinated wastewater applied to trickling filters (Sorber and Guter, 1975). Chlorination may not ensure safety in practicing sprinkler irrigation of wastewaters. Under the conditions that can exist some viruses may not be inactivated by chlorination of effluents prior to irrigation (Sorber and Guter, 1975; Sorber and Bausum, 1976; Bernarde, 1973). A buffer zone around a spray irrigation site is advisable to prevent public contact with aerosols. Pennsylvania requires a 61 m (200 feet) buffer zone (Morris and Jewel, 1976).

While some studies have shown that potentially infective aerosols exist near spray irrigation sites, there is a lack of epidemiological study on the effects upon exposed groups such as workers and neighbors. Quantitative data have been unavailable and inferences from qualitative data have not conclusively confirmed nor negated the existence of a health risk from viable wastewater aerosols (Hadeed, 1976).

Twenty-six states have regulations or guidelines pertaining to land application. Twenty-one of the twenty-six require secondary treatment prior to land application. Typical guidelines and regulations cover items such as system design, pre-application water quality, loading rate, buffer zone, monitoring, cover crops, storage, public access, and effluent quality (Morris and Jewel, 1976).

The soil system is composed of gas, water, microorganisms, minerals, and organic matter which form the solid matrix. Experience has indicated that it is a dynamic system undergoing physical, chemical, and biochemical interactions. Wastewater applied to the soil mixes with the existing soil water and may alter the nature and rate of change of the physical, chemical, and biochemical processes in the soil system (Gearheart and Middlebrooks, 1974).

Physical clogging of the soil pores and the resulting loss in the infiltration rate have caused many wastewater soil treatment systems to fail (Avnimelech and Nevo, 1964; Jones and Taylor, 1965; Mitchell and Nevo, 1964; Winneberger et al., 1960; Thomas et al., 1966; Amramy, 1961). In the particular case of municipal secondary effluents, the suspended solids concentration is typically low enough to avoid clogging (Morgan, 1975).

Pretreatment of wastewater should precede application to the land. Pretreatment should accomplish:

(a) protection of the health and hygiene of the public

(b) reduce the risk of noxious odors

(c) reduce the risk of clogging the soil system

Conventional secondary treatment is probably the best form of pretreatment to achieve these goals (Hartigan, 1974).

The potential hazard of high sodium accumulation to the physical properties of certain soils is of paramount concern. This hazard has been extensively studied, and saline and alkali soils can be improved by the proper management of irrigation practices (USDA, 1954).

It is well known that the addition of organic matter improves the aggregate stability of soils. Wastewaters high in organics have been used for this purpose (Merz, 1959). Baver (1969) showed that organic matter was conducive to the formulation of relatively large stable aggregates and that the effect of organics was more pronounced in soils containing small amounts of clay. The addition of small amounts of organic matter appeared to promote large stable aggregates of clay, silt, and sand.

The organic content of wastewater stabilization pond effluent, both dissolved and particulate (algae), may therefore have a beneficial effect on soil permeability. Martin and Waksman (1940) observed that the growth of microorganisms in soil led to the binding of soil particles, and the more readily organic material decomposed, the greater the effect on aggregation. Plant roots appeared to be very effective in promoting aggregation in soils. The unusual aggregation of soils around the roots of plants was probably the consequence of mechanical disturbance by roots and by wetting and drying action together with cementation by organic compounds (Jenny and Grossenbecker, 1963). The efficiency of spray irrigation of vegetated areas for wastewater treatment was due in part to enhancement of permeable structures by plant roots.

Filtration is important for removing suspended particles from wastewater effluents penetrating the soil and for retaining microorganisms that facilitate biological decomposition of dissolved and particulate matter. Even though the removal of suspended particles from water flowing through soils is easily observed, the processes involved are difficult to describe. Listed below are three of the simplest mechanisms which might describe a complex situation.

Case I - Straining at the soil surface. Under these conditions the suspended particles accumulate on the soil surface and become a part of the filter.

Case II - Bridging. Under these conditions suspended particles penetrate the soil surface until they reach a pore opening that stops their passage.

Case III - Straining and Sedimentation. This includes all of the conditions for Case I and Case II except that the suspended particles are finer than half of the smallest pore openings.

Irrigation with wastewater has a marked influence on the chemical equilibria of the soil. Organic matter and clay added via suspended solids can increase the cation exchange capacity of the soil (Ramati and Mor, 1966). Many of the dissolved chemicals in wastewater influence the suitability of the soil for crop production. Nitrogen and phosphorus compounds have a beneficial fertilizer value when retained in the soil. Data from Kardos et al. (1974) indicated that removal of nitrogen from wastewater used for irrigation was dependent upon the amount applied (i.e., the more wastewater applied the more nitrogen removed). However, the efficiency of removal decreased when the application rate increased. Kardos et al. (1974) also indicated that as nitrogen removal efficiency dropped due to high wastewater application rates, nitrate concentrations in the percolate increased. The amount of increase was dependent upon the type of crop grown. Pollution of groundwater by nitrates can be a serious problem (PHS, 1961; Stewart et al., 1967).

Phosphorus removal by crops, precipitation, and adsorption by soil colloids has been reported (Morgan, 1975; Enfield and Bledsoe, 1975). In most cases the soil has a large capacity for phosphorus removal, and little movement of phosphorus through the soil may be expected. The mechanisms of phosphorus removal were dependent on the soil texture, cation exchange capacity, soil pH, presence of calcium, amount of iron and aluminum oxides present, and crop uptake of phosphorus. Phosphorus forms precipitated with iron and aluminum at pH values below 6. In neutral or basic soils, precipitation primarily occurred with calcium (CRREL, 1972). If the phosphorus removal capacity of the soil was exceeded, the release of phosphorus to surface waters could be a problem (Taylor, 1967).

Increased concentrations of trace elements have been found in wastewater irrigated soils (Seabrook, 1975). Boron content has caused concern in areas where boron-sensitive crops were irrigated with wastewater (WPCB, 1955). Toxic concentrations of copper and zinc have apparently accumulated in the soil at sewage farms (Rohde, 1962).

The application of soil mantle treatment to upgrading stabilization pond effluent is limited by soil and groundwater characteristics and by the availability of land. However, most stabilization ponds are generally constructed near small cities and towns where land is available. Advantages of lower land prices and flow scale economies often make soil mantle treatment a cost-effective treatment method for these areas (Young and Carson, 1974). Several possible monetary benefits of soil mantle treatment were listed by Pound et al. (1975):

1. Sale of crops grown
2. Sale of treated water
3. Lease of purchased lands to farmers for the purpose of soil mantle treatment
4. Lease of land for secondary purposes such as recreation

When properly managed, soil mantle treatment is a practical method of upgrading stabilization pond effluent. Guidelines, design criteria, and economic analyses have been developed and distributed by the U.S. Environmental Protection Agency (1975b,c,d,e).

SECTION 5

METHODS AND PROCEDURES

LYSIMETER EXPERIMENTS

Soil Types

The four Utah Great Basin soil types chosen were Nibley, Parleys, Draper, and soil typical to the Utah State University Drainage Farm. These soils were chosen on the basis of major acreage, potential irrigated value and range in physical and chemical characteristics (Table 1).

Lysimeter Design

Eight lysimeters were constructed, 53 cm x 53 cm x 53 cm, with drains installed at the 7.6 cm and 38.1 cm depths providing the two sample points. The bottoms of the lysimeters have two way slopes which allow for complete and final drainage (Figures 1 and 2). The lysimeters were filled to 1.3 cm from the top, giving the drains mean depths of 7.6 cm and 38.1 cm with a 5 percent slope. The units were constructed of 15.9 mm (5/8'') exterior plywood, all corners reinforced with fiber stripping and the entire unit coated

TABLE 1. DESCRIPTION, LOCATION AND USE OF THE FOUR UTAH GREAT BASIN SOILS STUDIED

Soil Type	Texture	Sample Site Location	Use
Nibley	Silty Clay Loam	1.4 km S. 1 km E. of USU Animal Husbandry Farm	Irrigated crops and natural pasture
Parleys	Silty Loam	2.4 km E. of Hyde Park on alluvial fan	Irrigated grain crops and natural pasture
Draper	Sandy Loam	2.4 km E. Perry on alluvial fan	Irrigated fruit crops and natural pasture
USU Reclamation Farm	Clay	4 km W. and 1.6 km N. Logan	Irrigated grain crops and natural pasture

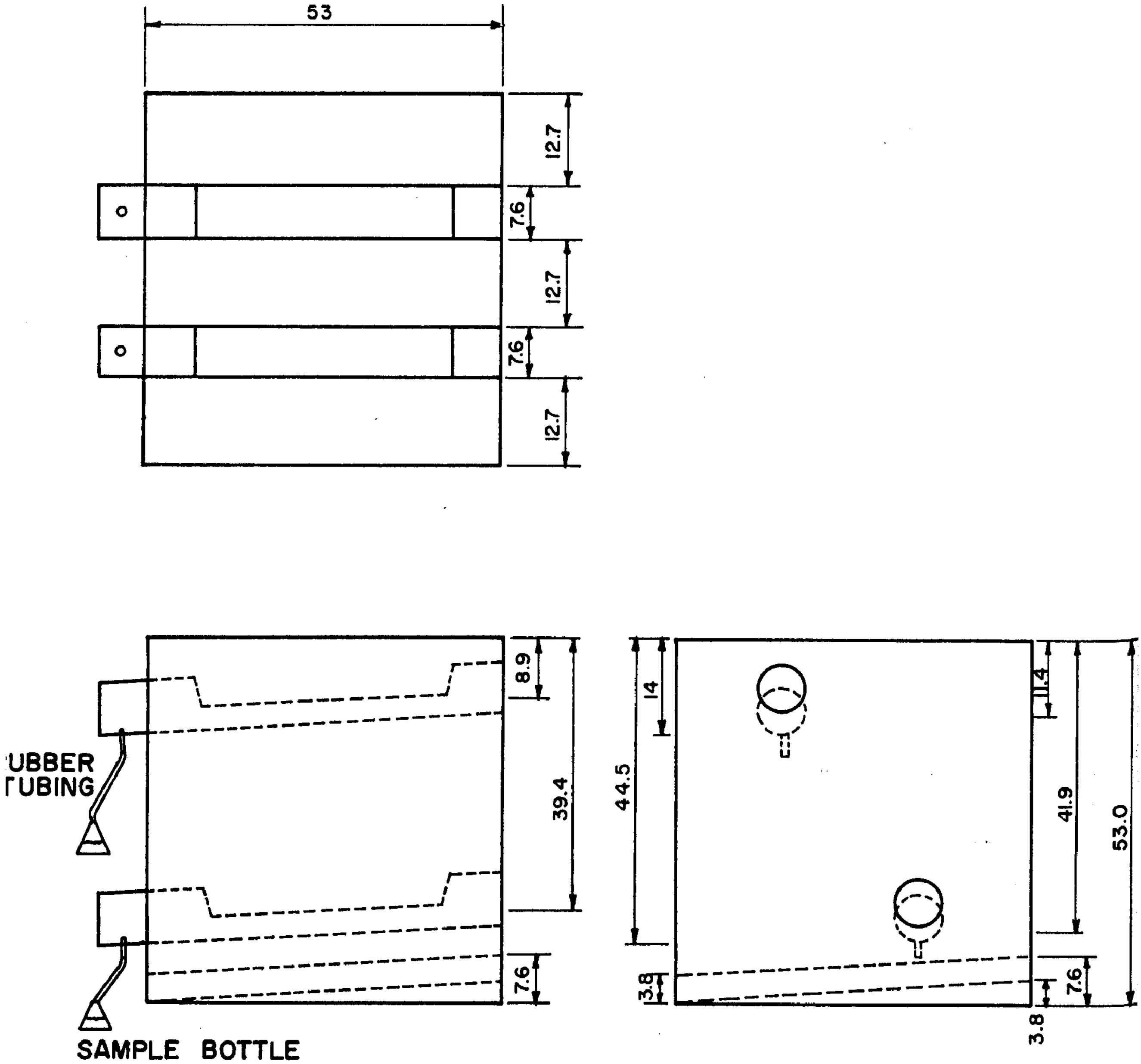
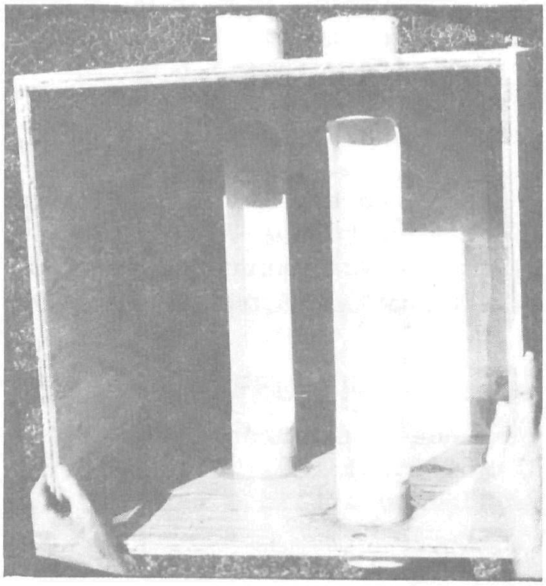


Figure 1. Design of lysimeter (all dimensions are centimeters).



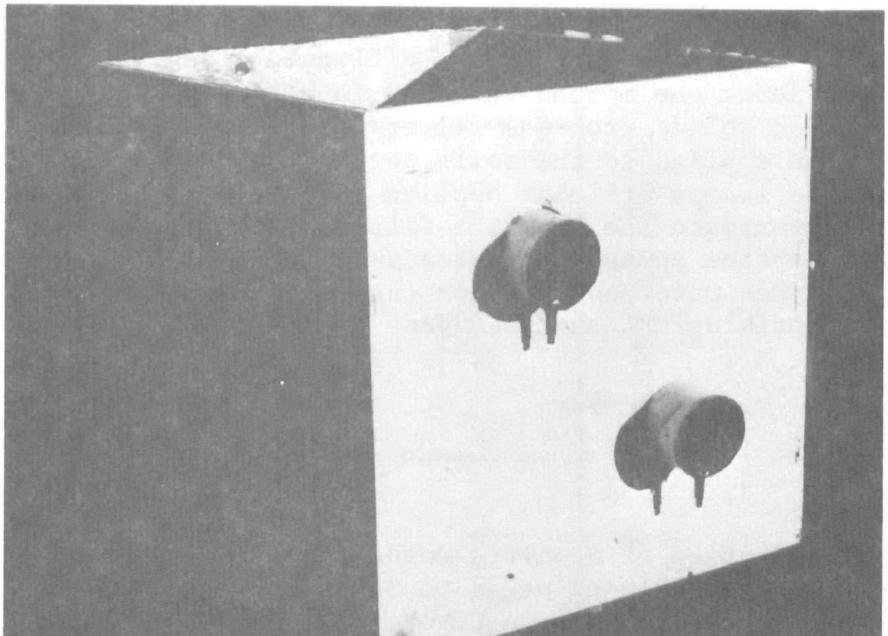


Figure 2. Lysimeter.

with marine glass resin. The drains were 7.6 cm (3'') polyvinyl-chloride (PVC) with the top half removed beginning 7.6 cm from each wall (Figure 1) to avoid collecting unfiltered samples due to possible sidewall channeling or short circuiting. Stainless steel wire with a 1.6 mm (16/inch) mesh was placed over the openings in the PVC and over the bottom drain outlet to prevent clogging. Next, a 3.8 to 5 cm layer of washed pea gravel was placed on the bottom.

Each soil type was placed in two lysimeters, and one of the lysimeters was saturated from the bottom up to the 7.6 cm drain and sampled at the 7.6 cm level. The second lysimeter was saturated up to the 38.1 cm level and sampled at that point, giving two data points for each soil type.

Soil Preparation

Soil samples were collected and transferred to the lysimeters as near as possible to the original soil profiles. The lysimeters were loaded in 10 cm lifts, each lift being rodded to attain a maximum and uniform compaction in all of the lysimeters.

A typical sample of each soil was submitted to the USU Soil, Plant and Water Analysis Laboratory for testing before and after application of wastewater stabilization pond effluent to measure the following properties: pH, electric conductivity, phosphorus, potassium, texture, lime, organic matter, exchangeable sodium, total sodium, water soluble sodium, cation exchange capacity, and percent saturation.

Prior to the application of lagoon effluent, fresh water was applied to the soils for at least one month, three to four times weekly to aid settling and leach suspended solids from the filters. Five centimeters of lagoon effluent were then applied to the soils three times a week and the specific conductance of the lagoon effluent applied and effluent from the filters was determined to approximate the time the filters were approaching steady-state operation. At the time an apparent steady-state condition was reached all of the chemical analyses were conducted on the influent and effluent from the lysimeters. Bacteriological analyses were begun when the chemical analyses were consistent.

SAMPLING

Sampling Schedule

Weekly determination of specific conductance started on September 5, 1974, and the chemical analyses began on September 25, and were conducted weekly until November 25, 1974. On October 29, the bacteriological analyses began. The bacteriological tests were conducted daily on the lagoon effluent applied and the effluents recovered from the lysimeters until November 29.

Sampling Procedure

Lagoon effluent was collected each day from the second cell of the Logan, Utah, wastewater stabilization pond system (Figure 3) in plastic, 19 l (5 gallons) containers. Two and one-half cm of the treated wastewater were

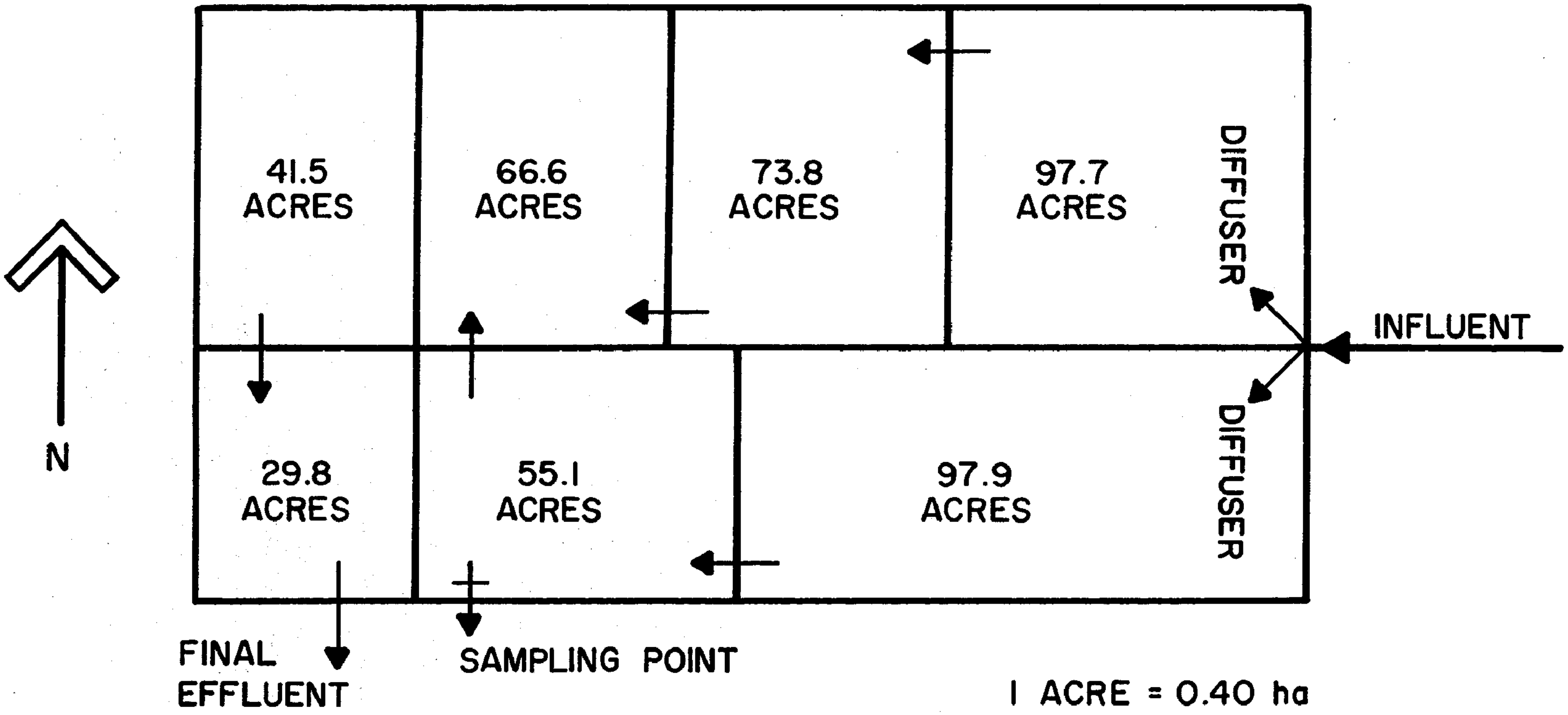


Figure 3. Schematic drawing of Logan waste stabilization lagoons.

applied to the soils. Samples from the appropriate effluent port on each lysimeter were collected in sterile 500 ml erlenmeyer flasks for the bacteriological analysis (Figure 1). On days when samples were to be taken for the chemical analyses as well, the bacteriological samples were collected first and then 2.5 liters were collected in 4-liter plastic containers to be used for the chemical analysis. The bacteriological and chemical analyses were conducted within six hours of the time the lagoon effluent was first applied to the lysimeters. The atmospheric temperature was always below 7°C; therefore, no further steps were taken to preserve the samples before analysis.

ANALYSES

Bacteriological Analyses

The bacteriological analyses were conducted according to Standard Methods (APHA, 1971).

Chemical Analyses

The lagoon effluent and lysimeter effluent samples were analyzed for: total carbon, total inorganic carbon, total organic carbon, suspended solids, volatile suspended solids, total unfiltered and filtered phosphate, orthophosphate, ammonia-N, nitrite-N, nitrate-N, pH, specific conductance, total algae cell counts, chlorophyll "a" and pheophytin "a." Methods described in Standards Methods were employed (APHA, 1971).

Final Soil Analyses

Upon completion of the testing period, the soils were allowed to freeze so that undisturbed core samples could be collected with a King tube. The soil core samples were separated by depth below the surface, and sub-samples were taken at the surface, 2.5 cm, 5 cm, 7.5 cm, 12.5 cm, 20 cm, and 32.5 cm levels, respectively. The sub-samples were analyzed for chlorophyll "a" and the presence of total and fecal coliforms by the three tube multi-dilution MPN technique described in Standard Methods (APHA, 1971).

The King tube is a stainless steel pipe 183 cm long with an inside diameter of 2.54 cm. On one end is a sharpened head (bottom left of Figure 4) with an inside diameter slightly smaller than that of the remaining tube. The other end has a steel jacket reinforcing the end (Figure 4). A hammer is used (bottom of Figure 4) to drive the tube into a compacted soil to remove an undisturbed soil sample. The core is then removed from the upper end. Samples used to determine remaining coliform populations at different depths in the soil were collected with a King tube and hammer scrubber and sterilized with methanol and flamed before each core sample was taken. The cores were then placed in sterile long plastic bags so as not to disturb the soil cores.

For the coliform determination the solid cores were aseptically separated at the desired depths below the surface. Approximately 4 grams of soil were placed in a tared dilution bottle. Approximately the same amount from the same depth was weighed, air dried and weighed again to determine the percent moisture. The soil suspension was then diluted to conduct the three tube

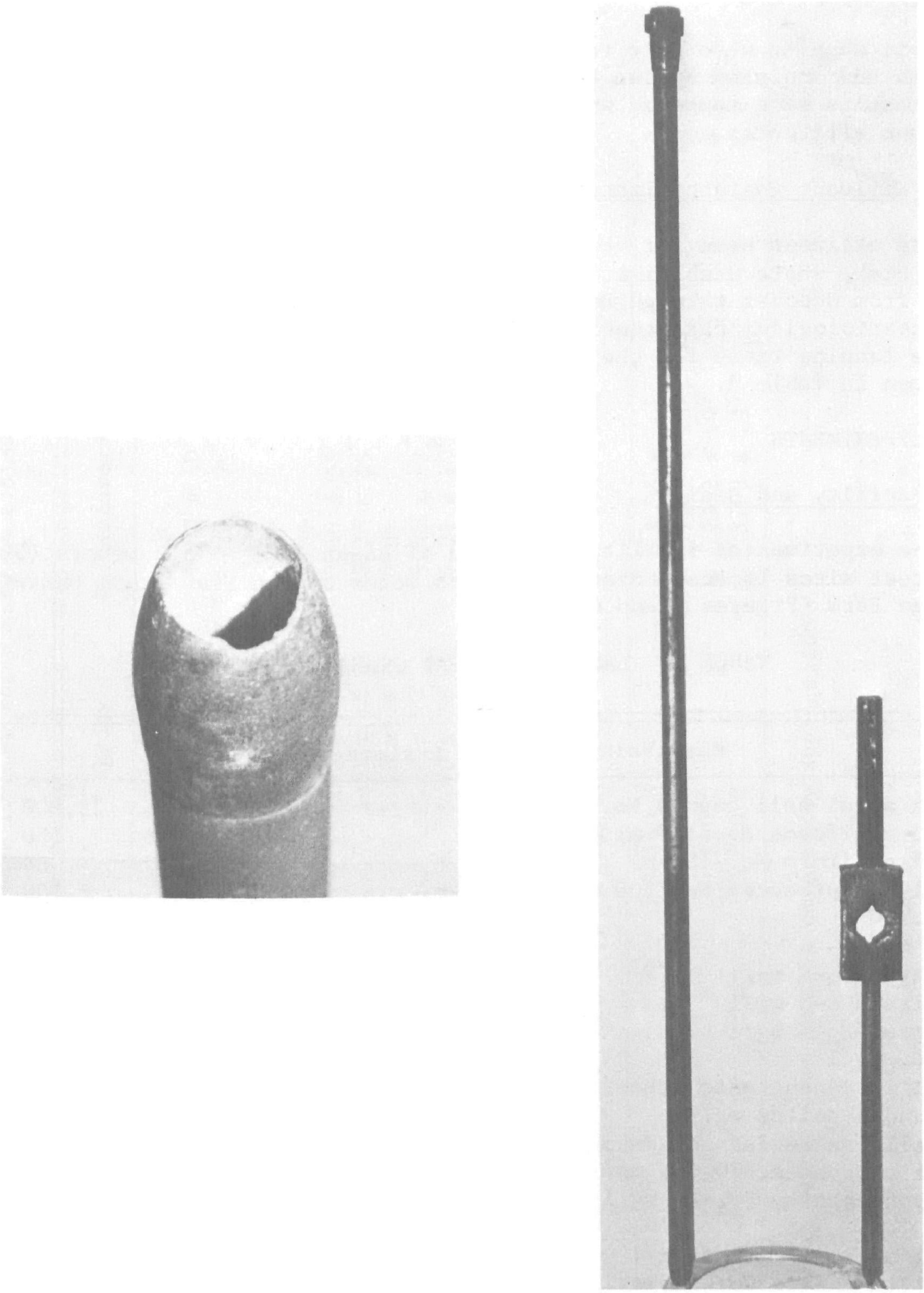


Figure 4. King tube and driver.

multi-dilution coliform MPN and fecal coliform MPN test. The results of the MPN determinations for coliforms or fecal coliforms in the soil are reported as MPN per dry weight of soil.

Soil samples were also taken from the lysimeters at the surface and 32.5 cm depth and analyzed by the USU Soil Plant and Water Analysis Laboratory. These results were compared with the soil properties before the application of lagoon effluents.

Lagoon Effluent Characterization

The effluent used for this study was taken from the second cell of the Logan, Utah, waste stabilization pond system. The lysimeter study was conducted from October through December. Mean values for the various chemical and bacteriological characteristics of the lagoon effluent is shown in Table 2. The loading rates for the various constituents applied to the lysimeters are given in Table 3.

FIELD EXPERIMENTS

Field Facility and Design

The experimental facility consisted of eight 15.2 x 15.2 meters (50 x 50 feet) test sites located adjacent to each other on the Utah State University Drainage Farm (Figures 5 and 6).

TABLE 2. LAGOON EFFLUENT CHARACTERIZATION

Mean Values for the Lysimeter Study	
Total algal cell counts No./ml	23,800
Total coliforms No./100 ml	160
Fecal coliform No./100 ml	64
Fecal Streptococci No./100 ml	100
Temp. ^oC	8
D.O. mg/l	19
Nitrate NO_3-N mg/l	0.2
Nitrite NO_2-N mg/l	0.1
Ammonia NH_3-N mg/l	4.1
B.O.D. mg/l	30
Specific conductance μmhos/cm	640
Suspended solids mg/l	28
Volatile suspended solids mg/l	17
Total phosphate, PO_4-P, mg/l	2.8
Orthophosphate, PO_4-P, mg/l	2.1
pH	8.1
Total organic carbon mg/l	15
Total inorganic carbon mg/l	58
Total carbon mg/l	75

TABLE 3. MEAN LOADING RATES USED IN LYSIMETER STUDY

Parameter	Mean Conc. mg/l	kg/day	kg/hectare/day	lbs/day	lbs/acre/day
BOD	30	2.17×10^{-4}	7.56	4.78×10^{-4}	6.78
Nitrate	0.15	1.09×10^{-6}	3.82×10^{-2}	2.41×10^{-6}	3.41×10^{-2}
Nitrite	0.04	2.68×10^{-7}	9.35×10^{-3}	5.9×10^{-7}	8.35×10^{-3}
Ammonia	4.1	3.04×10^{-5}	1.05	6.7×10^{-5}	9.35×10^{-1}
Suspended Solids	28.9	2.09×10^{-4}	7.30	4.6×10^{-4}	6.54
Volatile Suspended Solids	17.0	1.23×10^{-4}	4.30	2.71×10^{-4}	3.84
Total Phosphate	2.81	2.03×10^{-5}	7.10×10^{-1}	4.48×10^{-5}	6.35×10^{-1}
Orthophosphate	2.09	1.51×10^{-5}	5.28×10^{-1}	3.33×10^{-5}	4.72×10^{1}
Total Organic Carbon	15.6	1.13×10^{-4}	3.94	2.49×10^{-4}	3.52
Total Inorganic Carbon	58.0	4.20×10^{-4}	1.46×10^{-2}	9.25×10^{-4}	1.31×10^{2}
Total Carbon	75.0	5.40×10^{-4}	1.91×10^{2}	1.19×10^{-3}	1.71×10^{2}

Microbial Characteristics[a]

Parameter	Avg. Conc. No./100 ml	Organisms/Hectare/Day	Organisms/Acre/Day
Total Coliform	160.0	3.95×10^{6}	1.6×10^{6}
Fecal Coliform	64.0	1.63×10^{6}	6.6×10^{5}
Fecal Streptococci	100.0	2.72×10^{6}	1.1×10^{6}
Total Algal Cells	23,800.0	5.93×10^{8}	2.4×10^{8}

[a]Loading rates based on 2.54 cm per day application.

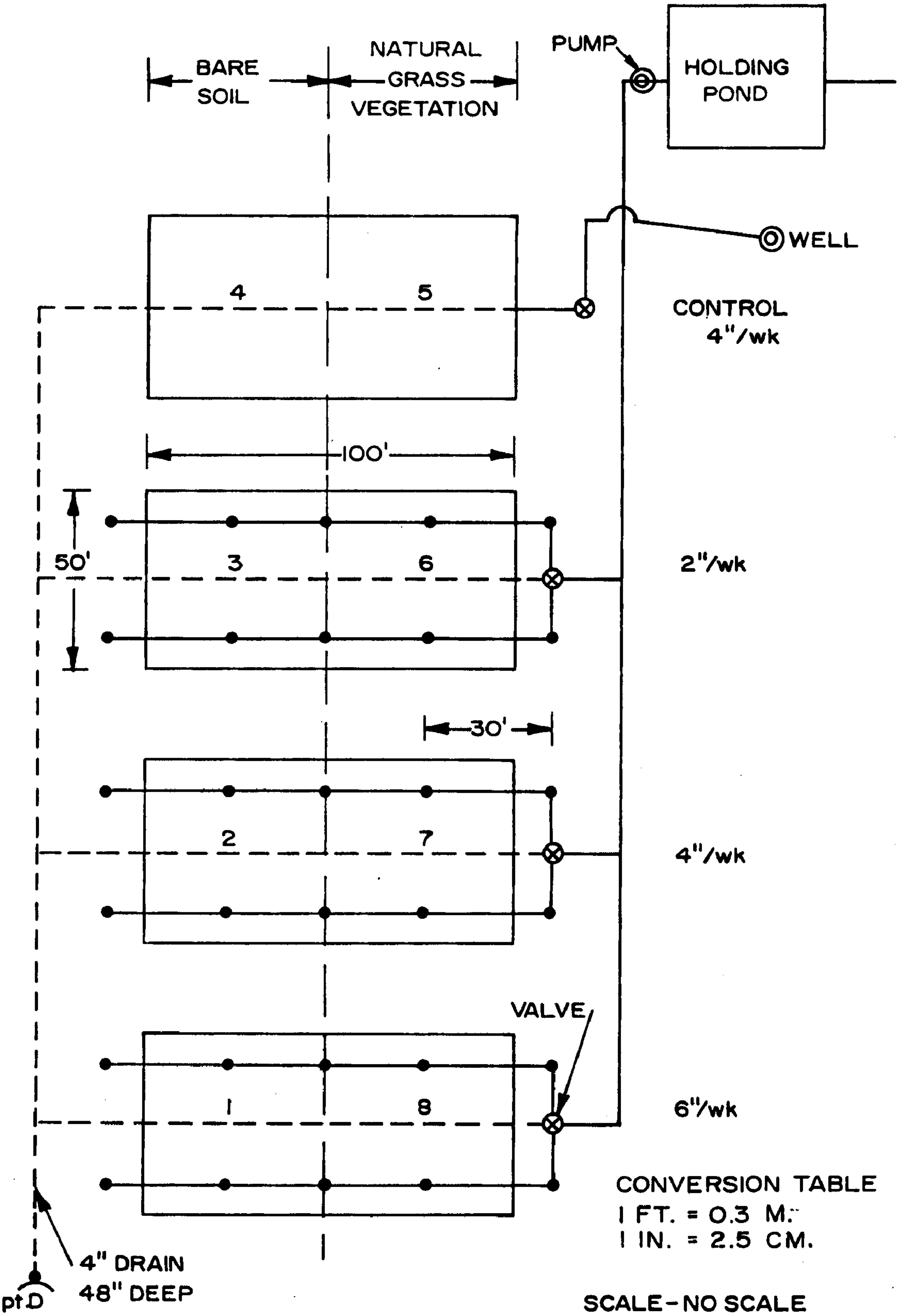


Figure 5. Test sites.

Figure 6. Drainage Farm test sites.

Thirty-four test holes were cored on the Drainage Farm for soil characterization purposes. The topsoil on the test sites was thin and composed of silty clay loam. Beneath the top soil was a gleyed or mottled clay. Water movement through the clay was limited. The clay presented a barrier to water movement whether the water was moving down from the surface or up from an artesian aquifer below.

The Drainage Farm is essentially level. An open drainage channel about 5 feet deep is located on the farm near the test sites. The open drain serves to remove surface water and some irrigation return flow.

Four of the eight test sites were covered with naturally occurring weeds and grasses and the other four sites were barren of vegetation. Effluent from the second cell of the Logan, Utah, wastewater stabilization pond system was used in the experiments. The effluent was pumped approximately two and one-half miles through a PVC pipeline to a holding pond near the test sites. From the holding pond the effluent was applied to the test sites with a solid set sprinkler irrigation piping network. Irrigation application rates of 5.1 cm (2 in.), 10.2 cm (4 in.), and 15.2 cm (6 in.) per week were used. One vegetated and barren site was irrigated at each of the respective irrigation rates for two seasons. In addition, one vegetated and one barren site received 10.2 cm (4 in.) per week of well water and served as experimental controls during the second season.

A mole drain 10.2 cm (4 in.) in diameter located 1.2 m (4 ft.) below the surface collected return flow from the sites. As shown in Figure 5 there was a 15.2 meter (50 foot) buffer zone between each pair of vegetated and bare sites to prevent interference from adjacent irrigation activities.

Equipment Design

The wastewater stabilization pond effluent was applied with a solid set sprinkler irrigation system. The components of the system were all aluminum piping with self-sealing and draining joints. The trunkline was 7.6 cm (3 in.) in diameter and laterals were 5.1 cm (2 in.) in diameter. The sprinklers were spaced 9.1 m (30 ft.) apart and were mounted on galvanized iron risers 76.2 cm (30 in.) above the soil surface. The sprinklers were of the ''Rainbird'' type having a 0.32 cm (1/8 in.) orifice and a full circle spray pattern. Wastewater was supplied to the sprinklers with a three horsepower centrifugal pump.

As shown in Figure 5 each pair of test sites was served by a block of two laterals. The system was designed to allow the simultaneous operation of two blocks. Operation of the control sites was independent of the operation of the sites receiving effluent. This allowed the control sites and the sites receiving effluent to be operated at the same time. Control of the irrigation system was managed with manually activated switches for pumps and manually operated valves in the pipeline. The locations of valves are shown in Figure 5.

The sprinklers were located so that generous overlapping of the spray patterns occurred (Figure 7). This ensured a high degree of uniformity in

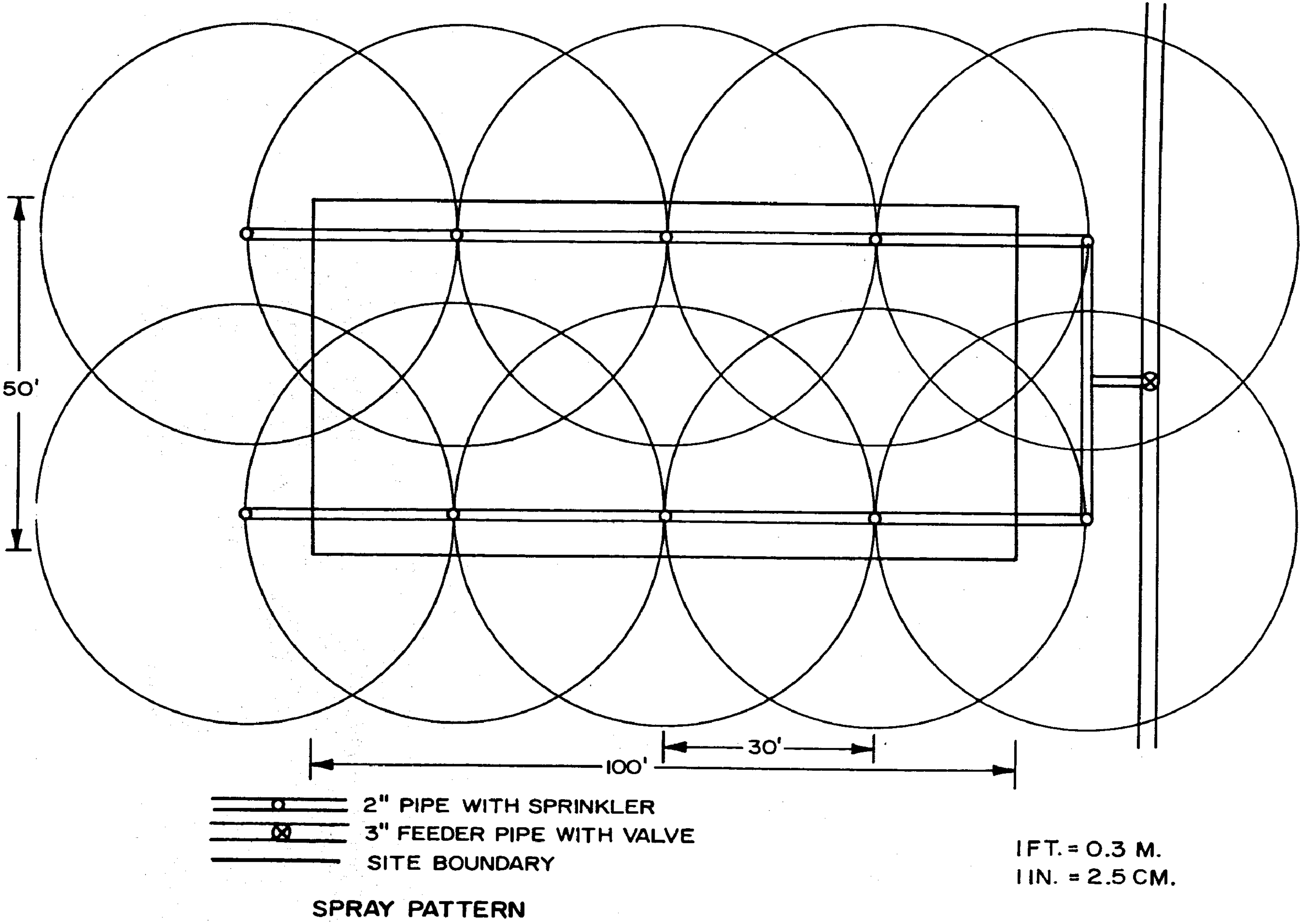


Figure 7. Spray pattern.

applying the effluent and control water. Much of the spray was applied outside the site boundaries to ensure application of water to each site under varying wind conditions.

Field measured flow rates indicated that the sprinkler system was capable of delivering 204 liters per minute (54 gallons per minute). This flow rate is equivalent to an application rate of 0.50 cm (0.197 in.) per hour. Rain gages installed at the soil surface showed that only 0.40 cm (0.159 in.) per hour or 80.7 percent actually reached the ground. The difference was assumed to be caused by evaporation and wind drift.

Effluent and control waters were applied to the sites on four succesive days each week. On the remaining three days the sites were allowed to rest. At the 0.50 cm (0.197 in.) per hour application rate, 7 hours and 37 minutes were required on each application day to apply water to the sites receiving 15.2 cm (6 in.) per week. For the sites receiving applications of 10.2 cm (4 in.) and 5.1 cm (2 in.) per week, 5 hours and 5 minutes and 2 hours and 33 minutes were required, respecpectively. Four hours and 33 minutes per day were required to apply well water at a rate of 10.2 cm (4 in.) per week to the control sites.

Sampling

On each of the test sites, soil moisture sampling devices were installed at depths of 10.2 cm (4 in.), 30.5 cm (1 ft.), 61 cm (2 ft.), and 91.4 cm (3 ft.). Figure 8 shows two sampling devices as they appear when installed in the soil. These samplers were used in collecting soil moisture samples to determine variations in water quality with depth. The sampling devices consisted of a length of PVC tubing with a porous ceramic cup attached to the

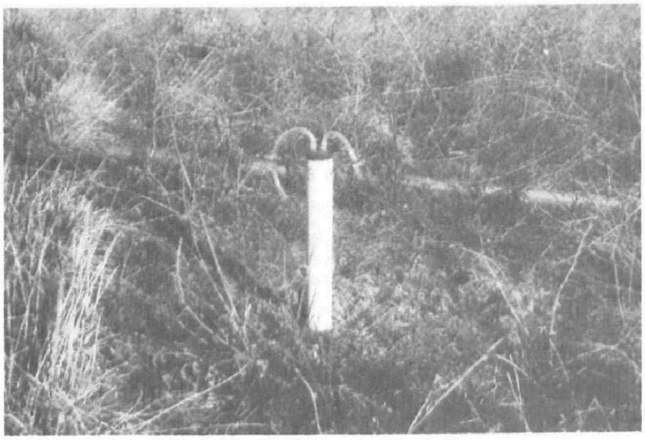


Figure 8. Sampling device.

end placed below the soil surface and a two-hole stopper in the surface end (Figure 9).

The size of materials that can enter the sampling device was determined by the pore size of the ceramic cup. The porous ceramic cups were made of 1 bar ceramic material. The bubbling pressure is the pressure required to force air through a plate of the ceramic material after the plate has been thoroughly wetted with water. The bubbling pressure and pore size relationship is defined by the equation $D = 30\ \gamma/P$ where D is the pore diameter in microns, γ is the surface tension of water measured in dynes/cm, and P is the bubbling pressure measured in mm/Hg (SEC, 1974). According to this formula a 1 bar (750 mm/Hg) ceramic plate would have a pore diameter of 2.9 microns when the water temperature is 20°C.

Impurities in water range in size from a few Angstroms for dissolved substances to a few hundred microns for suspended particles (Weber, 1972). Colloidal particles normally range in size from 1 to 100 millimicrons (Sawyer and McCarty, 1967). The 1 bar ceramic cups with 2.9 micron pore size will, therefore, allow passage of water samples containing dissolved, colloidal size, and a portion of the suspended size materials.

Tubing, connectors, and clamps were installed as shown in Figure 9. By applying suction to tube A with a portable hand pump when clamp b was closed and then closing clamp a, a partial vacuum was established in the sampling device. After a period of 10 to 16 hours, depending on the available soil moisture, a water sample was drawn into the sampling device through the porous cup. The water sample was then collected by loosening clamps a and b and pumping the sample out through tube B into a container. Samples were immediately transported to the laboratory for analysis.

In most cases analysis of the water samples began within one hour after sampling. Refrigeration at 4°C in the dark was used for preservation when storage of samples was required. Twenty-four hours was the longest time that any samples were stored, and the most perishable parameters were analyzed first.

During the first irrigation season, one sampler at each of the four depths was used on the experimental sites. After discovering difficulties in obtaining sufficient sample volume with this arrangement, additional sampling devices were installed for the second season. Each site had two sampling devices at each of the four depths throughout the second season. These duplicate samples were combined in the field.

Soil samples were taken with a slotted 5.1 cm (2 in.) coring device from each of the eight experimental sites. The sample cores were selected to isolate depths from the surface to 15.2 cm (6 in.) below the surface, 22.9 cm (9 in.) to 38.1 cm (15 in.) below the surface, and 76.2 cm (30 in.) to 91.4 cm (36 in.) below the surface. Samples were taken just before the first irrigation season and at the end of the first and second irrigation seasons.

Chemical Analyses

The water samples were analyzed for the N-forms, P-forms, total organic carbon, and specific conductance on a weekly basis. The holding pond water,

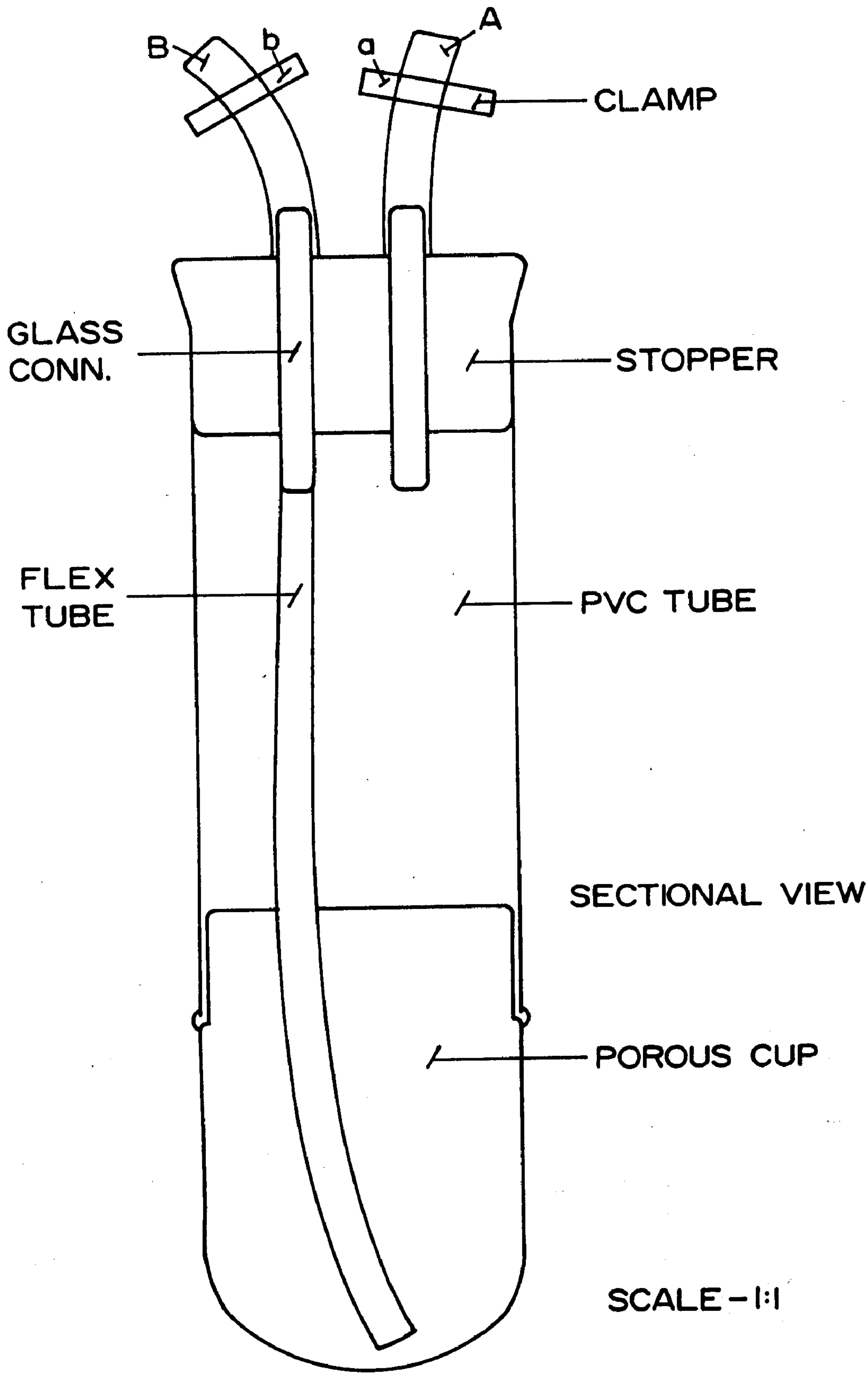


Figure 9. Soil moisture sampling device.

control water, and the return flow from the 10.2 cm (4 in.) mole drain were analyzed weekly for suspended solids and rehydrated volatile suspended solids. All of the analyses were performed according to Standard Methods (APHA, 1971).

Soil samples were analyzed to determine NO_3-N, Na, K, Ca, percent N, percent C, pH, P, specific conductance, and cation exchange capacity.

Vegetation Samples

An experiment was conducted at the end of the second irrigation season to determine if any differences in vegetative growth occurred on the different test sites. Vegetation samples were taken from each of the sites receiving wastewater stabilization pond effluent, the control site, and from an adjacent area that received no irrigation. Five separate 1 square meter areas were randomly chosen from each site. The vegetation was removed near the soil surface from each area using electric clippers. The vegetation was air dried, weighed, and then each sample was ground into a homogeneous mass. Ten percent of each pulverized sample was ashed in a muffle furnace and the ashed weight of vegetation per acre was computed.

Ammonia Stripping

An experiment was performed to determine the amount of volatile ammonia that was being stripped from solution during the spraying process. Samples were collected on three occasions and a sample was collected at a sprinkler nozzle and at the soil surface. Approximately five minutes were required to collect an adequate volume of sample at the soil surface. The water sample did not come in contact with the soil. The only difference between the nozzle sample and the surface sample was the passage of the water through the air as spray droplets. The samples were collected in BOD bottles to prevent volatilization of ammonia within the atmosphere of the container. Three replicates were collected on each occasion to ensure experimental accuracy.

Statistical Analyses

The statistical analyses of the data were accomplished with the assistance of the Utah State University Statistical Program Package (Hurst, 1977). The Multivariate Data Collection Program (MDCR) coupled with the Stepwise Multiple Regression Package (SMRR) was used to perform a general least squares multiple regression analysis of variance. The design was a factorial with water type (stabilization pond effluent or control water), cover type (vegetated or bare), season (1975 or 1976), application rate (5.1 cm/wk, 10.2 cm/wk, 15.2 cm/wk) and weeks (1, 2, 3 weeks) used as the main effects. Two-way interactions were examined and are shown in the appropriate analyses sections which follow.

SECTION 6

RESULTS AND DISCUSSION

LYSIMETER EXPERIMENTS

SAMPLING DIFFICULTIES

The lysimeters were constructed to monitor the effluents from the soil at the 7.6 cm and 38.1 cm soil depths. Although there is much evidence to indicate that the majority of the bacteriological and chemical removal occurs in the first few centimeters of soil, it was very difficult to obtain reliable data at the 7.6 cm depth for a number of reasons. Much of the data from the 7.6 cm sample points were invalid because of short circuiting at the soil surface. This short circuiting was caused by the drying and cracking on the surface between sewage applications. A lysimeter of the size used in this study with so much surface area and surface disturbance as the lagoon effluent was applied would cause nonuniform soil depth which was very critical in evaluating removal at 7.6 cm depth. Often short circuiting was so extreme, samples were not obtained at all from the 7.6 cm level. However, much of the information gathered from the 7.6 cm level was valid and helpful in explaining some of the conditions observed. Fortunately, the principal objective was not to establish at what depth the removal occurred but to study which soil characteristics produced best removals. The 38.1 cm sample points provided information that lead to interesting conclusions.

BACTERIOLOGICAL REMOVAL

The results of the bacteriological analyses for total coliform, fecal coliform, and fecal streptococcal group at the 7.6 cm and 38.1 cm depths are shown in Table 4. Due to an error in technique or use of an inferior method of determination, in some cases the fecal coliform counts were higher than the total coliform which is unlikely.

Although all soils were effective in removing the indicator organism, there was a marked difference in the degree of removal between the Drainage Farm soil and Parleys soil. Removals obtained with Draper and Nibley soils fall between the Drainage Farm and Parleys soils with some variability between the Draper and Nibley soils. Table 5 shows the geometric mean bacterial counts in the lagoon effluent applied to the lysimeters and the effluents from the lysimeters for a 21 day period. Table 6 shows the removal of organisms per cm of soil depth for the four soils and the three organisms. These rates clearly show that the Drainage Farm soil was the most efficient, followed by Nibley, Draper, and Parleys. Graphical presentations of the decrease in counts with depth for the four soils are shown in Figures A-1 through A-4 in

TABLE 4. COUNTS FOR TOTAL COLIFORM, FECAL COLIFORM, AND FECAL STREPTOCOCCAL GROUP AT THE 7.6 AND 38.1 CENTIMETER DEPTHS

TOTAL COLIFORM

Sample Date	Lagoon Effluent	Draper 7.6 cm	Draper 38.1 cm	Nibley 7.6 cm	Nibley 38.1 cm	Parleys 7.6 cm	Parleys 38.1 cm	Drainage Farm 7.6 cm	Drainage Farm 38.1 cm
10/30	OC	110	OC	NS	OC	NS	OC	NS	OC
11/1	OC	1	OC	NS	40	OC	OC	OC	< 1
11/3	48	4	2	OC	24	OC	44	OC	< 1
11/5	76	< 1	< 1	4	4	OC	12	OC	5
11/7	494	26	42	244	40	60	66	16	< 1
11/9	300	40	33	NS	103	OC	400	486	< 1
11/10	650	26	20	247	11	240	96	640	1
11/11	720	7	145	304	12	20	88	40	4
11/12	200	6	< 1	44	7	< 1	20	60	3
11/13	60	< 1	< 1	NS	10	20	24	30	< 1
11/14	64	5	< 1	12	13	< 1	9	< 1	2
11/15	13	< 1	< 1	NS	3	< 1	4	27	< 1
11/16	60	< 1	2	NS	10	< 1	< 1	< 1	< 1
11/17	48	< 1	OC	35	3	OC	2	OC	< 1
11/18	65	OC	OC	NS	3	OC	OC	20	2
11/19	45	< 1	< 1	NS	3	< 1	1	< 1	< 1
11/20	25	OC	OC	20	6	OC	< 1	OC	< 1
11/21	20	OC	< 1	13	10	< 1	1	< 1	3
11/22	27	< 1	< 1	NS	6	< 1	< 1	20	< 1
11/23	40	< 1	< 1	40	4	< 1	2	10	< 1
11/24	10	< 1	< 1	20	3	30	2	10	< 1
11/25	33	2	< 1	32	3	< 1	< 1	< 1	2
11/26	8	45	112	NS	264	146	195	1350	< 1
11/27	60	21	< 1	NS	20	180	18	920	< 1
11/29	50	29	< 1	NS	32	250	19	200	< 1

FECAL COLIFORM

Sample Date	Lagoon Effluent	Draper 7.6 cm	Draper 38.1 cm	Nibley 7.6 cm	Nibley 38.1 cm	Parleys 7.6 cm	Parleys 38.1 cm	Drainage Farm 7.6 cm	Drainage Farm 38.1 cm
10/30	13	OC	OC	NS	OC	NS	OC	NS	OC
11/1	16	1	< 1	NS	3	10	6	17	< 1
11/3	7	2	< 1	13	< 1	3	2	2	< 1
11/5	7	3	< 1	NS	2	11	3	OC	< 1
11/7	200	2	33	NS	6	130	13	157	< 1
11/9	TNTC	22	26	NS	20	TNTC	186	TNTC	< 1
11/10	TNTC	30	18	141	4	TNTC	87	TNTC	< 1
11/11	135	2	51	130	10	110	14	115	< 1
11/12	95	7	8	NS	2	10	6	45	1
11/13	55	7	3	NS	< 1	1	2	40	< 1
11/14	37	2	7	1	3	10	3	10	< 1
11/15	16	5	5	NS	1	20	1	10	1
11/16	46	6	4	NS	2	36	14	48	< 1
11/17	17	9	5	< 1	3	9	6	9	< 1
11/18	44	5	2	NS	3	24	7	31	< 1
11/19	32	3	1	NS	1	14	7	14	< 1
11/20	5	1	3	68	2	11	7	OC	< 1
11/21	31	4	3	44	6	4	16	7	< 1
11/22	26	5	2	NS	1	37	13	2	< 1
11/23	38	1	1	72	2	2	4	8	< 1
11/24	19	2	1	11	1	27	7	29	< 1
11/25	92	2	3	14	1	203	9	27	< 1
11/26	1000	200	70	NS	166	1000	200	1200	< 1
11/27	520	10	4	NS	32	80	150	95	< 1
11/29	610	2	1	NS	47	50	145	42	< 1

FECAL STREPTOCOCCUS

Sample Date	Lagoon Effluent	Draper 7.6 cm	Draper 38.1 cm	Nibley 7.6 cm	Nibley 38.1 cm	Parleys 7.6 cm	Parleys 38.1 cm	Drainage Farm 7.6 cm	Drainage Farm 38.1 cm
10/30	94	44	75	NS	15	NS	OC	NS	OC
11/1	166	47	19	NS	7	25	63	141	< 1
11/3	12	20	9	111	3	90	< 1	335	< 1
11/5	104	22	4	NS	8	145	15	291	< 1
11/7	187	26	80	98	4	217	2	302	< 1
11/9	285	30	3	NS	1	320	22	275	1
11/10	274	23	16	65	5	188	42	324	< 1
11/11	135	19	18	52	15	155	6	152	< 1
11/12	180	36	9	NS	3	< 1	< 1	211	< 1
11/13	137	28	8	NS	3	< 1	< 1	120	1
11/14	112	21	6	NS	1	51	< 1	362	< 1
11/15	78	24	3	NS	< 1	73	1	510	< 1
11/16	56	21	5	NS	2	27	< 1	112	< 1
11/17	47	9	6	5	1	51	1	2000	< 1
11/18	50	16	4	NS	3	142	27	375	< 1
11/19	57	20	4	NS	3	62	1	50	< 1
11/20	107	8	3	11	2	83	2	1205	< 1
11/21	37	7	1	24	7	96	8	812	1
11/22	107	9	4	NS	3	122	26	4000	< 1
11/23	30	9	3	30	16	27	5	5700	< 1
11/24	52	2	2	< 1	14	30	4	630	1
11/25	85	5	1	26	14	80	3	2690	< 1
11/26	1000	48	11	NS	59	550	59	1530	< 1
11/27	600	31	5	NS	30	200	50	1000	< 1
11/29	165	2	1	NS	25	50	39	200	< 1

NS--No Sample OC--Overgrown TNTC--Too Numerous To Count

TABLE 5. MEAN BACTERIAL COUNTS OVER A 21-DAY PERIOD

Soil Type	Depth Below Surface	Total Coliform, Counts/100 ml	Fecal Coliform, Counts/100 ml	Fecal Streptococcus, Counts/100 ml
Drainage Farm	Lagoon Effluent			
	Surface	160	64	100
	7.6 cm	92	34	860
	38.1 cm	1	<1	<1
Nibley	Lagoon Effluent			
	Surface	160	64	100
	7.6 cm	81	50	42
	38.1 cm	15	3	6
Draper	Lagoon Effluent			
	Surface	160	64	100
	7.6 cm	9	6	20
	38.1 cm	7	8	10
Parleys	Lagoon Effluent			
	Surface	160	64	100
	7.6 cm	47	34	94
	38.1 cm	41	20	11

TABLE 6. REMOVAL RATES OF INDIVIDUAL ORGANISMS FOR THE FOUR SOILS

Soil Type	Bacterial Organisms		
	Total Coliform	Fecal Coliform	Fecal Streptococcus
Drainage Farm	0.091	0.083	0.088
Nibley	0.050	0.068	0.060
Draper	0.062	0.051	0.052
Parleys	0.015	0.031	0.050

$$\text{Rates} = \frac{\text{Log organisms removed}}{\text{cm of soil}}$$

Appendix A. The primary reasons for the better removals by Drainage Farm soi is the texture. The Drainage Farm soil was by far the most dense, and remov organisms by the three mechanisms of straining, bridging, and straining and sedimentation. It appears that the texture is the most important factor between these four soils in terms of bacterial removal.

REMOVAL OF PHYSICAL AND CHEMICAL CONSTITUENTS

The results of the physical and chemical analyses are summarized in Tables A-1 through A-15 in Appendix A. The characteristics of the four soils before and after the application of lagoon effluent are summarized in Table 7. Individual constituents are discussed separately in the following sections.

Nitrogen

Figures 10, 11, and 12 show the concentrations of nitrate-nitrogen, nitrite-nitrogen, and ammonia-nitrogen in the lagoon effluent and the effluent samples collected at the 38.1 cm sampling point on the lysimeters containing Drainage Farm soil. Variations in the concentrations with time at the 7.6 and 38.1 cm depths for the Draper, Nibley, and Parleys soils are shown in Figures A-5 through A-13 in Appendix A. Due to the short circuiting near the surface, the 7.6 cm sample points cannot be considered reliable.

An appreciable increase in nitrate concentration over the amounts present in the lagoon effluent is shown in Figure 10 and Figures A-5 through A-13. This increase is attributable to the production of ammonia from the decomposition of organics present in sewage and trapped on and in the soil and that already present in the soil as well as the oxidation of ammonia present in the lagoon effluent.

Figures 10 and 12 show that in the lagoon effluent the concentrations of the nitrate-nitrogen remained relatively constant and the ammonia-nitrogen concentration increased toward the end of the lysimeter study.

A balance of the nitrogen applied and removed from the lysimeter indicated that the soils contained significant amounts of nitrogen before the lagoon effluent was applied. Leaching of nitrates from the soils accounts for part of the high concentrations of nitrate-N in the lysimeter effluents.

Nibley (silty clay loam) and Drainage Farm (clay) soils produced appreciably higher concentrations of nitrate in the lysimeter effluents collected at the 38.1 cm depth than the effluents from the Parleys (silty loam) and Draper (sandy loam) soils. Nitrates are more easily leached from sandy soils, and the denser or clay-like soils produced higher levels of nitrate with the higher amounts of organic matter present. The Drainage Farm and Nibley soils produced the lowest concentrations of ammonia-N indicating that ammonia is not as readily leached out.

Total Organic Carbon (TOC)

To explain the nitrate build-up in the soils, a high quantity of ammonia and/or organic nitrogen would be required. Ammonifiers comprise a large percentage of the bacteria and fungi in soil, and these organisms are heterotrophic (utilize organic carbon for growth). Figure 13 shows the concentration of TOC in the influent and effluents from the lysimeters containing Drainage Farm soil. Variations in TOC concentrations with time for Draper, Nibley, and Parleys soils are shown in Figures A-14 through A-16 in Appendix A. Figure 13 shows that the concentrations of TOC in the effluents correspond fairly close to the concentrations of TOC in the lagoon effluent applied.

TABLE 7. CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE FOUR SOILS BEFORE AND AFTER THE APPLICATION OF LAGOON EFFLUENT

	DRAPER			NIBLEY			PARLEYS			DRAINAGE FARM		
	Before Test Period	After Test Period		Before Test Period	After Test Period		Before Test Period	After Test Period		Before Test Period	After Test Period	
		Top	32.5 cm		Top	32.5 cm		Top	32.5 cm		Top	32.5 cm
pH	7.1	8.4	7.8	7.4	8.1	7.7	7.6	8.1	7.7	8.1	8.2	8.3
ECe mmhos/cm	1.1	.7	.5	.5	.7	.5	.6	.9	.6	.9	.7	.5
P mg/l	13.0	21.0	19.0	27.0	31.0	26.0	4.5	11.0	3.9	7.1	32.0	6.4
K mg/l	171.0	81.0	110.0	490.0	378.0	408.0	398.0	315.0	389.0	490.0	399.0	450.0
Texture	Sandy Loam	Sandy Loam	Silt Loam	Silt Loam	Clay	Clay	Silt Loam	Silt Loam	Silt Loam	Clay	Silty Clay Loam	Silty Clay Loam
Lime	+	+	+	+	++	++	++	++	++	++	++	++
Org. Matter %	2.3	.5	1.2	3.7	1.0	1.1	1.9	1.1	1.2	5.5	2.2	2.8
Exch. Na me/100g	.2	.2	.2	.3	.4	.3	.2	.4	.4	.8	.4	.4
Total Na me/100g	.2	.2	.3	.3	.5	.4	.2	.5	.4	1.2	.5	.6
Water Sol. Na. me/100g	.1	.1	.1	.1	.1	.1	.1	.1	.1	.3	.2	.1
Cation Exch. Capacity me/100g	9.9	5.1	8.8	23.6	19.6	21.2	17.7	11.8	12.2	19.7	12.0	15.7
Water Saturation %	28.0	21.0	29.0	56.0	60.0	66.0	42.0	42.0	44.0	83.0	81.0	90.0
Moisture Storage Capacity cm/cm	2.54/34	2.54/34	4.45/34	4.45/34	5.70/34	5.70/34	4.45/34	4.45/34	4.45/34	5.70/34	5.08/34	5.08/34

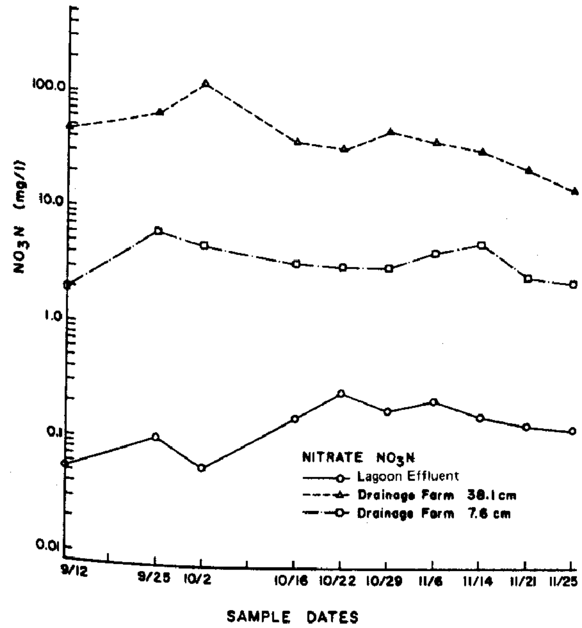


Figure 10. Nitrate-N concentrations in the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

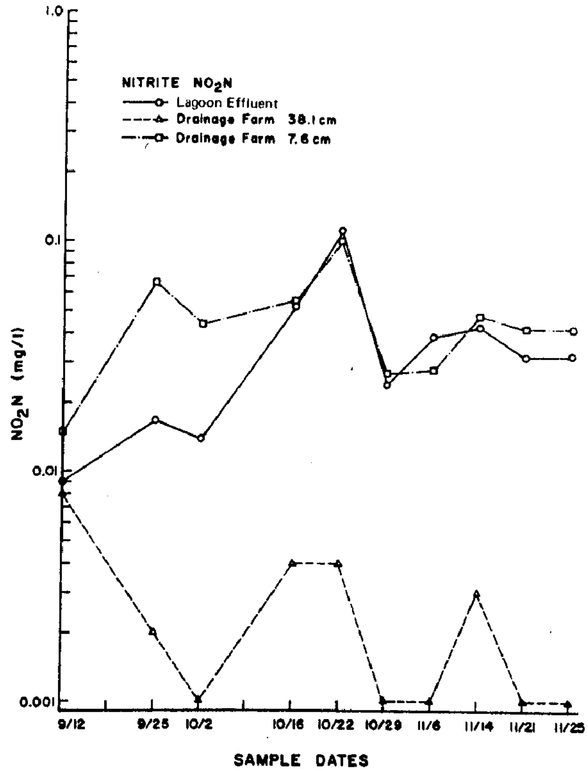


Figure 11. Nitrate-N concentrations in the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

An examination of the before and after analyses of the soils (Table 7) shows a marked decrease in the organic material present in the soils. The clay-like soils, Nibley and Drainage Farm, again show the greatest decrease in organic matter, 70 percent and 50 percent, respectively; whereas, Draper soil experienced a 48 percent reduction and Parleys was reduced by 37 percent (all reductions calculated at the 38.1 cm depth).

Figure 13 shows that organics were leached from the soil or passed through the soil. Table 7 shows a significant decrease in organic content of the soil after the application of lagoon effluent indicating that the lagoon effluent was leaching organics from the soils.

Algal Cells

Figure 14 supports the observation that the Drainage Farm soil provides the best treatment of lagoon effluent followed by Nibley, Draper, and Parleys soils. The removal of algal cells should be controlled by straining, bridging, and straining and sedimentation. At the beginning the percent removal of

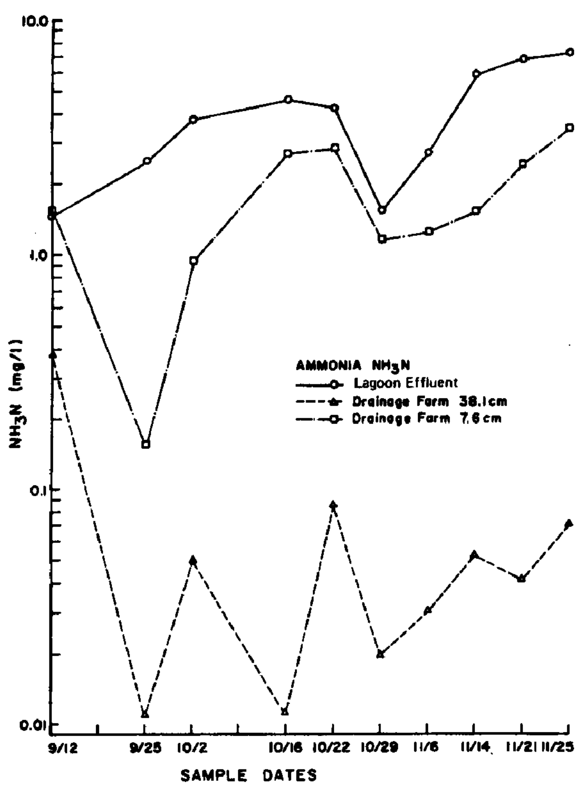


Figure 12. Ammonia-N concentrations in the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

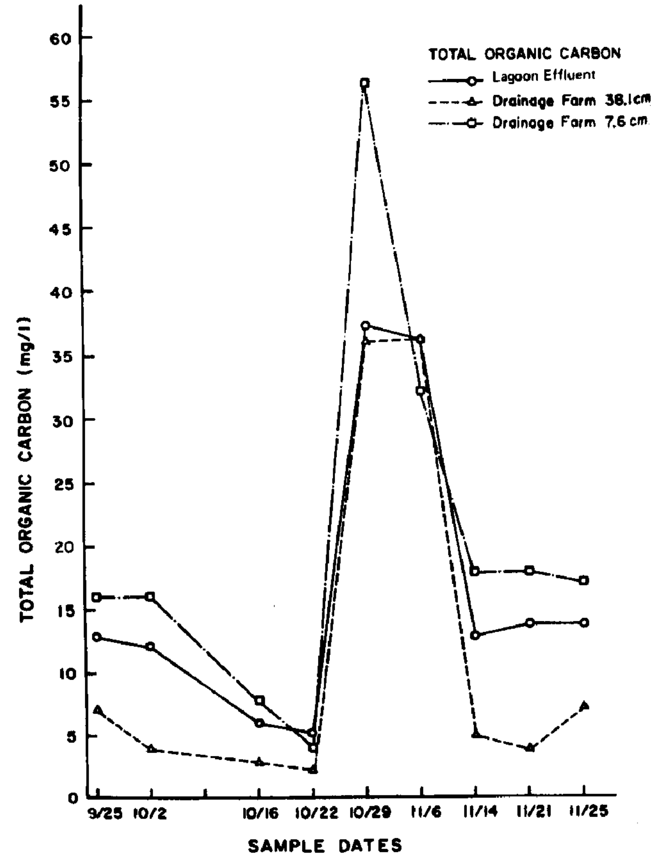


Figure 13. Total organic carbon concentrations in the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

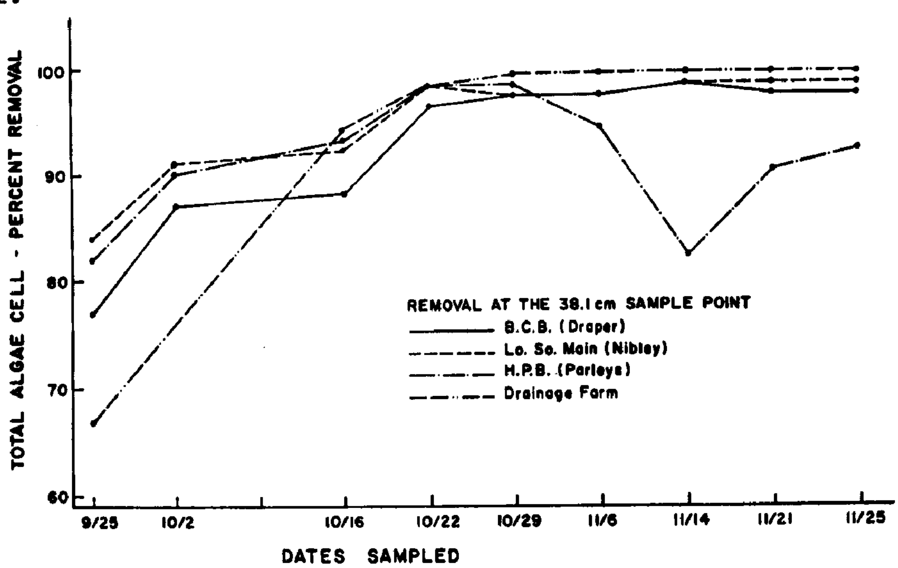


Figure 14. Total algal cell percent removal at the 38.1 centimeter depth for all soils studied.

algae was much lower than toward the end of the experiments. This increased removals could have been caused by the buildup of a film on the soil surface or the elimination of soil separation (cracking) near the end of the experiment. Before the biological analyses began, lagoon effluent was applied to the lysimeters only three times weekly as opposed to daily application near the end of the experiment. In the soils with a higher percent clay, the cracking would be expected to be more severe, thereby explaining the lower algae removal by the Drainage Farm (clay) soil initially. As the algal cells accumulated on the soil surface, the removal would be expected to increase as observed. The sudden decrease in percent removal by the Parleys soil after October 29 occurred because the soil surface of this lysimeter was re-leveled drastically disturbing the clogged pores and decreasing the filterability. After October 29, the suspended solids and volatile suspended solids in the effluents from the disturbed lysimeter increased as shown in Figures A-19 and A-22 in Appendix A.

Suspended Solids

Figures 15 and 16 show the suspended and volatile suspended solids concentrations in the lagoon effluent and the effluent from the lysimeters for the Drainage Farm soil for the duration of the lysimeter experiment. Both suspended and volatile suspended solids were removed effectively with concentrations less than 5 mg/l for the suspended solids and less than 2 mg/l for the volatile suspended solids passing through the soil. Variations in the suspended and volatile suspended solids concentrations for Draper, Nibley, and Parleys soils are shown in Figures A-17 through A-22 in Appendix A. The concentrations of suspended and volatile suspended solids in the influent remained fairly constant while concentrations in the effluents at the 38.1 cm sampling points were constantly decreasing. The increasing removal toward the end of the period shows an increased filtering effect caused by straining and sedimentation and also utilization of the volatile or organic matter present. Drainage Farm soils produced the best solids removals with Nibley second. Both of these soils have tighter pore spaces and longer residence times which provide good removal by filtration and retain the liquid longer allowing the organisms to utilize the organic matter. Solids removals obtained with the Draper and Parleys soils were good with concentrations of less than 10 mg/l in the effluents. The mean suspended and volatile suspended solids removals provided by the Draper and Parleys soils were approximately 85 percent after an acclimation period.

Phosphorus

Phosphorus removal by a soil is a result of a combination of adsorption of phosphate and precipitation of compounds of phosphorus. Shewman (1973) found that the soil properties most likely correlated with adsorption would be surface area and the related properties, percent clay, and cation exchange capacity. The quantity and condition of lime present probably influences both precipitation and adsorption.

Figures 17 and 18 of the Drainage Farm soil show that almost all of the phosphate exists as orthophosphate. Total and orthophosphate concentrations in the influent and effluent samples for Draper, Nibley, and Parleys soils

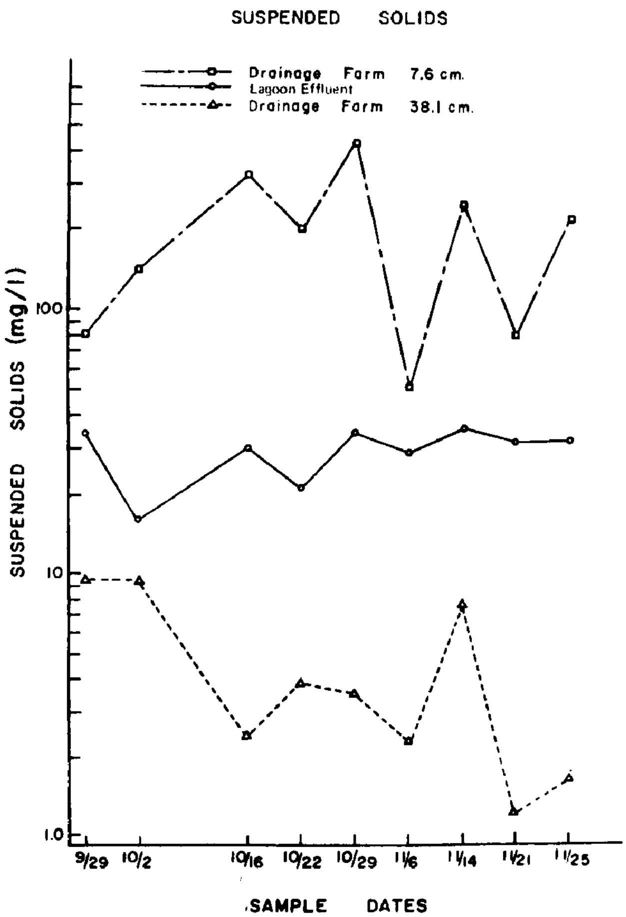


Figure 15. Suspended solids concentrations in the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

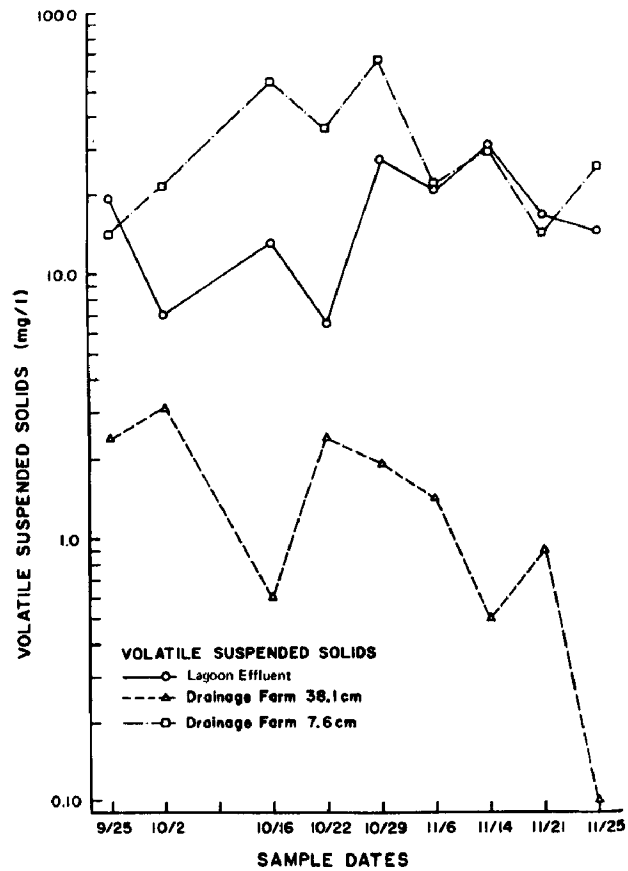


Figure 16. Volatile suspended solids concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Drainage Farm soil.

are shown in Figures A-23 through A-28 in Appendix A. The total phosphate concentrations in the samples collected at the 38.1 cm sampling point show consistent results, fluctuating only when the influent concentration varies. The removal of total phosphate appeared to be attributable to adsorption. Orthophosphate influent concentrations were less than the total phosphate in the influent, but the concentrations of orthophosphate in samples from the 38.1 cm sampling points were approximately equal with the total phosphate, suggesting a change of form or increase from another source.

Drainage Farm soil was again the most effective treatment media followed by Parleys, Draper, and Nibley. As stated earlier, phosphorus removal capacit is based on surface area and these soils show this to be true. Drainage Farm (clay), Parleys (silt loam), and Draper (sandy loam) were the most effective; however, Nibley should have removed phosphorus more effectively based on surface area. Nibley soil, a silty clay loam, should have removed phosphorus at a rate comparable to the Drainage Farm soil.

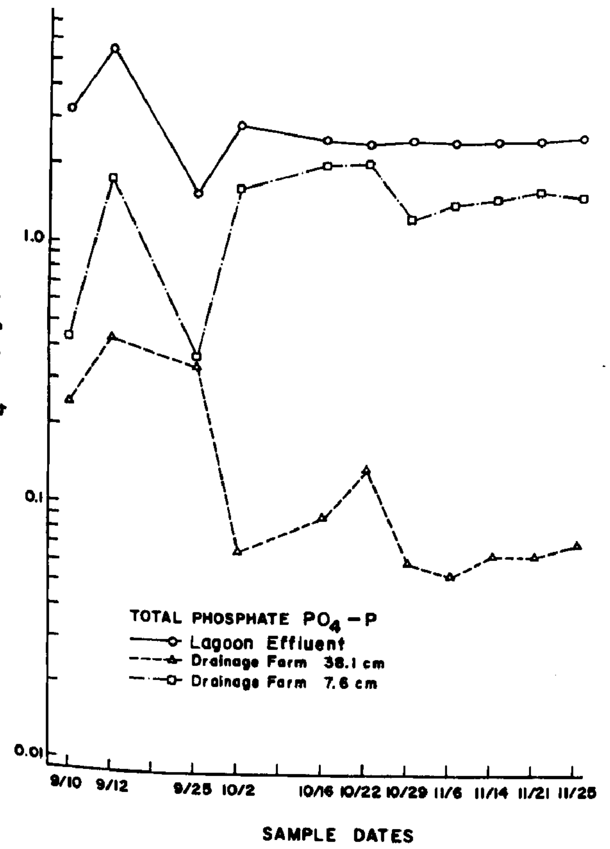


Figure 17. Total phosphate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

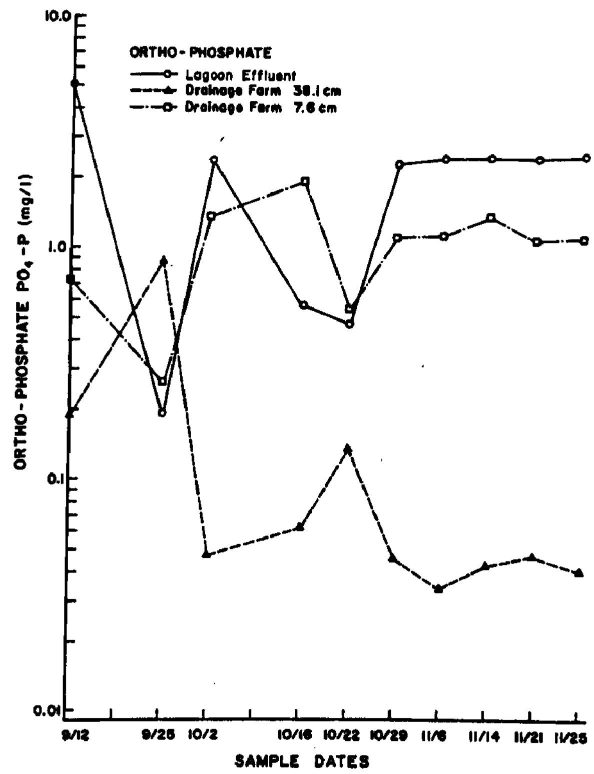


Figure 18. Orthophosphate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

The cation exchange capacities (C.E.C.; see Table 7) of the soils were: Nibley, 23.6; Drainage Farm, 19.7; Parleys, 17.7; and Draper, 9.9. Nibley soil had the highest (23.6) exchange capacity and better phosphorus removal was expected. Either the Nibley soil did not have the capacity to perform at the loading rates applied, or there was short circuiting within the bed. The influent phosphorus concentrations to the lysimeters were low varying from 2 to 4 mg/l; therefore, only a small degree of short circuiting would heavily influence the concentrations in the effluents. The percent of clay and quantity of lime in the soils (Table 7) also supports the observed results; however, here again Nibley does not follow the rule so we must conclude, a small degree of channeling may have occurred in this lysimeter.

pH

Figure 19 shows the pH values for the lagoon effluent applied to the soils and the pH values for the samples collected at the 7.6 cm and 38.1 cm

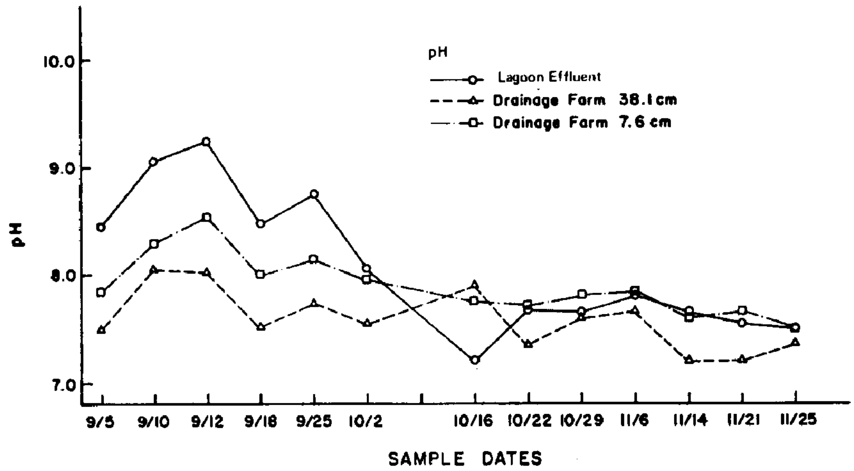


Figure 19. The pH values for the influent and effluent samples collected at the 7.6 and 38.1 centimeter sampling depths for the lysimeters containing Drainage Farm soil.

sampling depths in the lysimeters containing Drainage Farm soil. The pH values for the influent and effluent from the lysimeters containing Draper, Nibley, and Parleys soils are given in Figures A-29 through A-31 in Appendix A. The pH values for the samples collected at the 7.6 cm sampling depth were generally lower than the pH values in the lagoon effluent applied but not as low as the pH values in the effluent collected at the 38.1 cm sampling depth.

The pH value of the lagoon effluent was usually in the range of 7.8 to 8.5. The pH values from the 7.6 cm samples averaged around 7.5 to 8 while the 38.1 cm samples produced pH values around 7.0 to 7.25. The drop in pH may have been caused by production of CO_2 and organic acids resulting from bacterial action in the soil. Nitrification of the ammonium and removal of carbonate also reduces pH. These factors would almost all be dependent on the detention time for their degree of effect. Therefore, it is generally observed that those samples from the 38.1 cm sampling depth which had the longest detention time produced the greatest reduction in pH values.

Changes in Soil Properties

The soils studied provided good removal of various constituents and bacteria, but their individual characteristics did not change drastically as Table 7 indicates. As in the determination of chlorophyll ''a'' and pheophytin ''a'' in the lagoon effluent, the analysis of the core samples for chlorophyll ''a'' did not detect concentrations high enough to be of significant value. The noticeable changes occurred in phosphorus, percent organic matter, and cation exchange capacity.

The phosphorus, as would be expected, increased on the surface of all soils especially on the clay (Drainage Farm). Because phosphate does not move readily through the soil, an increase was observed on the surface and a slighte increase at the 32.5 cm depth. As indicated by Table 7, the phosphorus removal by Parleys and Draper soils were also significant.

The organic matter in the soils decreased considerably as discussed earlier; however, it is apparent that this decrease had some affect on the cation exchange capacity. The soils with a higher percentage of organic matter at the start, i.e., Nibley and Drainage Farm soils had a higher C.E.C. ''Soils high in organic matter have substantial cation exchange capacities because of the large negative charge developed by the humus'' (Coleman and Mehlich, 1957). Therefore, the C.E.C. was observed to decrease proportionally with the decreased organic material in the final analysis of the soils.

SECTION 7

RESULTS AND DISCUSSION

FIELD EXPERIMENTS

OPERATION DIFFICULTIES

Obtaining adequate samples with the soil moisture sampling devices was difficult especially during the first irrigation season. Often samples of sufficient volume to run the entire battery of tests could not be obtained. This problem was negated to a considerable degree during the second season when additional sampling devices were installed.

Only soil samples were obtained on the control sites during the first irrigation season because well water was not available. During the second season well water was applied to the control sites.

Numerous mechanical failures prevented the collection of continuous data during the first season. A submersible turbine pump was initially used in the holding pond to supply stabilization pond effluent to the sprinklers. After three weeks of satisfactory performance, the pump became hopelessly clogged with the matted algal material growing in the holding pond. When the pump was unclogged, only one or two days of operation was obtained. A centrifugal pump was then selected to replace the submersible turbine pump. Uninterrupted operation of the sprinkler system resumed on the eighth week of the first irrigation season. The centrifugal pump continued to give unfailing service for the remaining part of the first season and throughout the second irrigation season.

Several pipe ruptures occurred when exposed pipeline was damaged by vehicles in the field or damaged by vandals. The pipeline appeared to be the target for irresponsible marksmen. Such events hampered the operation of the system and the collection of data.

The experimental time period covered 13 weeks the first season starting on July 27 and ending October 8, 1975. The second season began on June 28 and ended on October 8, 1976, covering a span of 14 weeks. The data collection proceeded without interruption throughout the second irrigation season.

OPERATION AND OBSERVATIONS

Some difficulties were encountered operating at the irrigation rates used in this study. The 15.2 cm (6 in.) per week rate was far in excess of the infiltration capacity and evapotranspiration demand of the Drainage Farm system. Throughout both irrigation seasons the vegetated and bare sites receiving 15.2 cm (6 in.) per week of effluent experienced extensive ponding of water on the soil surface. This high application rate saturated the soil to the point that water was still standing after the weekly three day drying period. A floating algal mat developed in standing water on the bare site receiving 15.2 cm (6 in.) per week. The clay layer beneath the topsoil presented a barrier to vertical movement of this excess water through the soil. With the 15.2 cm (6 in.) per week rate, more water was available for percolation than could pass through the clay barrier. Water infiltrated the topsoil until reaching the clay and then moved horizontally beyond the site boundaries.

On the bare site receiving 10.2 cm (4 in.) of effluent per week, ponding and horizontal migration of the irrigation water also occurred, but the problem did not occur until mid-season. With the 10.2 cm (4 in.) per week application rate it took a few weeks to fill the moisture capacity of the soil and then ponding and horizontal migration occurred. On the vegetated site receiving 10.2 cm (4 in.) of effluent per week, ponding and migration of the water beyond the site boundaries did not occur until the last three or four weeks of the irrigation season. During the hottest part of the summer, evaporation and transpiration rates were high and all water applied to the vegetated site receiving 10.2 cm (4 in.) per week was gone before the start of irrigation on the following day. In the fall, near the end of the irrigation season when temperatures were lower and the growth of vegetation had subsided, ponding persisted on the vegetated site receiving 10.2 cm (4 in.) per week.

With the 5.1 cm (2 in.) per week application rate, ponding and horizontal migration of the irrigation water was not a problem at any time on the vegetated site. On the bare site the problems did not occur until near the end of the irrigation season. Five cm (2 in.) was well within the combined evapotranspiration and infiltration capacity found with the vegetated site. Even at the end of the irrigation season when the water demand was lowest, ponding and horizontal migration did not occur.

On all of the bare sites receiving effluent, an algal growth appeared on the surface of the soil. The intensity of the algal growth appeared to be about the same with all of the application rates. Algal growth was not observed on the vegetated sites. Some algal growth was observed on the bare control site. The intensity of the algal growth on the control site was minute in comparison to that on the sites receiving effluent application. Apparently the nutrient content of the effluent stimulated algal growth on the sites receiving effluent. Some of the algae observed on the surfaces of the bare plots were contained in the effluent and were trapped on the surface as the water passed into the soil. The moist conditions and high nutrient content of the effluent probably encouraged the algae to reproduce on the soil surface. Ponding and horizontal migration of water on the control sites was similar to that occurring on the sites receiving effluent at the same 10.2 cm (4 in.) per week application rate. This indicates that the heavier algal growth on the effluent test sites had little effect on the infiltration rate.

Large mosquito populations were observed in the Drainage Farm area. On the test sites there was a noticeable increase in the number of hostile mosquitoes as one moved to the sites receiving the higher application rates.

Shallow standing water provided mosquito breeding areas on the sites receiving 15.2 or 10.2 cm (6 or 4 in.) per week.

Because mosquitoes are an unpleasant nuisance and a possible disease transmission vector, it is important to operate a soil mantle treatment system so that mosquito breeding areas do not develop. Of the application rates used at the University Drainage Farm, only the 5.1 cm (2 in.) per week used on a vegetated site avoided the mosquito problem. An absence of standing water and frequent drying out of the area are desirable conditions to inhibit mosquito reproduction. The control of mosquito breeding was directly related to the application rate and the ability of the soil and vegetation to assimilate the wastewater. The difficulties encountered in this study show the importance of conducting pilot scale studies before installing a full scale irrigation system for soil mantle treatment of wastewater stabilization pond effluent.

The water recovered from the drainage system appeared to be colorless and free from turbidity. The drainage effluent was also free of odors and was similar to a typical effluent from an irrigation farm. Details of the changes in the chemical and sanitary characteristics of the wastewater stabilization pond effluent as it passed through the soil are presented in other paragraphs.

APPLICATION TO LOGAN SYSTEM

Approximately 32,200 m^3/day (8.5 MGD) of wastewater are treated by the Logan City wastewater stabilization pond system. A soil mantle treatment facility of 1,160 hectares (2,860 acres) would be required to treat the effluent assuming an application rate of 5.1 cm (2 in.) per week and a 20 week season. This is a conservative estimate of the land requirement since higher application rates may be permissible during peak evapotranspiration periods. Climate, soil type, vegetation employed, and the characteristics of the wastewater are factors which will affect the land requirement. Land requirements are site specific and must be evaluated at each location before a system is constructed.

SPECIFIC CONDUCTANCE AND SODIUM ADSORPTION RATIO

The specific conductance data are shown in Tables B-1 and B-2 and graphically in Figures B-1 through B-8. The results of the sodium adsorption ratio (SAR) determinations are shown in Table B-15.

The results of the statistical analysis of the specific conductance data is summarized in Table 8. The statistical results showed that none of the specific conductance results were significant at the 95 percent confidence level. The correlation coefficient (R^2) was only 0.10, which indicated that one-tenth of the performance characteristics of the soil mantle treatment process were attributable to specific conductance. The variation in the observed specific conductance levels was probably caused by differences in the soil system between sites and between depths in the soil profile.

Although not indicated by statistical results, some observations can be made. Figures B-1 through B-8 show that the specific conductance of the

TABLE 8. SPECIFIC CONDUCTANCE STATISTICAL ANALYSIS

Main Effects	Significant @ 95 Percent	
Water Type	No	No[a]
Cover Type	No	No[a]
Application Rate	No	No[a]
Sample Depth	No	No[a]
Season	No	NA
Weeks	No	No[a]
<u>Two-Way Interactions</u>		
Cover Type x Application Rate	No	No[a]
Cover Type x Sample Depth	No	No[a]
Cover Type x Weeks	No	
Application Rate x Sample Depth	No	No[a]
Application Rate x Weeks	No	No[a]
Water Type x Weeks	No	
Sample Depth x Weeks	No	
Water Type x Sample Depth		No[a]

$R^2 \simeq 0.10$
$R^2 = 0.098$[a]

[a]Analysis of data with season 1 excluded.

stabilization pond effluent and the control water were approximately equal and much lower than that of the water samples collected each week. Several factors indicate increased salinity with depth. After passing through just the top 10 cm (4 in.) of soil, the specific conductance of the water samples was usually double or more than that of the applied irrigation water. An apparent trend of increasing specific conductance is shown in Figures B-2 through B-8. The conductivity of the soil mositure extract taken from soil samples also seem to increase with depth. Table B-15 shows that the SAR values for the water samples were usually higher in water samples taken at the 91.4 cm (3 ft.) depth than at the 10.2 cm (4 in.) depth. This is an indication that salinity not only increases with depth, but that the salts involved may be sodium salts. The lysimeter study showed that the specific conductance of stabilization pond effluent increased as the water percolated through soil.

The increase in salinity in the water samples can be explained by the salt balance concept described by the following equation (USU, 1969):

$$Q_c C + S_w + \text{others} - (Q_d C + Sppt + S_c) = 0$$

in which

Q_c = quantity of irrigation water
Q_d = quantity of drainage water
C = concentration of salt
S_w = salt from weathering

Sppt = salt precipitated
S_c = salt in the crops

Figure 20 illustrates the salt balance concept and how the salt concentration of the soil solution can be affected.

The apparent increase in salinity in the water samples can be explained by:

1. Consumptive use (evapotranspiration) of water by the vegetation increases the concentration of salts in the soil solution (USU, 1969; Jurinak, 1975)

2. Salt concentration often increases with depth in the soil profile due to the dynamic nature of the salt transport (USU, 1969)

3. Salt concentration is affected by weathering and precipitation processes during irrigation (USU, 1969; Jurinak, 1975)

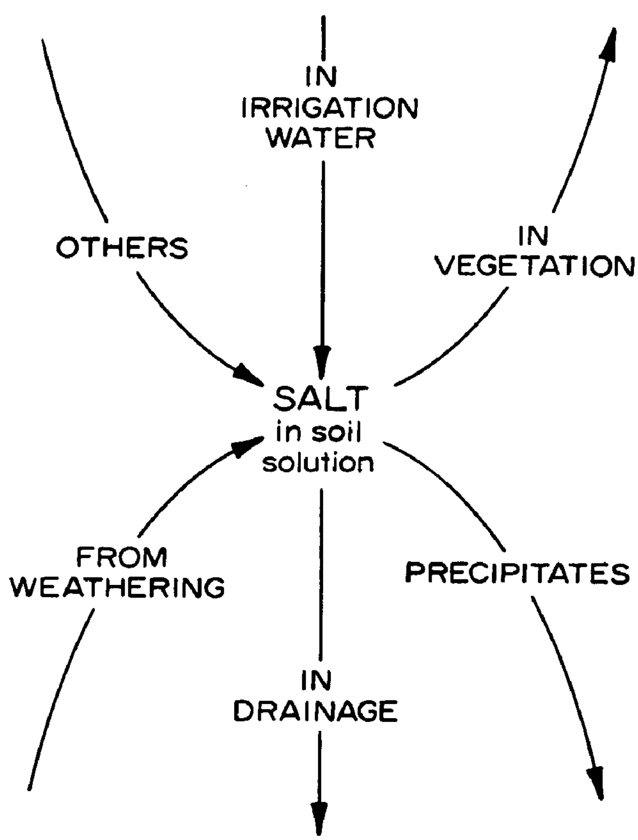


Figure 20. Salt concentration in the soil solution.

There was some evidence that leaching of salts occurred in the soil mantle treatment system. The specific conductance values of the water samples taken during the second irrigation season appear to be lower, on the average, than during the first season. A downward or negative slope on the specific conductance graphs (Figures B-2 through B-8) suggests leaching. In a majority of the soil tests, a decrease in specific conductance and sodium was observed between the initial specific conductance and the values observed at the end of the second irrigation season (Table B-14). There is some question about the reuse of treated wastewater that might be collected in subsurface drains. Pillsbury and Blaney (1966) considered water having a specific conductance of 7500 micromhos/cm or more ''essentially valueless for irrigation water.'' The specific conductance of many of the water samples exceeded 7500 micromhos/cm. This was especially true at the 91.4 cm (3 ft.) sample depth.

Figure 21 is a classification diagram for the evaluation of salinity and sodium hazards of irrigation water (USDA, 1954). The classification scheme used in Figure 21 is explained in Table 9.

If values of specific conductance from Table B-1 and sodium adsorption ratios from Table B-15 are indexed on Figure 21, it can be seen that in most cases the hazard due to salinity in crops was high to very high. The hazard due to sodium ranges from low to very high. At the 91.4 cm (3 ft.) depth the sodium hazard was usually medium or high. The combination of C_3 and C_4 salinity hazard with predominantly S_2, S_3, and S_4 sodium hazards, make the soil mantle treated water undesirable for reuse as irrigation water especially on a soil such as that found at the USU Drainage Farm (i.e., high clay, poor drainage).

AMMONIA

The ammonia-N removals obtained with the soil mantle treatment process are shown in Tables B-3 and B-4 and Figures B-9 through B-16. Mechanisms for removal of ammonia from wastewaters using a soil mantle treatment process include stripping when sprinkler application is used, nutrient uptake by vegetation, and the changing of ammonia to other nitrogen forms by nitrification.

The holding pond used in this study experienced a vigorous algal bloom during most of both irrigation seasons. The bloom was a thick, green, floating mass covering the entire surface of the shallow pond. Free carbon dioxide is used by the algae in photosynthetic processes. The effects on the chemistry of the wastewater are described by the following relationships:

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows HCO_3^- + H^+$$

$$HCO_3 \rightleftarrows CO_3^= + H^+$$

$$CO_3^= + H_2O \rightleftarrows HCO_3^- + OH^-$$

If algae lower the concentration of carbon dioxide in the water, a shift in equilibrium will occur resulting in a decrease in H^+ and an increase in OH^- which increases the pH value of the water.

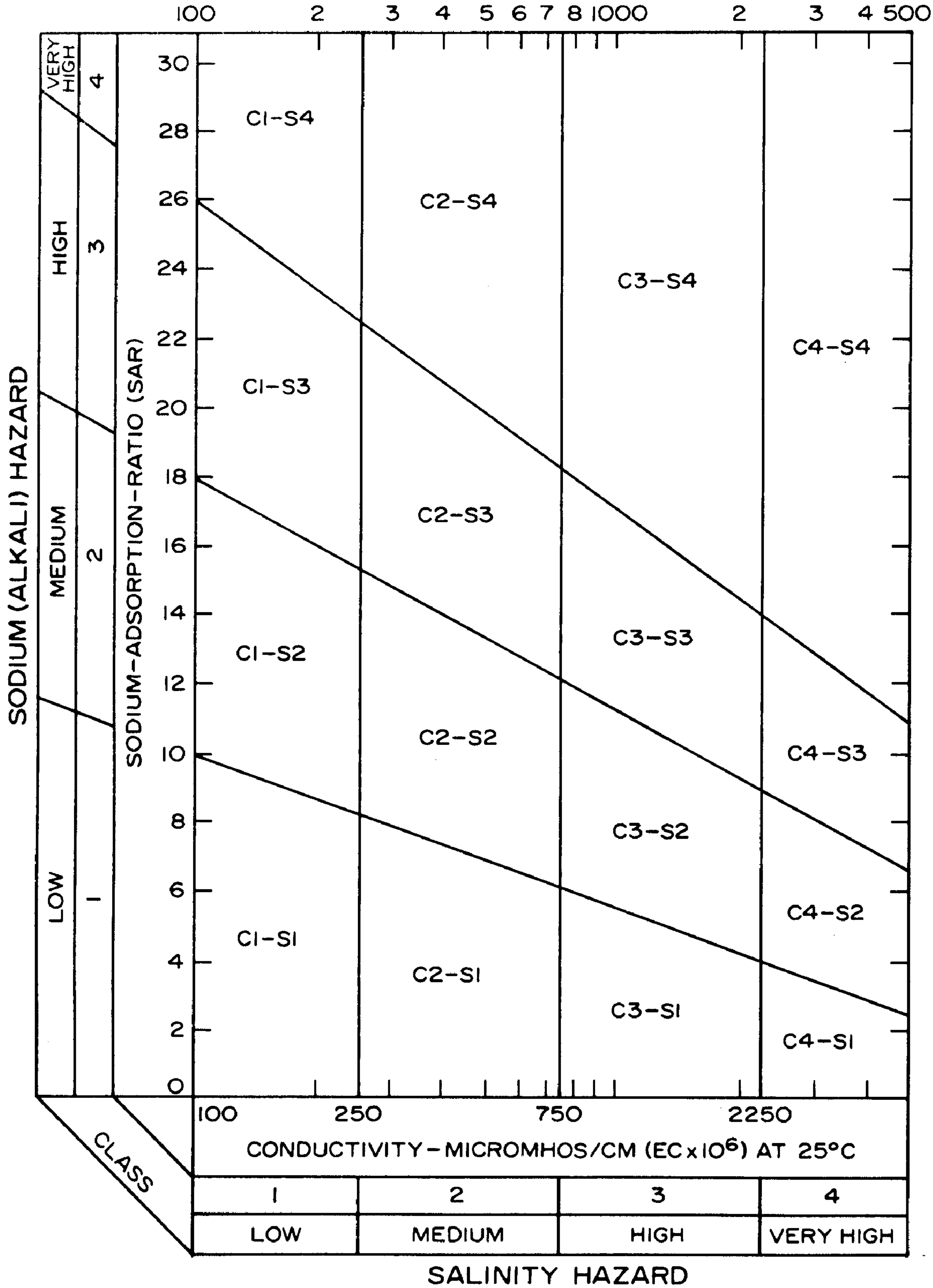


Figure 21. Diagram for the classification of irrigation waters.

TABLE 9. DESCRIPTION OF CLASSIFICATION SCHEME SHOWN IN FIGURE 21

Conductivity

Low-salinity water (C_1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C_2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C_3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C_4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (S_1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-sodium water (S_2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S_3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management--good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S_4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Algae can also obtain carbon dioxide from bicarbonates and carbonates. When this occurs, the chemistry of the system can be described by the following equations:

$$2HCO_3^- \rightleftarrows CO_3^= + H_2O + CO_2$$

$$CO_3^= + H_2O \rightleftarrows 2OH^- + CO_2$$

Again, algal activity results in an increased hydroxide concentration and a corresponding increase in pH value. The pH value of the wastewater stabilization pond effluent was about 9 as a result of algal activity.

Ammonia exists in equilibrium with ammonium ions in a water solution as described below.

$$NH_4^+ + OH^- \rightleftarrows NH_3^o + H_2O$$

$$\frac{[NH_4^+][OH^-]}{[NH_3^o]} = K_b = 1.8 \times 10^{5}$$

$$\frac{[NH_4^+]}{[NH_3^o]} = \frac{1.8 \times 10^{-5}}{[OH^-]}$$

The above relationship indicates that approximately 36 percent of the total ammonia in the stabilization pond effluent should be in the form of volative ammonia at a pH value of 9. Stripping of this volatile ammonia requires air-water contact. Considerable contact was provided during the sprinkling process Table 10 represents the results of an investigation into the stripping process during the second irrigation season.

The spraying process was highly efficient in stripping volatile ammonia from the stabilization pond effluent. The average removal was 35 percent. The pH value of the effluent and the large air-water contact surface provided by the spray provided ammonia stripping conditions.

TABLE 10. AMMONIA REMOVAL FROM STABILIZATION POND EFFLUENT VIA STRIPPING DURING THE SPRINKLING PROCESS

Date	Effluent at Sprinkler Nozzle		Effluent at Soil Surface		Percent Removal
	Ammonia-N µg/1	pH	Ammonia-N µg/1	pH	
8-17-76	995	9.0	658	9.0	34%
8-25-76	457	8.9	265	8.9	42
8-30-76	1220	8.8	868	8.7	30
					$\bar{x}$=35%

The fate of ammonia in a soil mantle treatment system can be described by one or more of the transformations shown in Figure 22. Stripping of ammonia in the soil system was minimal because of the limited air-water contact area. The water application rates used were high enough that water saturated conditions existed in the soil most of the time. The primary source of ammonia stripping was the spraying process as previously discussed.

As shown in Table 11, the cover type used was not a significant factor at the 95 percent confidence level. This means the nutrient uptake by vegetation was not an important ammonia removal mechanism. The vegetation utilized in this experiment was not harvested so ammonia-N taken up by the plants would probably be returned to the soil when the plants died. The net removal of ammonia-N would, therefore, be minimal even if uptake was significant. Ammonia-N adsorption on clay by cation exchange, entrapment in intermicellular layers, and adsorption by organic matter are possible ammonia removal mechanisms (Lance, 1972). Entrapment of ammonia-N in intermicellular layers of clay is limited in most cases, while adsorption by organic matter has been shown in many cases to exceed adsorption by the mineral portion of the soil in ammonia-N removal from percolating waters (Lance, 1972). Under proper conditions, a nitrification-denitrification process may result in the ultimate removal of nitrogen from a soil mantle treatment system. An aerobic condition for nitrification followed by an anaerobic condition for denitrification is required. This removal process was probably quite limited with the sites receiving 10.2 cm (4 in.) and 15.2 cm (6 in.) per week of irrigation water. The nearly constantly saturated condition of the soil was not favorable for aerobic conditions. The nitrification-denitrification process may have played a role in ammonia removal with sites receiving 5.1 cm (2 in.) per week of irrigation water. With this application rate some drying of the soil was observed between application periods, and this is essential for aeration of the soil.

There was a significant difference in the ammonia-N concentrations observed between the first and second irrigation seasons. Table 12 shows the source of difference between the seasons.

No significant difference in ammonia concentrations was observed between seasons at the four water sample depths. The difference between seasons occurred only with the stabilization pond effluent. Season 1 was significantly higher in concentration than season 2. The concentration of ammonia-N observed in soil treated water samples appears to be independent of the concentration observed in the applied irrigation water.

Table 13 presents a statistical comparison of the two water types used. No significant difference in the ammonia-N concentrations was shown between samples obtained from sites receiving effluent and sites receiving control water. The ammonia-N concentration in the irrigation waters was significantly different. This further supports the hypothesis that the ammonia-N concentration observed at any particular depth in the soil is independent of the concentration in the applied irrigation water. The ammonia-N concentrations observed in the soil treated water samples may be assumed to be a function largely of conditions in the soil system rather than ammonia-N concentrations in the irrigation water.

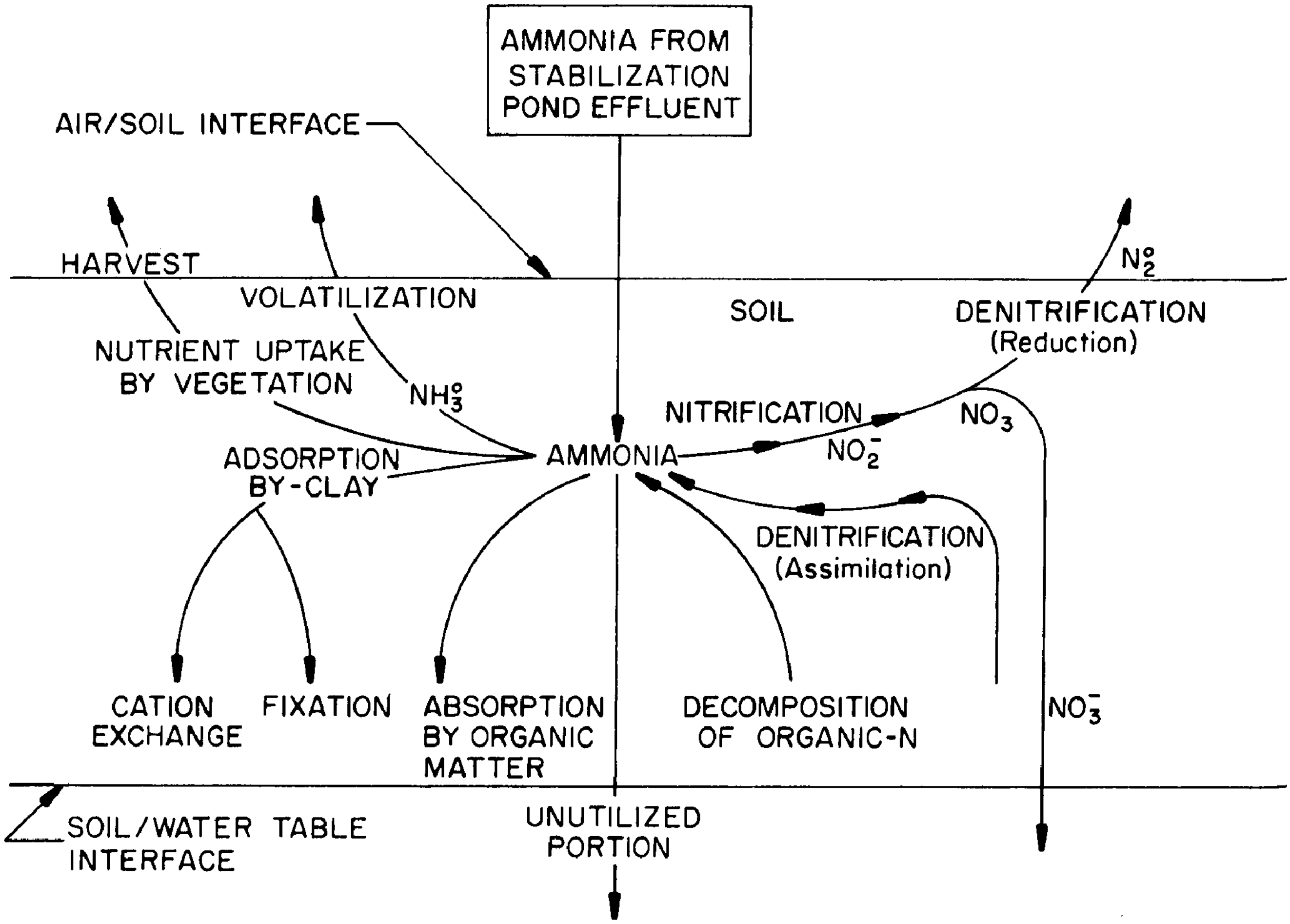


Figure 22. Ammonia transformations in a soil mantle treatment system.

TABLE 11. AMMONIA-N STATISTICAL ANALYSIS

Main Effects	Significant @ 95 Percent
Water Type	Yes
Cover Type	No
Application Rate	No
Sample Depth	Yes
Season	Yes
Weeks	Yes
Two-Way Interactions	
Cover Type x Application Rate	No
Cover Type x Sample Depth	No
Cover Type x Weeks	No
Application Rate x Sample Depth	No
Water Type x Sample Depth	Yes
Application Rate x Weeks	No

$R^2 = 0.457$

TABLE 12. COMPARISON OF MEAN AMMONIA-N CONCENTRATIONS MEASURED DURING SEASON 1 AND SEASON 2

Sample Depth	Ammonia-N Concentration (μg/1); Season No Significant Difference at 95 Percent Confidence	
10.2 cm (4 in.)	47 (S_1)[a]	57 (S_2)
30.5 cm (1 ft.)	37 (S_1)	65 (S_2)
61.0 cm (2 ft.)	58 (S_1)	124 (S_2)
91.4 cm (3 ft.)	133 (S_1)	440 (S_2)
Stabilization Pond Effluent	2230 (S_2)	832 (S_2)

[a]Code: (S_1) season 1, 1975. (S_2) season 2, 1976.
Application rate and cover type are not significant at a 95 percent confidence level and were ignored in computing the above means.

TABLE 13. COMPARISON OF MEAN AMMONIA-N CONCENTRATIONS MEASURED AT SITES RECEIVING STABILIZATION POND EFFLUENT AND SITES RECEIVING CONTROL WATER

Sample Depth	Ammonia-N Concentration (μg/1); Water Type No Significant Difference at 95 Percent Confidence	
10.2 cm (4 in.)	57 (E)[a]	34 (C)
30.4 cm (1 ft.)	65 (E)	29 (C)
61.0 cm (2 ft.)	124 (E)	74 (C)
91.4 cm (3 ft.)	456 (E)	31 (C)
Irrigation Water	832 (E)	181 (C)

[a]Code (E) Stabilizaton Pond Effluent. (C) Control Water
Cover type and application rate were not significant at a 95 percent confidence level and were ignored in computing the above means. Season 1 data were excluded because no control water was applied during season 1.

Some significant differences in ammonia-N concentrations were observed between sample depths on sites receiving effluent irrigation water. Table 14 presents a statistical comparison of ammonia-N concentrations between sample depths for the two water types used in this study.

With sites receiving stabilization pond effluent, a mean ammonia-N removal of over 95 percent was obtained after percolation through the top 10.2 cm (4 in.) of the soil profile. At lower depths the ammonia-N concentration increased, becoming significant at the 95 percent confidence level upon reaching the 91.4 cm (3 ft.) depth. There are several possible reasons for the increase. Ammonia-N previously adsorbed on the soil by cation exchange may have been released into the soil solution when competing cations such as Ca and Mg were introduced with the irrigation water. Because the soil was saturated with water most of the time, anaerobic conditions likely existed in the soil, especially at the lower depths. Under anaerobic conditions, denitrification may occur. Nitrites and nitrates are both reduced by the process of denitrification primarily to nitrogen gas by denitrifying bacteria, but a few carry the process to ammonia-N (Sawyer and McCarty, 1967). Nitrates were present in abundance as will be shown in a following section of this report on nitrates. The amount of total organic carbon present as an energy source for denitrification increases with depth (see TOC Section). An anaerobic environment in the soil, the presence of denitrifiable forms of nitrogen, and an organic carbon energy source, make assimilative denitrification a possible explanation of the increased ammonia-N concentrations observed at lower depths in the soil.

Ammonia-N is a product of anaerobic decomposition of organic matter (Sawyer and McCarty, 1967). Decomposition of organic matter present in the soil may be the reason or a contributing factor to increased ammonia concentration at lower soil profile depths. Some increases in ammonia-N concentration with depth were observed on sites receiving control water. These increases were not significant at the 95 percent confidence level, however.

Table 15 summarizes the ammonia-N removal performance of the soil mantle treatment system. Over 90 percent removal of ammonia-N was obtained in the top 61.0 cm (2 ft.) of the soil. At the 91.4 cm (3 ft.) level the percent removal of ammonia-N decreased substantially.

Ammonia removal from wastewaters is desirable because of its nutrient value to troublesome aquatic plants and the nitrification oxygen demand exerted in surface waters. The soil mantle treatment process significantly lowers ammonia-N concentrations in percolated waters.

NITRATE AND NITRITE

The performance of the soil mantle treatment system for nitrate may be seen graphically in Figures B-17 through B-24. The data are presented in tabular form in Tables B-5 and B-6. Nitrite data are shown in Figures B-25 through B-32 and in Tables B-7 and B-8.

Nitrate is very mobile in soil systems (Sawyer and McCarty, 1967; USU, 1969) and the water samples obtained from the soil profile consistently

TABLE 14. COMPARISON OF MEAN AMMONIA-N CONCENTRATIONS MEASURED AT VARIOUS SAMPLE DEPTHS ON SITES RECEIVING STABILIZATION POND EFFLUENT AND SITES RECEIVING CONTROL WATER

Water Type	Ammonia-N Concentration (μg/l); Sample Depth No Significant Difference at 95 Percent Confidence				
Stabilization Pond Effluent	55 (4)	58 (12)	108 (24)	389 (36)	1165 (0)
Control Water	29 (12)	34 (4)	74 (24)	181 (0)	310 (36)

TABLE 15. MEAN AMMONIA-N REMOVALS OBTAINED AT VARIOUS SAMPLING DEPTHS AND FOR DIFFERENT WATER TYPES

Water Type	Sample Depth	Ammonia-N Removal %[a]
Stabilization Pond Effluent	10.2 cm (4 in.)	95%
	30.5 cm (1 ft.)	95
	61.0 cm (2 ft.)	91
	91.4 cm (3 ft.)	67
Control Water	10.2 cm (4 in.)	84%
	30.5 cm (1 ft.)	81
	61.0 cm (2 ft.)	59
	71.4 cm (3 ft.)	71

[a]Both seasons data combined.

contained nitrate-N. Because of its mobility, one would expect nitrate to leach from a soil containing nitrate when water is percolated through that soil. There was evidence that leaching of nitrate from the soil system took place during the two irrigation seasons observed in this study.

As noted in Table 16, the results of the statistical analysis of nitrate data indicate a significant difference between the concentrations observed during the first irrigation season and the second irrigation season. Investigation revealed that the nitrate concentrations in water samples during the first irrigation season were significantly higher at the 95 percent confidence level than the nitrate concentrations observed during the second season. This comparison was made for each season as a whole without regard to other main effects. A more specific comparison is made in Table 17.

TABLE 16. NITRATE-N STATISTICAL ANALYSIS

Main Effects	Significant @ 95 Percent	
Water Type	No	Yes[a]
Cover Type	Yes	Yes[a]
Application Rate	Yes	Yes[a]
Sample Depth	Yes	Yes[a]
Season	Yes	
Weeks	No	Yes[a]
Two-Way Interactions		
Cover Type x Application Rate	Yes	Yes[a]
Cover Type x Sample Depth	Yes	Yes[a]
Cover Type x Weeks	No	Yes[a]
Application Rate x Sample Depth	Yes	Yes[a]
Water Type x Sample Depth	Yes	Yes[a]
Application Rate x Weeks	No	No[a]

$R^2 = 0.352$
$R^2 = 0.620$[a]

[a]Analysis of data with season 1 excluded.

TABLE 17. COMPARISON OF MEAN NITRATE CONCENTRATIONS MEASURED DURING SEASON 1 AND SEASON 2

Cover Type	NO_3-N Concentration (μg/l); Season; Application Rate |No Significant Difference at 95 Percent Confidence Level|			
Vegetated	| 111	(2,6)[a]	2269	(1,6) |
	| 70	(2,4)	4941	(1,4) |
	79	(2,2)	1840	(1,2)
Bare	| 446	(2,6)	3233	(1,6) |
	8916	(2,4)	48200	(1,4)
	| 15570	(2,2)	13410	(1,2) |

[a]Code: (Season, Application Rate) Sites received stabilization pond effluent inches or cm ÷ 2.54 per week.

As shown in Table 17, the average nitrate concentrations observed appear to be substantially higher for each test site at each application rate during the first season with one exception. The difference between seasons is significant at the 95 percent confidence level for the vegetated site receiving 5.1 cm (2 in.) per week and the bare site receiving 10.2 cm (4 in.) per week of stabilization pond effluent. The apparent reason for the lower nitrate concentrations during the second season was leaching of nitrates through the soil system. This observation is substantiated when the soil analyses shown in Table B-14 are examined. Nineteen of the 24 soil sample locations showed a decrease in soil nitrate concentration from the initial (before irrigation) value to the end of the second irrigation season value.

One might hypothesize that nitrification of N-forms was responsible for the nitrate found in the water samples. Three factors negate this hypothesis. First, as shown in Table 18, nitrate concentrations in water samples from the vegetated sites, including the control, were not significantly different at the 95 percent confidence level during the second season even though the nitrate concentration in the stabilization pond and control water were significantly different at the 95 percent confidence level. Also, water samples from the bare site which received 10.2 cm (4 in.) of control water and the bare site which received 5.1 cm (2 in.) of stabilization pond effluent were not significantly different in nitrate concentration. Over two seasons, these two bare sites had received approximately equal amounts of irrigation water and therefore had the same potential for nitrate leaching. Indications were that the nitrate concentrations found in the water samples were not primarily functions of the nitrate concentration in the applied irrigation water.

Second, the nitrate-N concentration alone in water samples taken from the bare site receiving 5.1 cm (2 in.) per week and the bare site receiving 10.2 cm (4 in.) per week exceeded the average TKN of 5200 μg/l found in the stabilization pond effluent during the second season (Filip, 1976). Third, because of the high application rates used, anaerobic conditions likely existed making large scale nitrification improbable.

Complete nitrification of N-forms could not account for the amount of nitrate observed in these samples. It may be concluded that the nitrate-N concentrations observed in the water samples were primarily due to the leaching of nitrate-N present in the soil before the beginning of irrigation.

As shown in Table 18, where significant differences are indicated, the concentration of nitrate-N was least when the amount of water applied was greatest. When more water is percolated through the soil more nitrate may be leached from the soil.

There is a large difference between the nitrate concentration in water samples obtained from vegetated sites and bare sites as shown in Table 19. Two factors probably cause the disparity between the observed results. First, nutrient uptake by plants can remove nitrate-N from the lagoon effluent as it passes through the soil. A second and more important reason for the higher nitrate concentrations on the bare site is found when the soil analyses in Table B-14 are examined. In every case except for two samples, the initial soil concentration of nitrate was higher in the soil samples from the bare

TABLE 18. COMPARISON OF MEAN NITRATE CONCENTRATIONS MEASURED AT VARIOUS APPLICATION RATES, WATER TYPES, AND COVER TYPES FOR THE SECOND IRRIGATION SEASON

Cover Type	Mean NO_3-N Concentration (μg/l); Application Rate; Water Type (No Significant Difference at 95 Percent Confidence)							
Vegetated	72	(4E)[a]	79	(2E)	103	(6E)	214	(4C)
Bare	366	(6E)	6820	(4E)	11800	(4C)	12000	(2E)

[a]Code: (2E) 5.8 cm/wk (2 in./wk) w/stabilization pond effluent
(4E) 10.2 cm/wk (4 in./wk) w/stabilization pond effluent
(6E) 15.2 cm/wk (6 in./wk) w/stabilization pond effluent
(4C) 10.2 cm/wk (4 in./wk) w/control water

TABLE 19. COMPARISON OF MEAN NITRATE CONCENTRATIONS MEASURED AT SITES WITH DIFFERENT COVER TYPES

Application Rate and Water Type	Mean NO_3-N Concentration (μg/l); Cover Type (No Significant Difference at 95 Percent Confidence Level)			
6"/wk Effluent	103	(V)	366	(B)
4"/wk Effluent	72	(V)	6820	(B)
2"/wk Effluent	79	(V)	12000	(B)
4"/wk Control	214	(V)	11800	(B)

V = vegetated
B = bare

sites than in the soil samples from the vegetated sites. This prevailed with depth in the soil profile with the greater concentrations near the surface. Unknown factors have caused the soil nitrate to be higher where the bare sites were located. There appears to be a definite correspondence between the concentration observed in the soil treated water samples and the concentration observed in the soil samples. As shown in Table 19, no significant difference was found between nitrate concentrations in water samples obtained from vegetated or bare sites where the 15.2 cm (6 in.) per week sites were located. This corresponds to the results in the soil analyses where the least difference between vegetated and bare sites was observed. Also, the greatest difference in nitrate concentration between vegetated and bare sites in water samples corresponds to the greatest difference in nitrate concentration between vegetated and bare sites in soil samples. It is believed that initial soil nitrate concentrations affected the amount of nitrate found in the leachates more than any other factor.

Continued high rate irrigation of Drainage Farm soils should result in a further decrease in both leachate and soil nitrate concentration. An equilibrium value will be reached in time. This equilibrium value will be dictated by the irrigation application rate, the nitrogen content of the irrigation water, and the amount of nitrogen removed from the soil system by means other than leaching, such as removal of crops containing nitrogen obtained from the soil.

At the beginning of the irrigation seasons, higher nitrate concentrations were observed in the water samples than were observed after two or three weeks of irrigation on the vegetated sites. These peaks were probably due to nitrogen being returned to the soil by decaying plant materials and by evaporation concentration effects during the nonirrigation season. On the bare sites these effects were masked by the much higher nitrate concentrations.

Table 20 indicates little significant difference in nitrate concentration between depths in the soil.

No significant difference in nitrate concentrations in water samples was observed for the vegetated sites. Where significant differences occurred on the bare sites, no recognizable pattern of increase was shown.

Nitrate-N levels frequently exceeded the 10 mg/l concentration drinking water standard in the water samples obtained from the bare sites. These nitrate concentrations could possibly promote algal growth in surface waters but might be of use as a fertilizer in irrigation reuse.

CARBON

Several methods of testing the organic pollutional load of a water have been developed. The most common of these are the biochemical oxygen demand (BOD), chemical oxygen demand (COD), and the total organic carbon (TOC) tests. Because of the time advantage with the TOC test and the large number of samples to be tested, TOC values were the most practical, even though the BOD and COD tests are more commonly employed. The TOC concentration indicates the organic pollutional strength of stabilization pond soil mantle treated effluents. The results of the TOC analyses are presented in Table B-13.

The statistical analysis of the TOC data is summarized in Table 21. There was no significant difference at the 95 percent confidence level in the TOC content in the water samples due to the type of irrigation water applied, the presence or absence of vegetation, or the application rate of irrigation water. However, there was a significant difference in TOC concentration in water samples obtained at different depths in the soil. Table 22 shows the relationship between TOC concentration and soil depth.

There was a significant increase in TOC concentration as depth in the soil profile increased. The increase appeared to level off at the 30.5 cm (2 ft.) to 91 cm (3 ft.) depth. Because of the lack of statistical significance of other factors as well as depth in the soil profile, the increase in TOC concentration with depth was likely due to characteristics of the soil. The presence of organic carbon in the soil effluent suggests that anaerobic

TABLE 20. COMPARISON OF MEAN NITRATE CONCENTRATIONS MEASURED AT VARIOUS SAMPLING DEPTHS DURING THE SECOND SEASON

Cover Type	Water Type	Application Rate	Mean NO_3-N concentration (μg/ℓ); Soil Profile Depth No significant difference at 95 percent confidence									
Vegetated	Effluent	15.2 cm (6 in.)/wk	14	(12)*	14	(36)	77	(0)	121	(24)	279	(4)
Vegetated	Effluent	10.2 cm (4 in.)/wk	18	(4)	77	(0)	800	(36)	80.7	(24)	102	(12)
Vegetated	Effluent	5.1 cm (2 in.)/wk	294	(12)	77	(0)	88	(36)	93.1	(24)	110	(4)
Vegetated	Control	10.2 cm (4 in.)/wk	19	(0)	31	(4)	32	(36)	188	(12)	759	(24)
Bare	Effluent	15.2 cm (6 in.)/wk	77	(0)	202	(12)	223	(36)	254	(4)	1080	(24)
Bare	Effluent	10.2 cm (4 in.)/wk	77	(0)	303	(4)	10900	(36)	12400	(24)	13000	(12)
Bare	Effluent	5.1 cm (2 in.)/wk	77	(0)	5530	(4)	14100	(12)	17000	(36)	26300	(24)
Bare	Control	10.2 cm (4 in.)/wk	19	(0)	4150	(24)	5360	(12)	13300	(4)	38000	(36)

*Code: (application rates)
- 6 — 15.2 cm (6 in.)
- 4 — 10.2 cm (4 in.)
- 2 — 5.1 cm (2 in.)
- 0 — Applied Irrigation Water

TABLE 21. TOTAL ORGANIC CARBON STATISTICAL ANALYSIS[a]

Main Effects	Significant @ 95 Percent
Water Type	No
Cover Type	No
Application Rate	No
Sample Depth	Yes
Weeks	Yes
<u>Two-Way Interactions</u>	
Cover Type x Application Rate	No
Cover Type x Sample Depth	No
Cover Type x Weeks	No
Application Rate x Sample Depth	Yes
Water Type x Sample Depth	No
Application Rate x Weeks	No

$R^2 = 0.551$

[a]Analysis of data with season 1 excluded.

TABLE 22. COMPARISON OF TOC CONCENTRATIONS MEASURED AT VARIOUS SAMPLING DEPTHS

Mean TOC Concentration (mg/l); Sample Depth
⌊No Significant Difference at 95 Percent Confidence Level⌋

⌊9.7 (0)[a]	14.9 (4)⌋	20.9 (12)	⌊24.6 (36)	27.9 (24)⌋

[a]Code: (4) 10.2 cm or 4 in.; (12) 30.5 cm or 1 ft.; (24) 61 cm or 2 ft.; (36) 9 cm or 3 ft.; (0) Irrigation Water.

Cover type, application rate and water type were insignificant at the 95 percent confidence level and were ignored in calculation of the above means.

decomposition of the solid soil organic components with ammonia produced as a by-product may have occurred. This was suggested earlier in this report.

PHOSPHORUS

Total phosphorus concentrations are shown in Figures B-33 through B-40 and in Tables B-9 and B-10. Orthophosphate concentrations are shown in Figures B-41 through B-48 and in Tables B-11 and B-12.

As irrigation water percolates through the soil, phosphorus may be added to or removed from the water. Whether addition or removal of phosphorus occurs depends upon the initial concentration of phosphorus in the irrigation water and upon the characteristics of the soil through which percolation occurs. If the initial concentration of phosphorus in the irrigation water is high, then it is likely that subsurface return flows will contain less phosphorus than the original water. If the concentration of phosphorus is low, then an increase may occur during the percolation process.

The oxidation pond effluent used for irrigation water in this study contained what may be termed ''appreciable'' amounts of phosphorus, 1 mg/l or more (USU, 1969).

Table 23 summarizes the initial findings of the orthophosphate-P statistical analysis.

As shown in Table 24, there was a significant difference in phosphorus concentration at the 95 percent confidence level between the first and second irrigation seasons. The analysis exhibited in Table 24 shows that there was no significant difference (95 percent confidence level) in orthophosphate concentration between season 1 and season 2 at the four soil depths where water samples were collected. The orthophosphate concentration in the stabilization pond effluent differed significantly between the two seasons. Although the applied orthophosphate concentration differs, the concentration in the percolate does not differ significantly, suggesting that the concentrations observed in the percolate were independent of the concentrations applied. Table 25 further substantiates this hypothesis.

Table 25 presents a statistical comparison of the two water types used. No significant difference in orthophosphate concentration was observed between sites receiving effluent and sites receiving control water at any of the sample depths. This occurred even though the orthophosphate concentration in the stabilization pond effluent was much higher than the concentration in the control water. Because there was no significant difference in orthophosphate concentration in the percolate between irrigation seasons when the applied effluent differed significantly, and because there was no sigificant difference in orthophosphate concentration in percolate coming from sites receiving effluent or control water when the control water was far lower in orthophosphate concentration than the effluent, it may be assumed that the concentrations observed in the percolate largely represent background levels inherent to the soil system. The orthophosphate concentration in the irrigation water was not shown to significantly affect concentrations observed in the percolate at any given depth. There were, however, some significant differences in orthophosphate concentrations observed between sample depths on sites receiving effluent. Table 26 presents a statistical comparison of orthophosphate concentration between sample depths for the two water types used in this study.

After a large reduction in orthophosphate concentration at the surface, a gradual but significant increase in concentration was observed as the sample depth increased with sites receiving stabilization pond effluent. This general trend occurred for vegetated and bare sites at the different application rates used. As noted in Table 23, cover type and application rate did not

TABLE 23. ORTHOPHOSPHATE-P STATISTICAL ANALYSIS

Main Effects	Significant @ 95 Percent
Water Type	Yes
Cover Type	No
Application Rate	No
Sample Depth	Yes
Season	Yes
Weeks	Yes
Two-Way Interactions	
Cover Type x Application Rate	No
Cover Type x Sample Depth	No
Cover Type x Weeks	No
Application Rate x Sample Depth	No
Water Type x Sample Depth	Yes
Application Rate x Weeks	No

$R^2 = 0.715$

TABLE 24. COMPARISON OF MEAN ORTHOPHOSPHATE-P CONCENTRATIONS MEASURED DURING SEASON 1 AND SEASON 2

Sample Depth	Orthophosphate-P Concentration (μg/l) No Significant Difference at 95 Percent Confidence	
10.2 cm (4 in.)	36 (S_1)[a]	74 (S_2)
30.5 cm (1 ft.)	56 (S_1)	118 (S_2)
61.0 cm (2 ft.)	93 (S_1)	186 (S_2)
91.4 cm (3 ft.)	122 (S_1)	243 (S_2)
Stabilization Pond Effluent	1530 (S_1)	1000 (S_2)

[a]Code: (S_1) season 1, 1975; (S_2) season 2, 1976.

Application rate and cover type were not significant at 95 percent confidence level and were ignored in computing the above means.

significantly affect orthophosphate concentrations at the 95 percent confidence level. The increase in orthophosphate concentration with sample depth on sites receiving effluent was not significant between adjacent sample depths but between alternate depths, illustrating the gradual nature of the increase.

TABLE 25. COMPARISON OF MEAN ORTHOPHOSPHATE-P CONCENTRATIONS MEASURED ON THE SITES RECEIVING STABILIZATION POND EFFLUENT AND SITES RECEIVING CONTROL WATER

Sample Depth	Orthophosphate-P Concentration (μg/l); Water Type			
	No Significant Difference at 95 Percent Confidence			
10.2 cm (4 in.)	74	(E)[a]	36	(C)
30.4 cm (1 ft.)	118	(E)	53	(C)
61.0 cm (2 ft.)	186	(E)	129	(C)
91.4 cm (3 ft.)	243	(E)	163	(C)
Irrigation Water	1000	(E)	28	(C)

[a]Code: (E) Stabilization Pond Effluent. (C) Control Water.

Cover type and application rate were not significant at a 95 percent confidence level and were ignored in computing the above means. Season 1 data were excluded because no control water was applied during season 1.

TABLE 26. COMPARISON OF MEAN ORTHOPHOSPHATE-P CONCENTRATIONS MEASURED AT VARIOUS SAMPLING DEPTHS ON SITES RECEIVING STABILIZATION POND EFFLUENT AND SITES RECEIVING CONTROL WATER

Water Type	Orthophosphate-P Concentration (μg/l); Sample Depth									
	No Significant Difference at 95 Percent Confidence Level									
Stabilization Pond Effluent	58	(4)[a]	101	(12)	156	(24)	212	(36)	1270	(0)
Control Water	28	(0)	37	(4)	53	(12)	129	(24)	163	(36)

[a]Code (4) 10.2 cm (4'') depth, (12) 30.5 cm (12'') depth, (24) 61 cm (24'') depth, (36) 91.4 cm (36'') depth, (0) irrigation water

Season 1 and season 2 data combined for stabilization pond effluent. No statistical difference shown between season 1 and season 2 at given depths or levels in the soil profile (see Table 24).

The increasing orthophosphate concentration at greater sample depths was probably due to the percolating water removing small amounts of phosphorus from the soil particles, from the oxidation of organics present in the soil, and/or from the soil solution. The mean concentration of orthophosphate also appeared to increase with depth on the sites receiving control water, but the increases were not shown to be significant at the 95 percent confidence level.

After percolation through the top 10.2 cm (4 in.) of soil, orthophosphate removal of 90 percent and above were typically observed and removal as high as 98 percent occurred at this depth. Similar performance was observed in the removal of total phosphorus. The overall phosphorus removal seen at the greater sample depths was less than at the 10.2 cm (4 in.) depth but still high. Table 27 summarizes phosphorus removal by the soil mantle treatment process.

Table 27 also shows that phosphorus concentration was lower in the percolate when the concentration was high in the irrigation water and that phosphorus concentration was increased in the percolate when the phosphorus concentration was low in the irrigation water. This was as expected. The percolate phosphorus concentrations were equilibriated to levels statistically indistinguishable at the 95 percent confidence level regardless of the type of irrigation water used in this study.

Figures 23 and 24 graphically illustrate phosphorus removal during the second irrigation season. The differences shown between cover types were insignificant at the 95 percent confidence level. This indicates that nutrient uptake by vegetation was not a significant phosphorus removal mechanism.

The silty clay loam soils used in this study supplies many adsorptive surfaces for phosphorus removal. Adsorption was probably the major phosphorus removal mechanism. Examination of the soil characteristics in Table B-14 shows that the cation exchange capacity was undiminished after two irrigation seasons with stabilization pond effluent. The basic environment of the soil also contains some calcium for precipitation with phosphorus. The soil system should provide phosphorus removal for many years.

TABLE 27. MEAN PHOSPHORUS REMOVALS OBTAINED AT VARIOUS SAMPLING DEPTHS AND FOR DIFFERENT WATER TYPES

Water Type		Orthophosphate-P	Total-P
Stabilization Pond Effluent	10.2 cm (4 in.)	- 95%	- 93 %
	30.5 cm (1 ft.)	- 92	- 90
	61.0 cm (2 ft.)	- 88	- 85
	91.4 cm (3 ft.)	- 83	- 82
Control Water	10.2 cm (4 in.)	- 31	+ 108
	30.5 cm (1 ft.)	+ 90	+ 93
	61.0 cm (2 ft.)	+ 364	+ 176
	91.4 cm (3 ft.)	+ 486	+ 234

[a]Code: - removal; + increase.
Both seasons data combined.

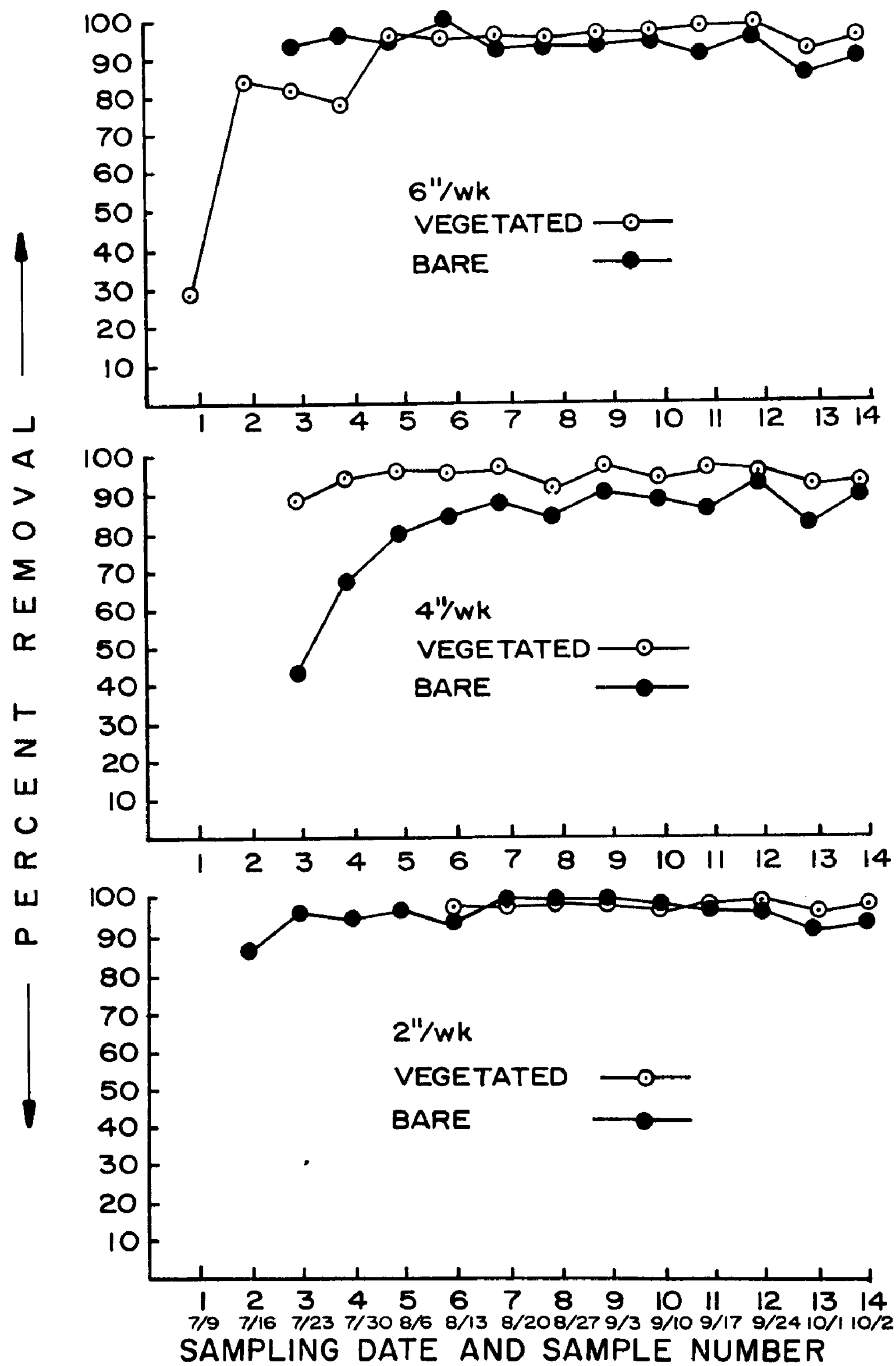


Figure 23. Percentage removal of orthophosphate-P at the 10.2 cm (4 in.) sample depth on vegetated and bare sites receiving 5.1 cm (2 in.), 10.2 cm (4 in.), 15.2 cm (6 in.) per week of stabilization pond effluent.

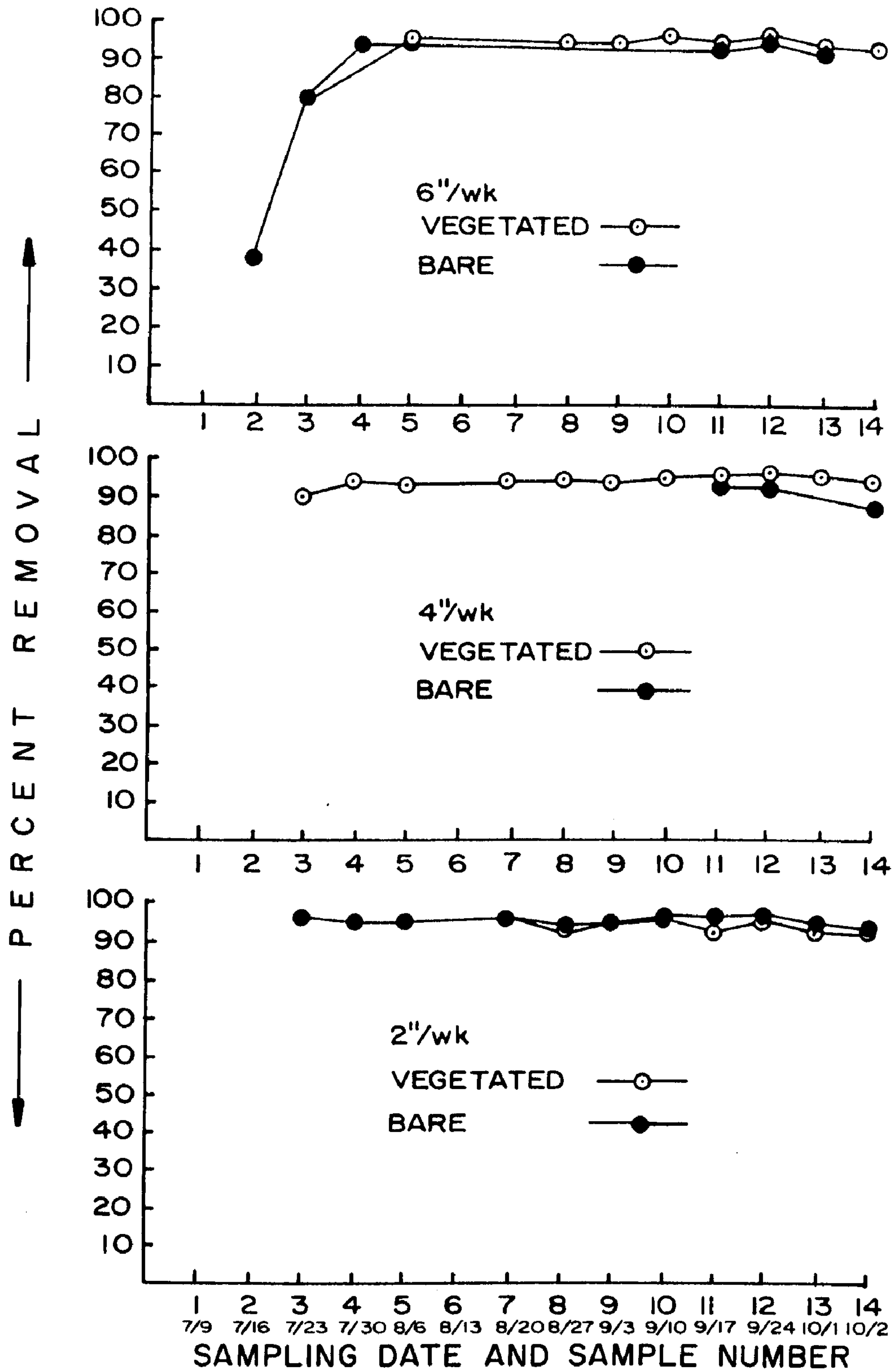


Figure 24. Percentage removal of total phosphorus-P at the 10.2 cm (4 in.) sample depth on vegetated and bare sites receiving 5.1 cm (2 in.), 10.2 cm (4 in.), 15.2 cm (6 in.) per week of stabilization pond effluent.

The time of the irrigation season was a significant factor in the phosphorus removal performance of the soil mantle treatment system. Figures B-34 through B-40 and B-42 through B-48 show that the largest variation in removal occurred at the beginning of the irrigation season. This variation was probably caused by phosphorus concentrations which had built up in the soil solution over the non-irrigation season when little water was moving through the soil. Decaying plant material could contribute phosphorus to the soil solution.

When irrigation resumed, this phosphorus was picked up with the soil water sampling devices. After a few weeks of irrigation, phosphorus removal became essentially constant.

In the lysimeter study using the Utah State University Drainage Farm soil, an average orthophosphate removal of 92.8 percent at a 38.1 cm (15 in.) depth was observed. A weekly application rate of 5 cm (2 in.) of effluent containing an average orthophosphate content of 2,300 μg/l was used in the lysimeter study. This removal corresponds closely to the 92 percent removal observed at the 30.5 cm (12 in.) depth in this field study. The phenomenon of high removal near the surface followed by a slight increase in concentration at lower depths did not occur. The reason for the difference in behavior between the field study and the lysimeter study was probably attributable to the fact that the lysimeters contained disturbed (i.e., mixed) soil.

Studies have shown that vigorous algal growth can occur when the phosphorus content in a water is 100 μg/l or more, and if growth is to be completely eliminated, concentrations of less than 20 μg/l are required (Wadleigh, 1968). Tables B-9 and B-10 show that subsurface return flows contained between 20 and 100 μg/l and often over 100 μg/l of total phosphorus. If subsurface water was to be collected in drains at a depth of approximately 90 cm (3 ft.) and returned to an open ditch or canal, algal growth could be expected to occur. Dilution with low phosphorus water could reduce the nutrient concentration to a level adequate to control algal growth, but the opportunity to dilute return flows occurs infrequently.

VEGETATION

The results of the vegetation growth study are shown in Table B-16. The comparison of mean growth between each of the vegetated sample sites showed that there was no significant difference at the 95 percent confidence level in the amount of vegetation. The additional moisture and nutrients supplied by the stabilization pond effluent made no observable difference in vegetation growth over areas receiving control water or no irrigation at all. No vegetation growth difference was observed between sites receiving different application rates of effluent. The grasses were predominantly pasture grass, some alfalfa, and dandelion.

SUSPENDED SOLIDS

Because the water collected in the 10.2 cm (4 in.) mole drain was a composite of drainage from all of the test sites, including the control site, it was impossible to make specific cause and effect comparisons between test factors such as cover type and application rates vs. suspended solids content. However, a general observation may be made.

During the two irrigation seasons the suspended solids content of the stabilization pond effluent was lowered with the soil mantle treatment process. As shown in Figure B-49, the suspended solids in the treated water were consistently lower than in the stabilization pond effluent.

Another observation was that the drainage water was not green in color as was the stabilization pond effluent. Algal cells were removed by the soil mantle treatment process.

EFFLUENT QUALITY AND STANDARDS

Suspended solids concentrations in the effluent from the mole drain collecting effluents from all eight test sites were consistently less than 3 mg/l (Figure B-49). The concentrations in the mole drain effluent were independent of the concentrations of suspended solids in the lagoon effluent. Suspended solids concentrations in the lagoon effluent were less than 20 mg/l the majority of the time, but when the concentrations were between 20 and 30 mg/l, there was no detectable difference in the quality of the effluent from the mole drain. Based upon the lysimeter studies of soil treatment of wastewaters and other field studies, the removal of suspended solids by spray irrigation will be excellent and little difficulty will be encountered in meeting standards for secondary effluents.

Based on the reduction of TOC, it appears that the irrigation wastewater treatment system will not produce an effluent which would meet the secondary effluent standards. However, the lysimeter studies showed significant changes in the organic content of the soils after the application of well water and lagoon effluent (Table 7). Leaching of organics from the soils accounts for the small decreases and frequent increases in TOC concentrations in the mole drain effluents during the field experiments. The change in organic content (percent C) of the Drainage Farm soils during the field experiments were small (Table B-14); however, the quantity of water passing through the soil at the field sites was very small when compared with the quantity of well water used to compact the lysimeter soils. At some point in the future, the carbon content of the Drainage Farm soils will stabilize and consistent carbon reductions will occur. Unfortunately, it is impossible to predict the time required to reach equilibrium with data from only two irrigation seasons.

Summaries of the mean concentrations of various constituents in the lagoon effluent and the samples collected at 0.9 m (3 ft.) below the surface of the field sites are shown in Tables 28 and 29 for 1975 and 1976, respectively. Statistical comparisons and discussions for each of the characteristics were presented in other sections of this report.

ECONOMICS OF SPRAY IRRIGATION OF WASTEWATER

The use of land application techniques for meeting wastewater discharge requirements must not only meet the technical criteria as established by water quality standards but must also meet economic constraints. The increasing popularity and increased technology in irrigation has greatly reduced the cost

TABLE 28. SUMMARY OF THE MEAN VALUES OF THE CHARACTERISTICS OF THE LAGOON AND FIELD SITE EFFLUENT SAMPLES COLLECTED DURING SEASON 1 (1975) AT 0.9 METER (3 FT) BELOW THE SOIL SURFACE

Characteristic	Oxidation Pond Effluent	Vegetated Site 6"/wk	Bare Site 6"/wk	Vegetated Site 4"/wk	Bare Site 4"/wk	Vegetated Site 2"/wk	Bare Site 2"/wk
Specific Conductance, µmhos/cm	658	3,840	2,650	3,530	12,500	2,940	41,800
Ammonia-N, µg/l	2,330	33	-	-	297	148	85
Nitrate-N, µg/l	655	2,990	-	5,480	24,400	12,500	9,380
Nitrite-N, µg/l	103	91	83	509	1,090	5	769
Total-P, µg/l	2,160	167	240	196	281	279	233
Orthophosphate-P, µg/l	1,530	64	102	-	147	-	168

TABLE 29. SUMMARY OF THE MEAN VALUES OF THE CHARACTERISTICS OF THE LAGOON AND FIELD SITE EFFLUENT SAMPLES COLLECTED DURING SEASON 2 (1976) AT 0.9 METER (3 FT) BELOW THE SOIL SURFACE

Characteristic	Oxidation Pond Effluent	Vegetated Site 6"/wk	Bare Site 6"/wk	Vegetated Site 4"/wk	Bare Site 4"/wk	Vegetated Site 2"/wk	Bare Site 2"/wk	Control Water	Vegetated Control 4"/wk	Bare Control 4"/wk
Specific Conductance, µmhos/cm	570	5,140	1,940	3,770	9,180	16,900	12,100	483	3,290	12,100
Ammonia-N, µg/l	832	122	74	274	1,330	935	151	181	449	182
Nitrate-N, µg/l	69	14	81	4	10,900	11	19,000	20	16	38,000
Nitrite-N, µg/l	58	2	30	55	1,900	2	517	1	2	589
Total-P, µg/l	1,460	176	195	202	696	373	344	74	266	226
Orthophosphate-P, µg/l	1,000	138	95	127	556	326	224	28	133	195
Total Organic Carbon, mg/l	12	26	18	23	25	34	29	4	33	32

for this type of equipment. There is a definite advantage from an economic standpoint for irrigation systems in wastewater treatment. For the most part other types of wastewater treatment systems are unique only to the wastewater industry and have not benefited from large demand pressures. The principal components of the irrigation system consist of pipe, pumps, control equipment (electronic and hydraulic), and certain specialized application systems. The application of wastewater to land would be a small component of the total irrigation picture in the United States if all waste were treated in this manner. One of the obvious advantages, from an economic standpoint, for land application of wastewater is the fact that research and development costs have been paid for and the private sector is highly competitive in the large market area of irrigation equipment. This situation allows for significant decreases in cost effectiveness for land application systems where land costs are not prohibitive and satisfactory soils exists.

The two most predominant types of irrigation systems, solid set and center pivot, will be evaluated and an algorithm developed for computing total system cost. Two alternatives were analyzed for solid set systems, (a) in-the-ground, and (b) on-the-ground wastewater distribution systems. A computer program was developed to assist in determining alternatives as they relate to spray irrigation techniques. Input data include all system and wastewater variables which affect the total cost. The output data are in the form of a graph which shows the cost of operation, cost of ownership, and the total system cost for various flow rates and application rates. The analysis of these variables was designed to be as complete as possible to further the utility of the computer model in decision making and design of spray irrigation waste treatment systems. A general discussion of the three configurations follows, and a detailed discussion of the computer program and the derivation of the basic costs is presented in Appendix C.

SOLID SET SYSTEMS

Solid set or on-the-ground irrigation systems are characterized by the permanent or immobile nature of the distribution lines. In some cases these distribution lines are buried to facilitate ease of operation and to increase the efficiency of on land water use. On ground systems, which are most often utilized on small plots of land, are manually changed from section to section as water demand necessitates. Determining the total acreage requirement for a given flow and application rate is the initial step in an economic analysis of irrigation systems. The following formula was used to make this determination.

$$A = Q/UC_1 \quad (1)$$

in which

- A = required application area (acres)
- Q = design flow rate of wastewater (million gallons/day)
- U = application rate (inches/day)
- C_1 = conversion factor (1 acre-inch/day equals 0.027153 million gallons)

The power requirements for a given flow and application rate must next be calculated. Since the area varies for different combinations of flow and application rate all friction loss factors will be unitized with respect to area. The total friction loss is comprised of the static pressure due to riser heights and terrain and the dynamic head losses due to velocity, flow, and pipe size. Equation 2 is used to determine the total friction loss of the system.

$$H_T = (AXH_2) + H_1 \quad \ldots \ldots \ldots \ldots \quad (2)$$

in which

H_T = total friction loss for the system (ft.)
A = area (acres)
H_1 = static head (ft.)
H_2 = friction loss per acre (ft.)

Power requirements for the system can now be determined once the hydraulic configuration for the design has been determined. Equation 3 has been used to calculate the power requirements for the total system.

$$P = (Q \times C_3 \times H_T)/4000 \text{ (drive efficiency) (pump efficiency)} \quad \ldots \ldots \ldots \ldots \quad (3)$$

in which

P = power (horsepower)
Q = flow (million gallons/day)
C_3 = conversion factor (694 gpm/1.0 MGD)
Drive efficiency = 0.7
Pump efficiency = 0.95

The total operating cost can now be determined including the various cost factors which are dependent on time and location.

Electrical Energy Cost

$$0_1 = P \times (4 \times 6\ G_1/G_R) \quad \ldots \ldots \ldots \ldots \quad (4)$$

in which

0_1 = electrical energy operating cost ($/year)
P = power (horsepower)
C_4 = 8760 hours/year
G_1 = fuel cost ($/kw)
G_R = fuel consumption (bhp-hrs/kw)

Fossil Fuel Energy Cost

$$0_2 = P \times C_4 \times G_2 \quad \ldots \ldots \ldots \ldots \quad (5)$$

in which

P = power (horsepower)
0_2 = fossil fuel operation cost ($/year)
C_4 = 8790 hours/year
G_2 = cost of power unit maintenance ($/bhp-hr)

Power Unit Maintenance Cost
and Reservoir Maintenance

$$O_3 = C_5 \times D_1 \times A + (C_6 G_3) \quad (6)$$

in which

O_3 = power unit maintenance cost and reservoir maintenance (\$/year)
D_1 = capital cost of sprinklers, pipe, and drainage
C_5 = maintenance constant (assumed to be @ 5/1000 of the capital cost per year)
C_6 = assumed manpower requirement for maintenance in hours per year (80 hrs/year)
G_3 = cost of maintenance (\$1/hr)

Labor Cost to Operate System

$$O_4 = C_7 \times A \times G_4 \quad (7)$$

in which

L = labor requirement to operate system (hr/acre/day)
C_7 = days in a year (365)
A = area (acres)
G_4 = hourly wage for system labor (\$/hr)

Harvesting Cost

$$O_5 = D_2 \times A \times K \quad (8)$$

in which

O_5 = harvesting cost (\$/year)
D_2 = cost of harvesting (\$/acre)
A = area (acres)
K = number of harvest per year

Total Operation and Maintenance Cost

$$O_T = O_1 + O_2 + O_3 + O_4 + O_5 \quad (9)$$

in which

O_T = total operation and maintenance cost (\$/year)
O_1 = electrical energy cost (\$/year)
O_2 = fossil fuel energy cost (\$/year)
O_3 = power unit maintenance cost (\$/year)
O_4 = capital investment and maintenance cost (\$/year)
O_5 = harvesting cost (\$/year)

Cost associated with interest and principal payback must be considered for each segment of capital investment. The equations used for these determinations are found below. The interest rate could be different for each segment of capital investment which would necessitate rearrangement of the equation. For purposes of this calculation the interest rate was the same for all categories of capital investment.

$$T = I\,[(C_8 \times Q) + (45 \times P) + (D_3 \times A) + D_4 + (D_5 \times A) + (D_6 \times A)] + (D_7 \times A/20) + (D_8 \times A) + (D_9 \times A/20) \quad . . . . (10)$$

in which

- I = interest factor
- C_8 = 4951 (the capacity of the storage reservoir was assumed to be one day's flow, the cost of a reservoir was assumed to be $\$1.00/yd^3$, and 4951 yd^3 is equal to a million gallons)
- Q = design flow (MGD)
- D_3 = cost of pipe ($/acre)
- D_4 = cost of pipe trailer
- D_5 = cost for sprinklers ($/acre)
- D_6 = cost for the drainage system ($/acre)
- D_7 = cost of installation of sprinklers and drainage system ($/acre)
- D_8 = dollar value of the crop grown on the land before the treatment system was installed ($/acre)
- D_9 = cost of land acquisition ($/acre)

Value of the Crop

The economic value of the crop must be considered in the economic analysis of the treatment system. The cost of the existing crop not realized is considered in the preceding equations. In most cases, if irrigation was not to be used, the crop value of the wastewater system should exceed the crop value prior to the installation of the irrigation system. This will not always be the case, and some thought should be given to this consideration. The value of the crop obviously depends on the specific crop grown and on the regional market values for the crop.

$$W_T = W_1 \times A \times K \quad . . . . (11)$$

in which

- W_T = total yearly dollar value ($/year)
- A = area of the system (acres)
- K = harvests per year (number/year)
- W_1 = crop value ($/acre)

$$O_s = O_T + T - W_T \quad . . . . (12)$$

in which

- O_T = total operation and maintenance cost ($/year)
- T = interest cost ($/year)
- W_T = total yearly dollar value of crop grown ($/year)
- O_s = system operation and maintenance cost including the annual value of the crops ($/year)

Figures 25 through 27 show the operation and maintenance costs, the ownership costs, and the total costs, respectively, for an on-the-ground solid set irrigation system. Comparable costs for an in-the-ground solid set irrigation system are shown in Figures 28 through 30. Various individual costs used to calculate costs and plot the figures are summarized in Table 30.

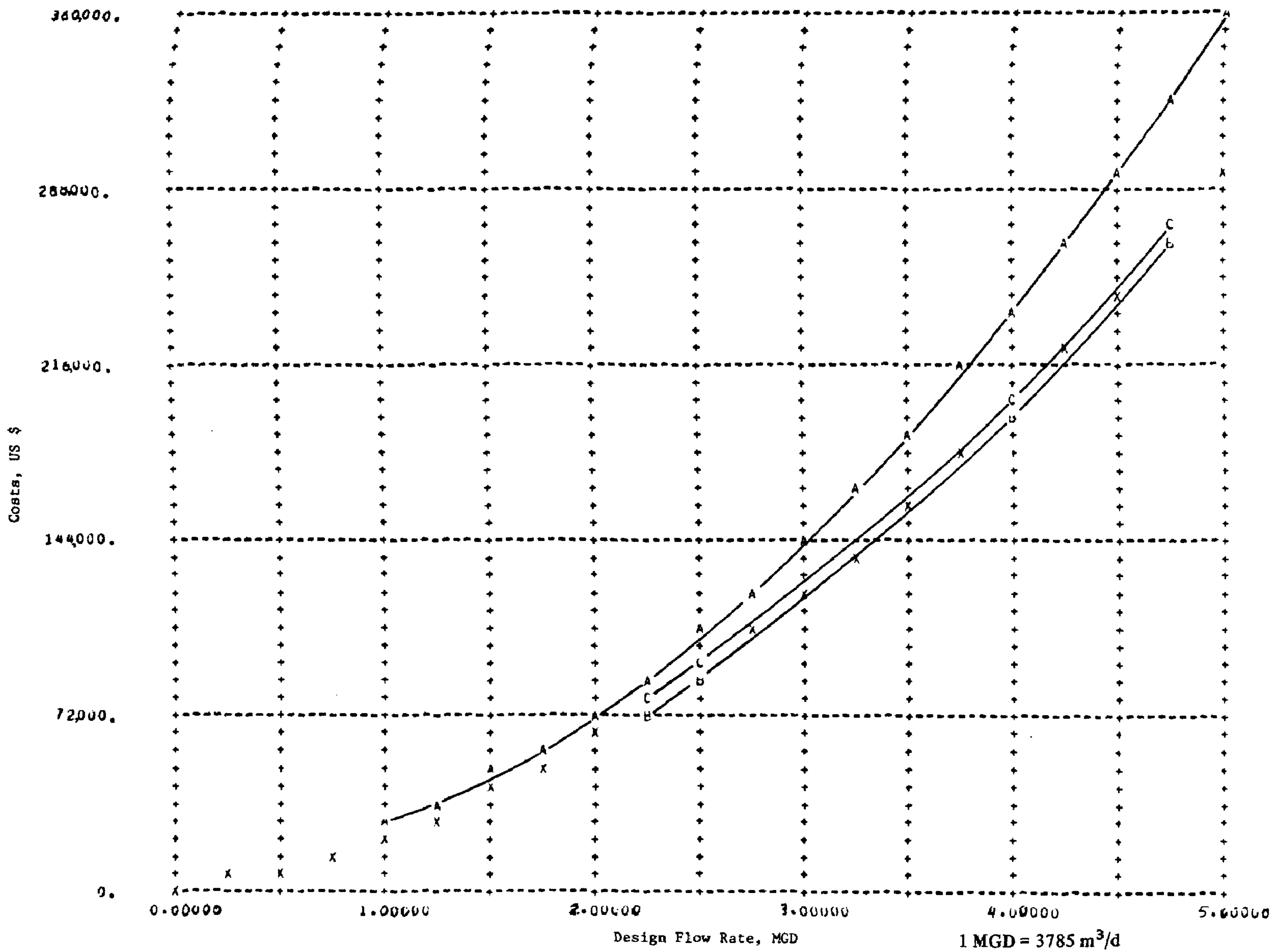


Figure 25. Cost of operation for on-the-ground solid set irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

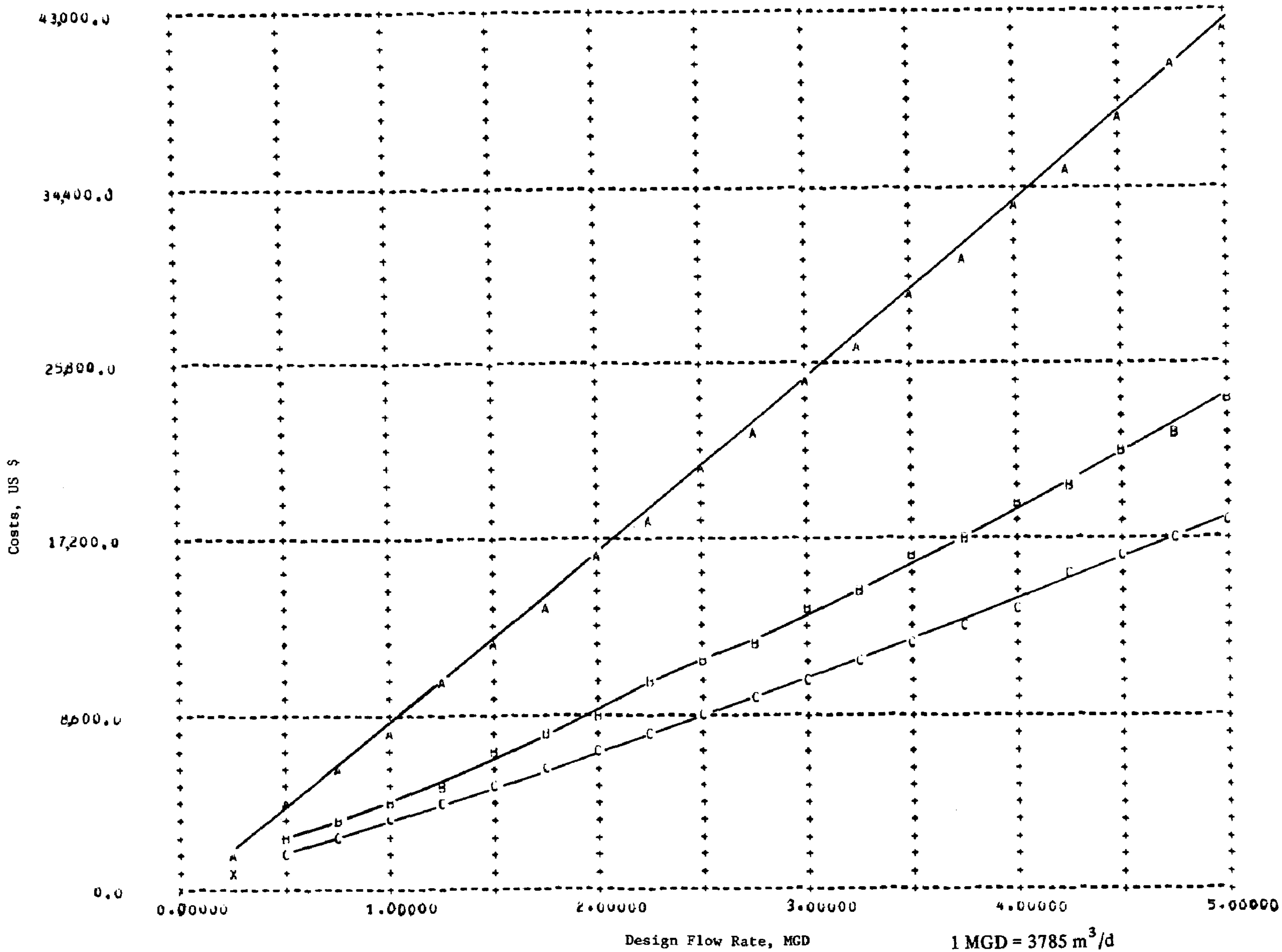


Figure 26. Cost of ownership for on-the-ground solid set irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

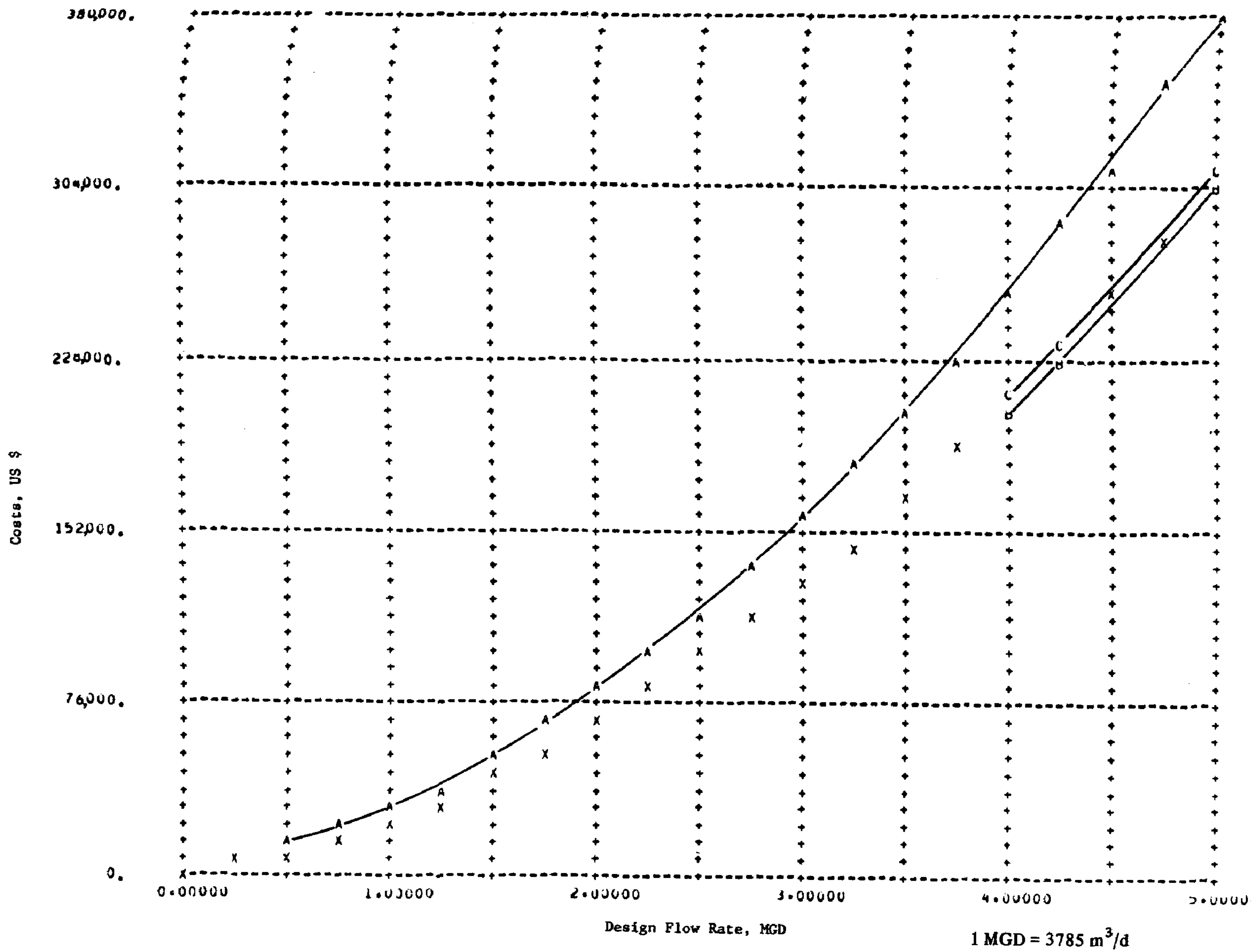


Figure 27. Total system cost for on-the-ground solid set irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

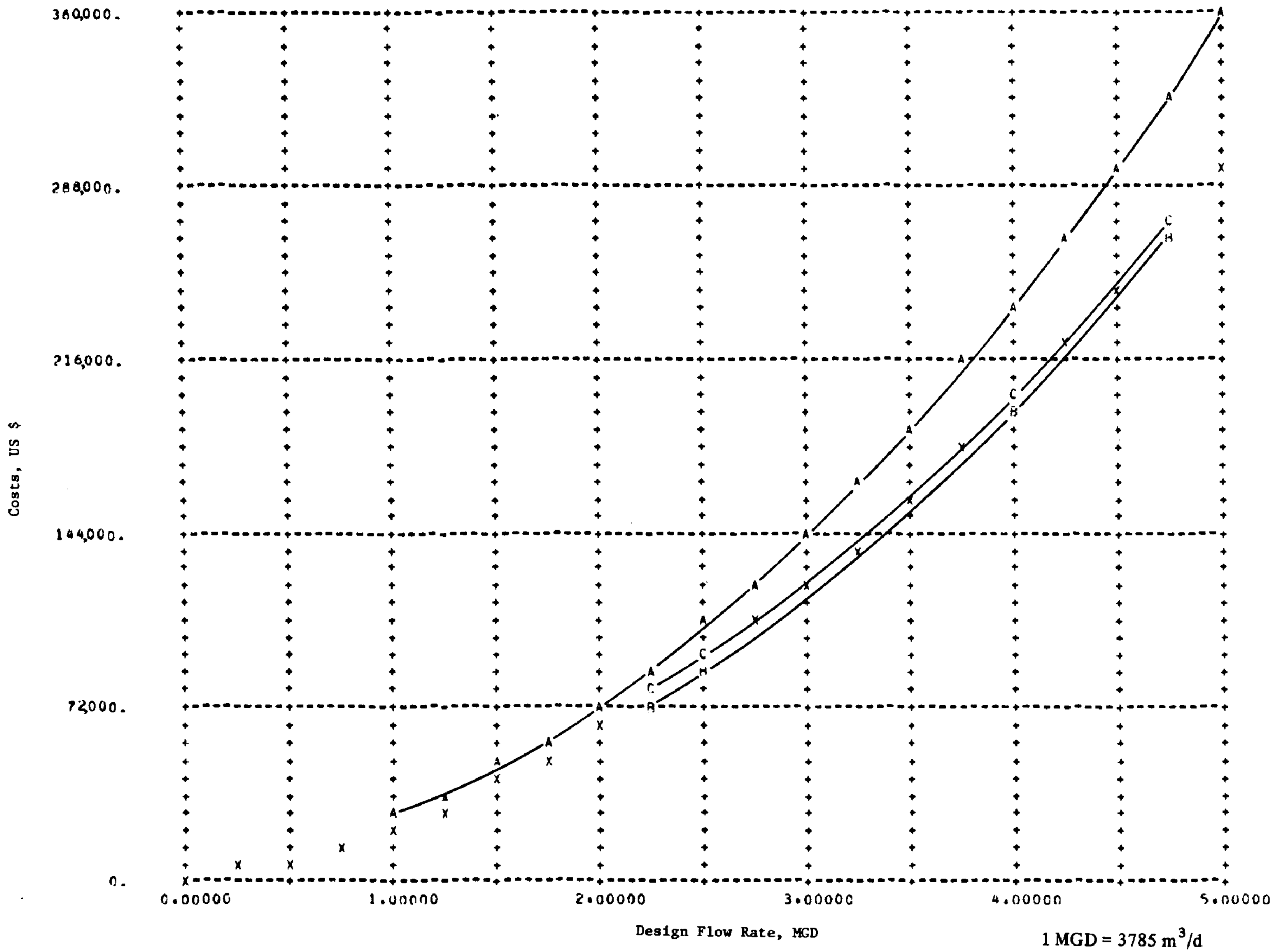


Figure 28. Cost of operation for in-the-ground solid set irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

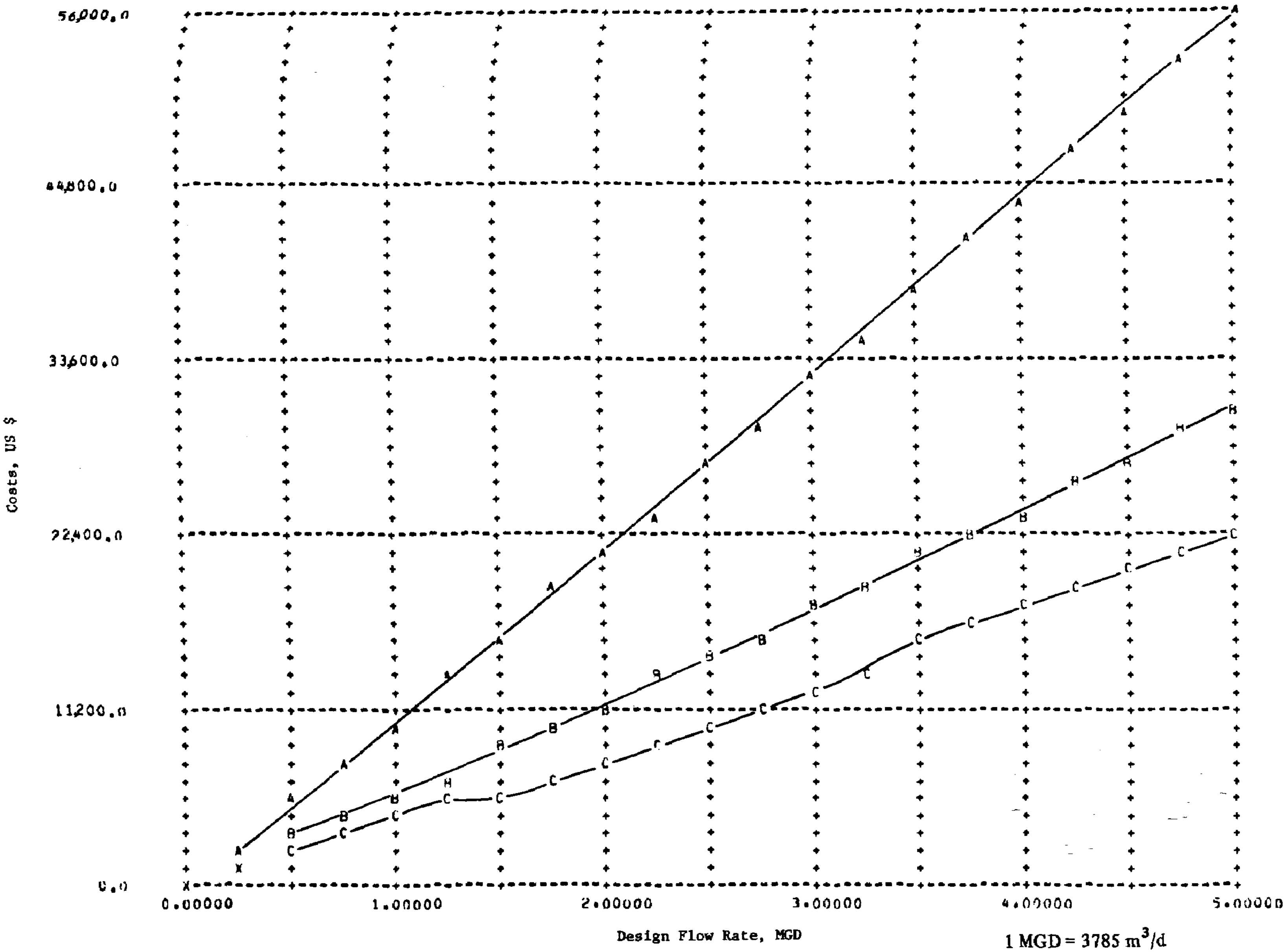


Figure 29. Cost of ownership for in-the-ground solid set irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

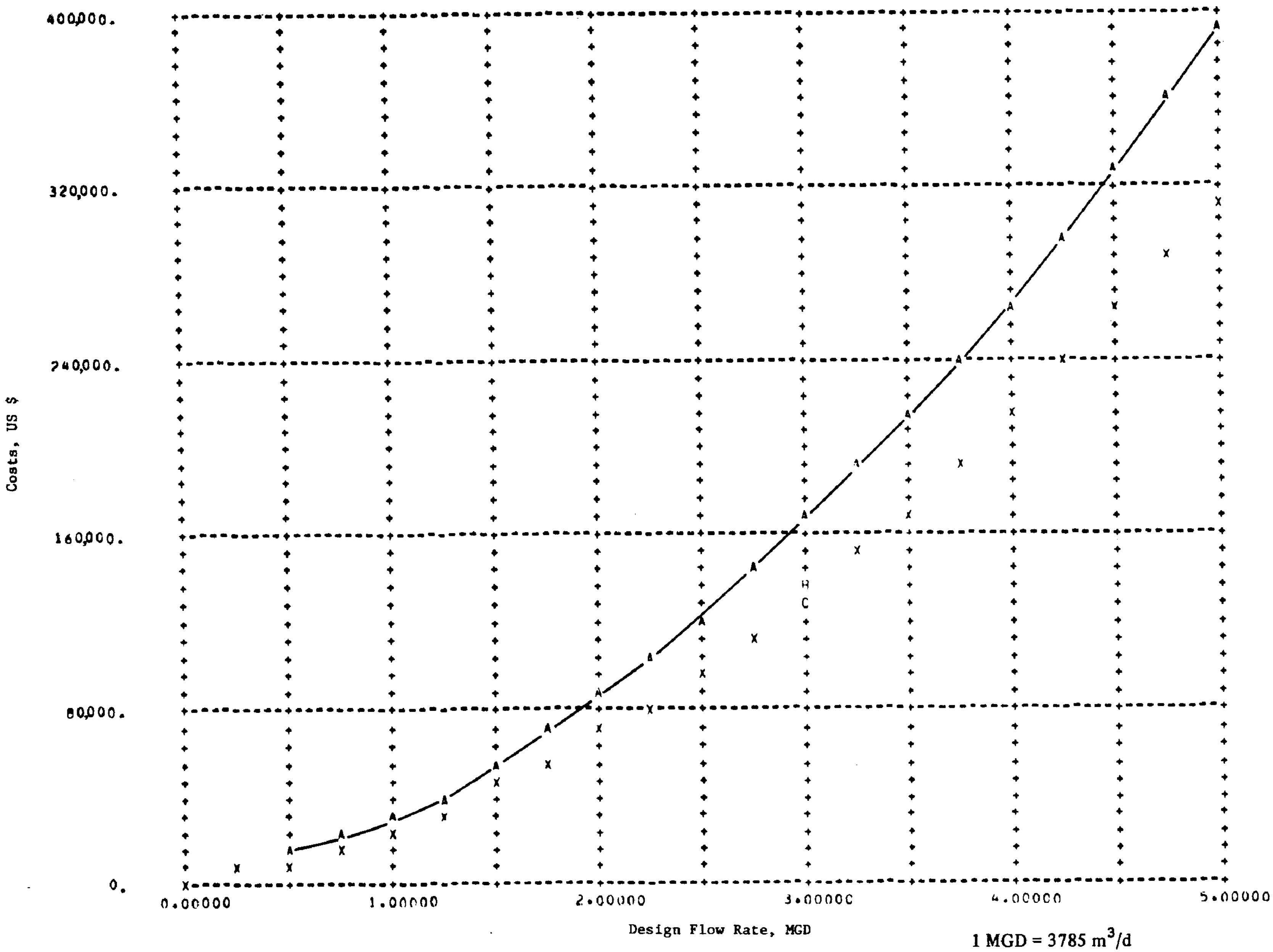


Figure 30. Total system cost in-the-ground solid set irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

TABLE 30. VALUES USED TO CALCULATE COSTS SHOWN IN FIGURES 25 THROUGH 33

FC	=	\$0.05/kw, fuel cost
FEON	=	1.18 bhp-hrs/kw, fuel consumption
OC	=	\$2.0/gallon, oil cost
OCON	=	9000 bhp-hrs/gal, oil consumption
CPU	=	\$0.000045/bhp-hr, cost of power unit maintenance
CIEQ	=	\$21.21/acre, cost of irrigation equipment
CRMAN	=	\$3.0/hr, cost of reservoir maintenance
EFMM	=	0.05 hr/acre/day, labor/equipment
WAGE	=	\$3.0/hour hourly wage of system labor
CHAR	=	\$18/acre, cost of harvesting
SFL	=	121.5 ft./ft., standard friction loss
HPX	=	3.0 harvests/year
WCPA	=	\$75.0/acre, value of crop
TW	=	120, Hazen-Williams coefficient
D	=	0.822 ft., diameter of pipe
ISPF	=	\$0.65/ft., installation of sprinkler system
ISDF	=	\$0.20/ft., installation of drainage system
RINT	=	9%, interest rate
RLE	=	20 years, reservoir life expectancy
PMTLE	=	15 years, pump, motor, transmission life expectancy
PLE	=	20 years, pipe life expectancy
CPPA	=	\$27.27/acre, cost of pipe
PTLE	=	15 years, pipe trailer life expectancy
CPT	=	\$350, cost of pipe trailer
SPLE	=	20 years, sprinkler life expectancy
CPASP	=	\$1/acre, cost for sprinkler
DSLE	=	20 years, drainage system life expectancy
CPADS	=	\$6/acre, cost for drainage system
CISPDS	=	\$1.0/acre, cost of installation and drainage system
PC	=	\$0/acre, cost of land outlay production due to its use as treatment for lagoon effluent
LCPA	=	\$600/acre, cost to buy the land

1 gal. = 3.7 l
1 acre = 0.4 ha
1 ft. = 0.3 m

CENTER PIVOT SYSTEM

The state-of-the-art in spray irrigation is the center pivot system consisting of a center feed with an extended traveler which pivots around the center feed either by electric motors or hydraulic motors. The spray nozzles are mounted along the traveler in various configurations based upon the specific terrain, crop, and local climatology. The center pivot system normally irrigates a circular area but with modifications can effectively wet a square area. The center pivot systems are quite versatile and have encouraged many agriculturists to enter into irrigated crop programs. The center pivot systems are attractive for use in irrigating with wastewater because of relatively low initial cost, low labor cost, low maintenance requirements, low energy cost, and versatility as to application. One of the grestest advantages of the center pivot irrigation system used in wastewater treatment is the availability of trained manpower to operate this system. There already exists a pool of trained manpower who have installed, operated, and maintain spray irrigation systems. Parts and supplies are locally available in many parts of the United States where center pivot systems are presently utilized in agriculture. There are definitely some unique aspects of irrigating with wastewater which must be addressed, but the hardware and labor aspects are well established and readily available.

The costs for the center pivot system are calculated from Equations 1 through 12 with a minor change due to geometric consideration for circular irrigated areas.

$$S = \left[\frac{Q(V/1.318)}{C_w(R_h)0.63}\right]^{1.85} \quad \ldots\ldots\ldots\ldots\ldots \quad (13)$$

in which

S = system headloss (ft./ft.)
R_h = hydraulic radius (ft.)
C_{HW} = Hazen-Williams coefficient
Q = design flow (MGD)

The next step is to determine the total headloss for the system. The size of field required for a given flow and application rate is determined from the expression given in Equation 14.

$$R = [(A \times 43.560)/\pi]^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots \quad (14)$$

in which

R = radius of the pivot in feet
A = area in acres

Once the radius of the required field is calculated then the dynamic headloss can be computed for the radius of the area. The dynamic headloss plus the standard headloss are then added to give the total headloss for the system.

Figures 31 through 33 show the operation and maintenance costs, the ownership costs, and the total costs, respectively, for a center pivot irrigation system. Various individual costs used to calculate costs and plot the figures are summarized in Table 30.

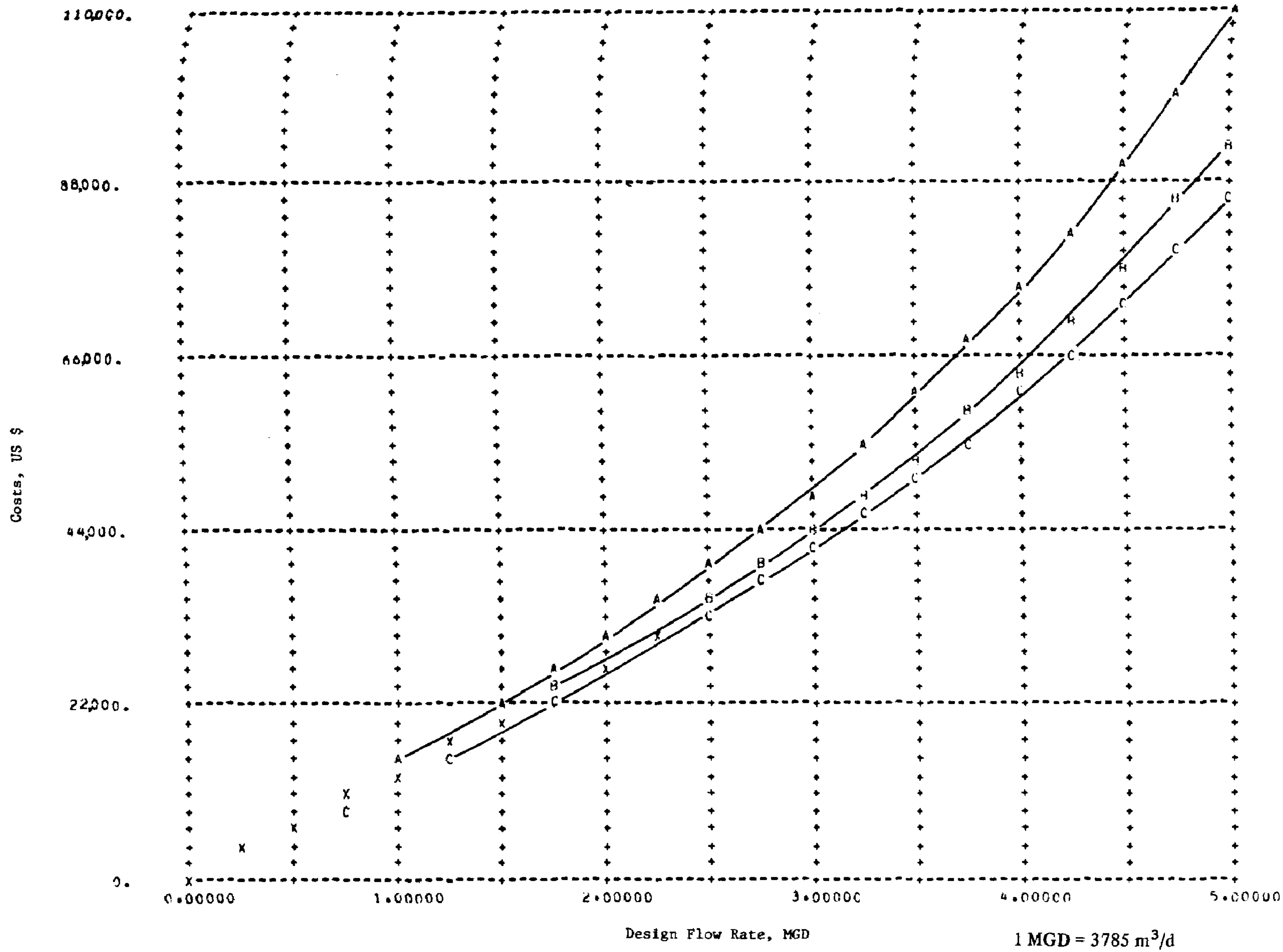


Figure 31. Cost of operation for center pivot irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

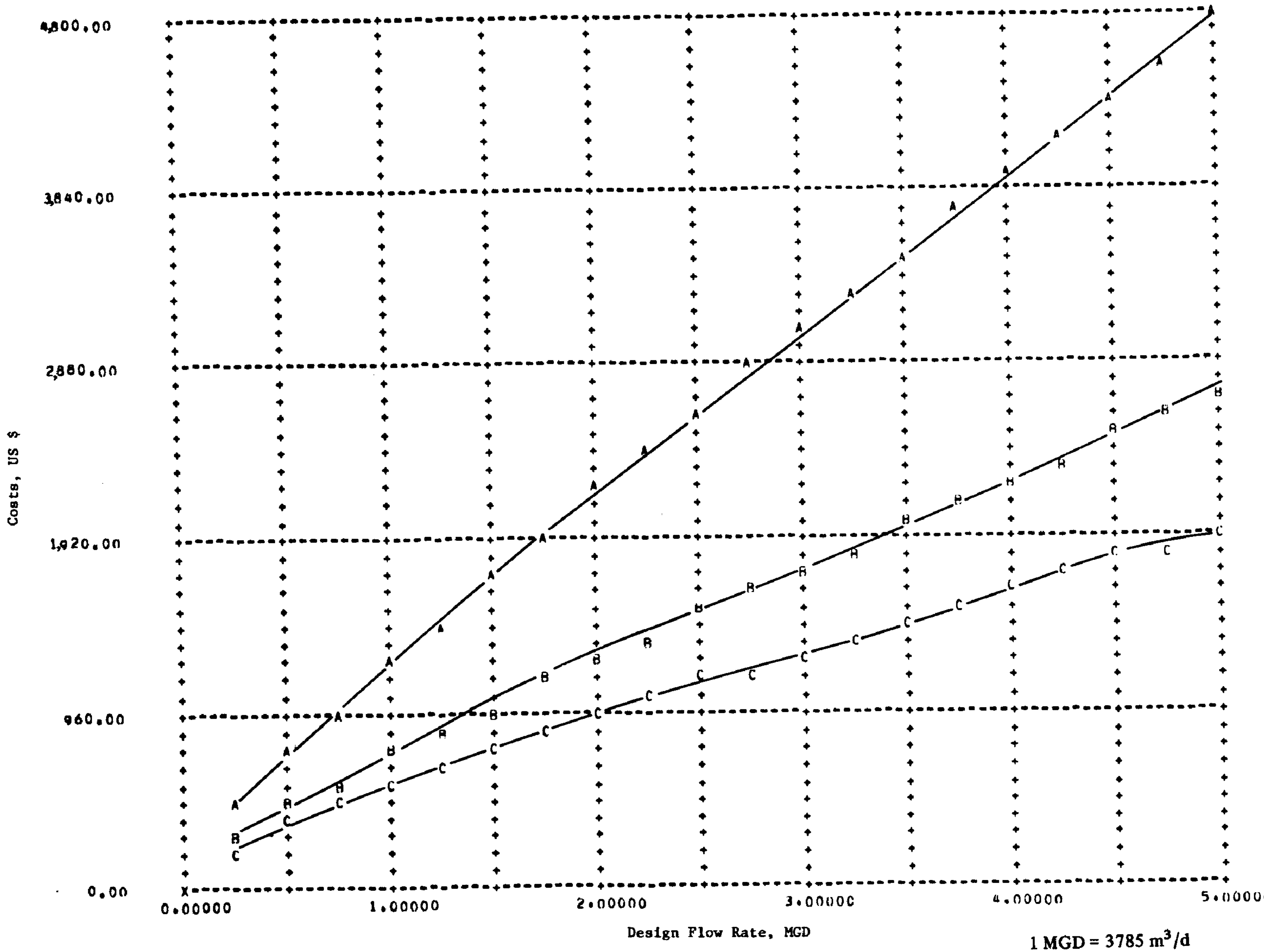


Figure 32. Cost of ownership for center pivot irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

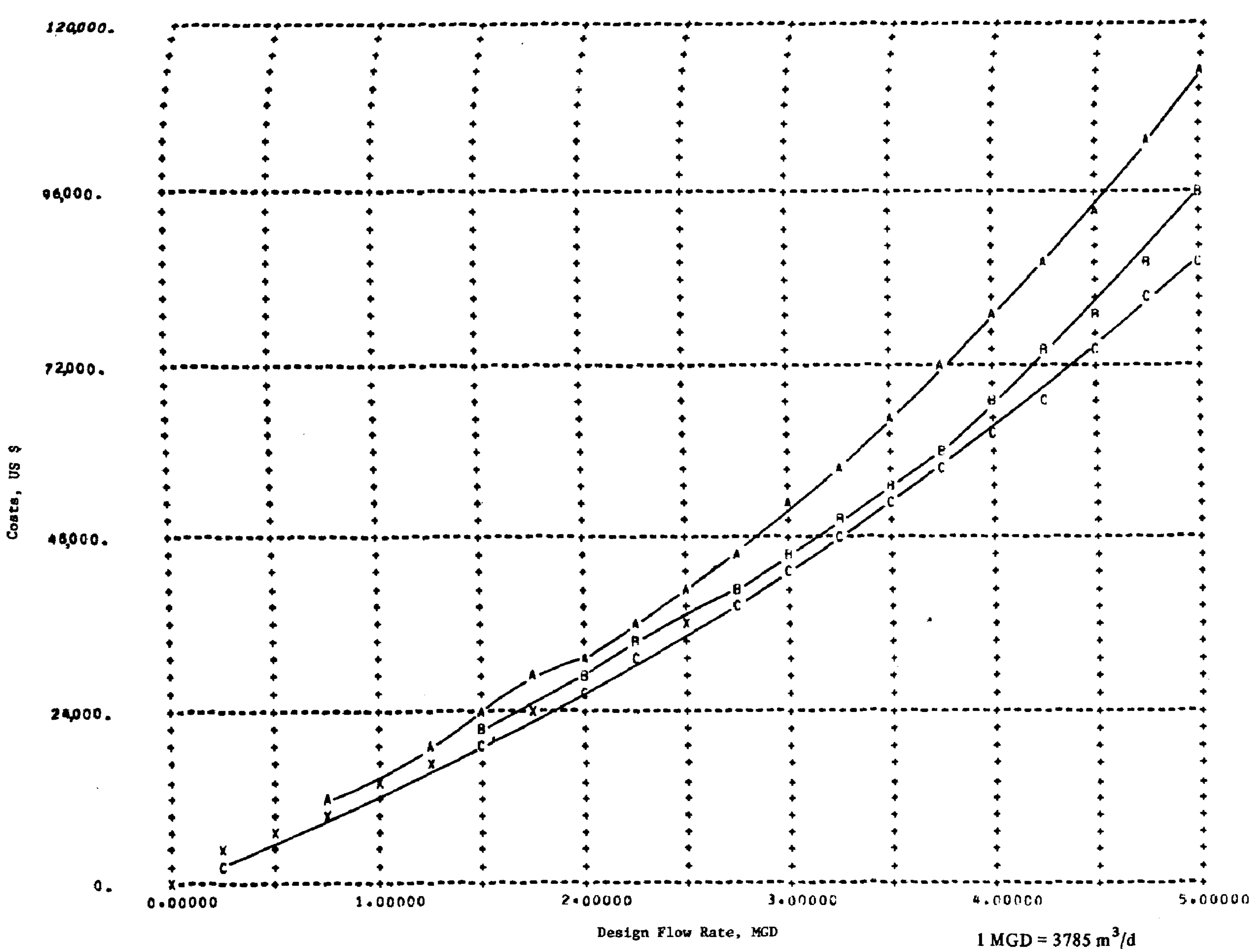


Figure 33. Total system cost for center pivot irrigation system. (A = 2.0, B = 4.0, C = 6.0, inches/acre/day.)

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APPENDIX A

RESULTS OF LYSIMETER EXPERIMENTS

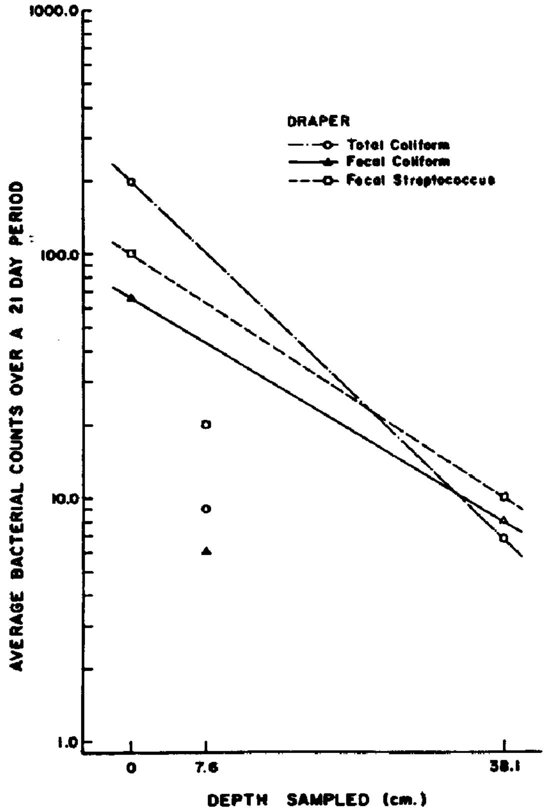


Figure A-1. Average bacterial populations at points within Draper soil during test period.

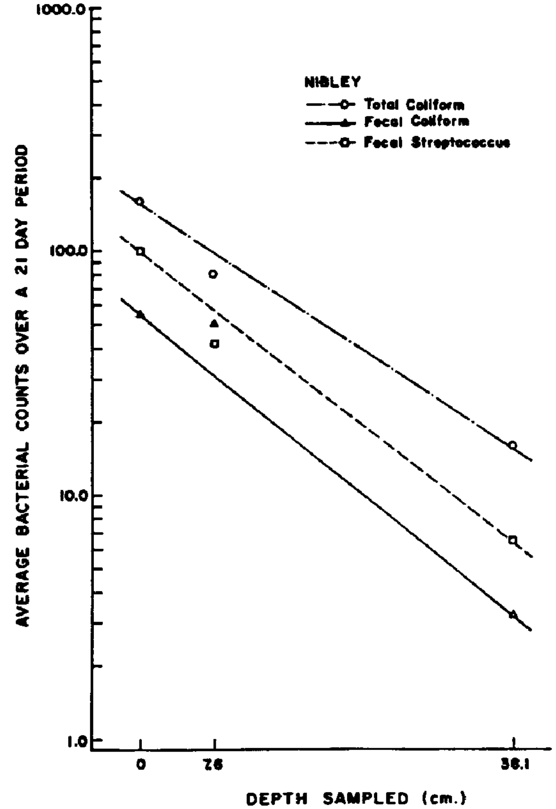


Figure A-2. Average bacterial populations at points within Nibley soil during test period.

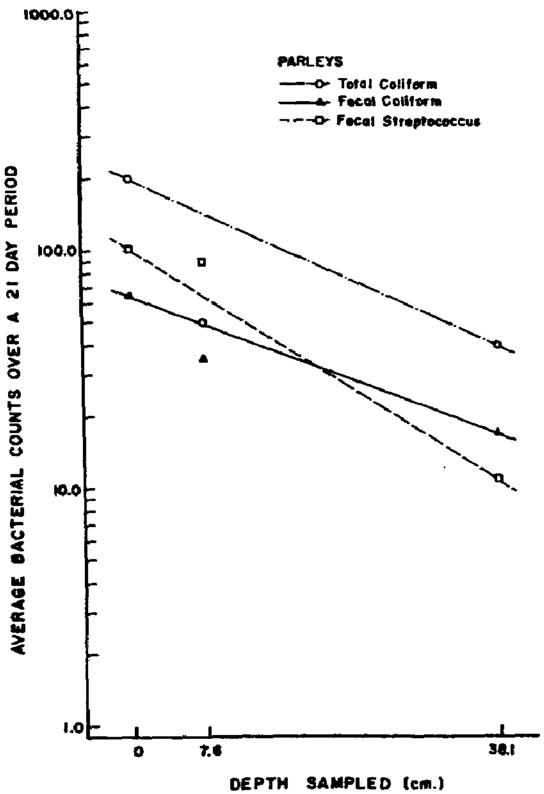


Figure A-3. Average bacterial populations at points within Parleys soil during test period.

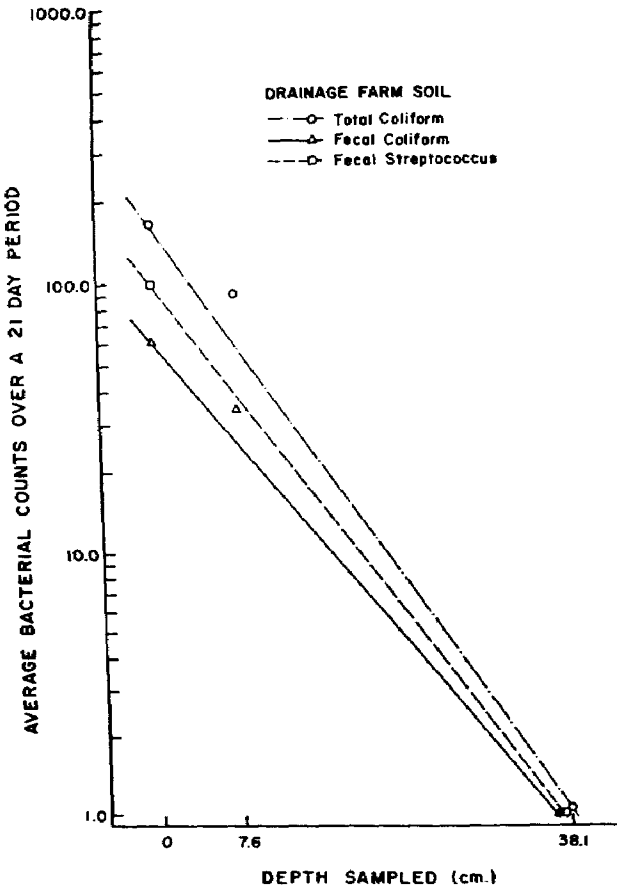


Figure A-4. Average bacterial populations at points within Drainage Farm soil during test period.

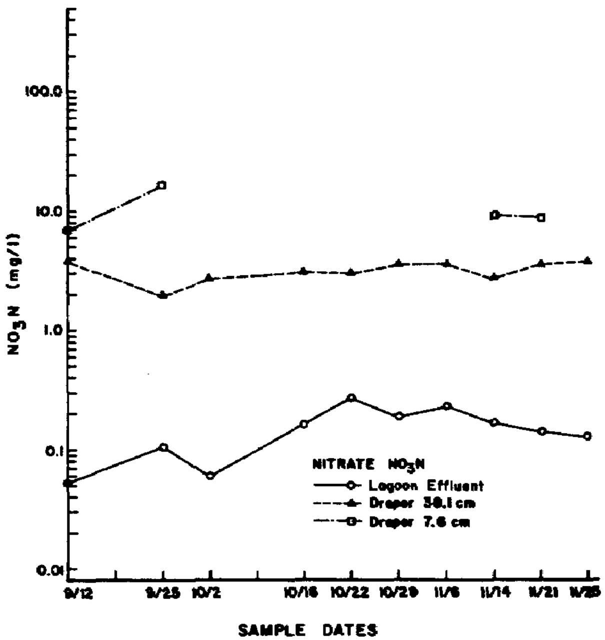


Figure A-5. Nitrate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

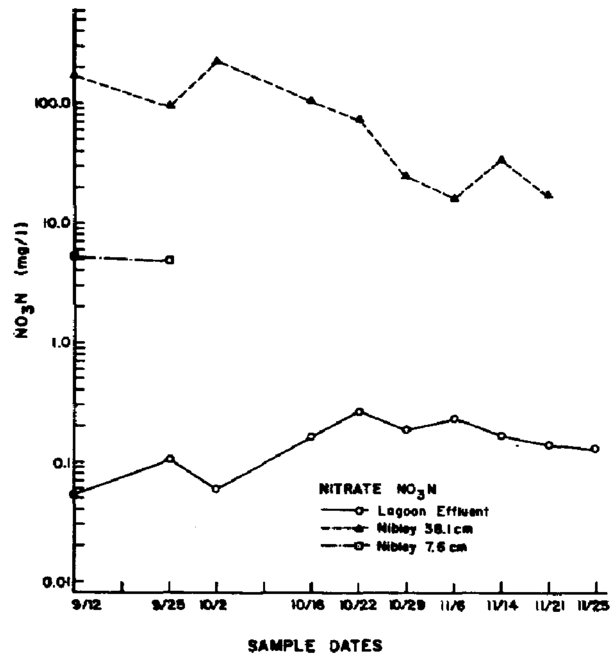


Figure A-6. Nitrate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

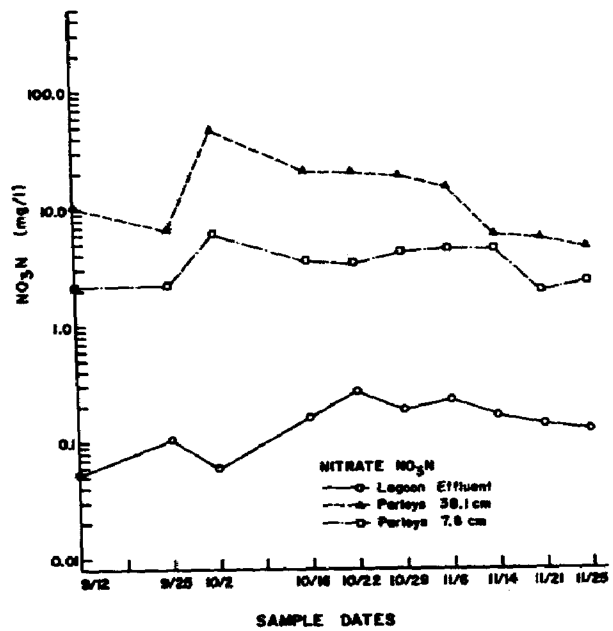


Figure A-7. Nitrate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

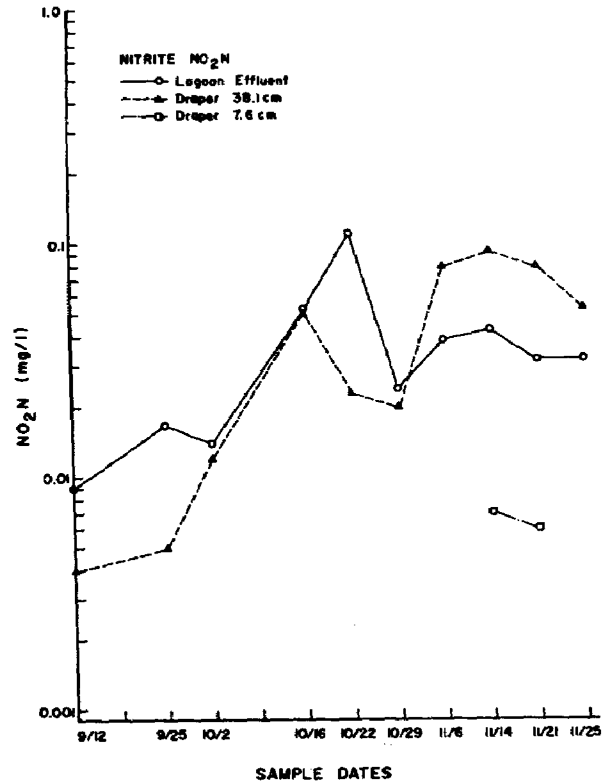


Figure A-8. Nitrite concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

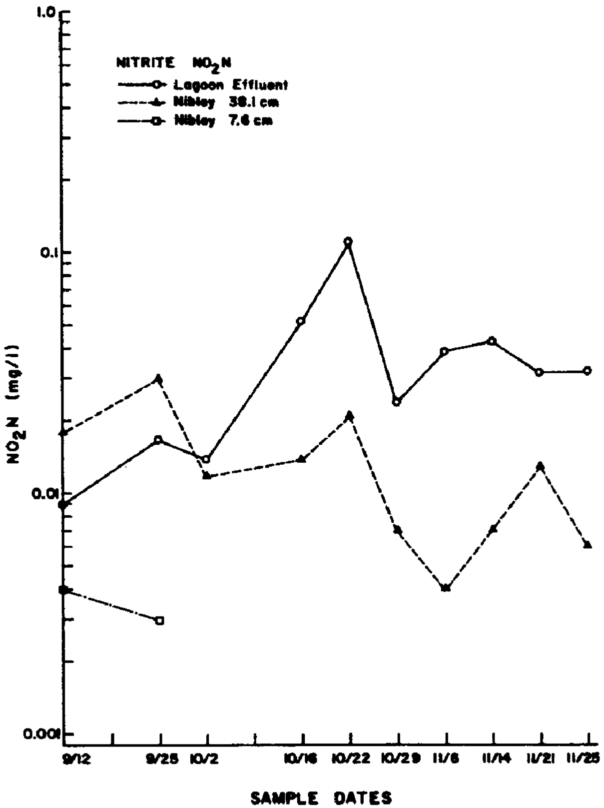


Figure A-9. Nitrite concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

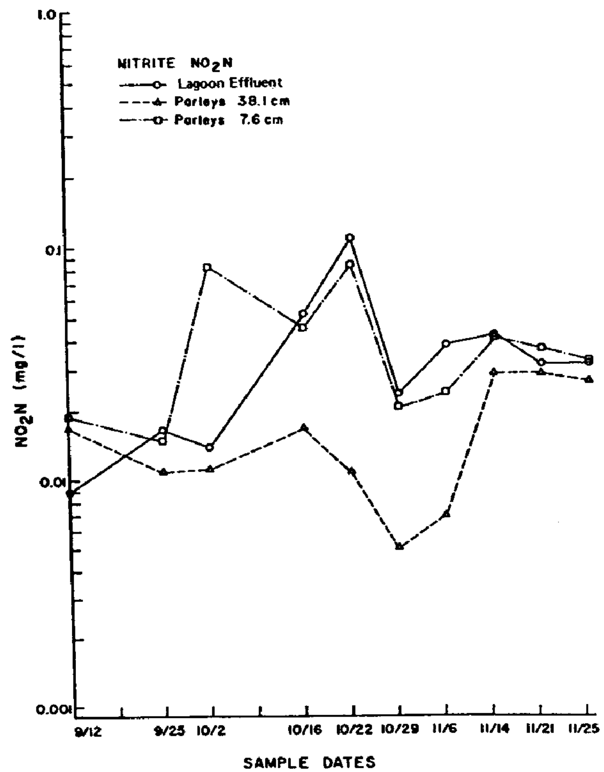


Figure A-10. Nitrite concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

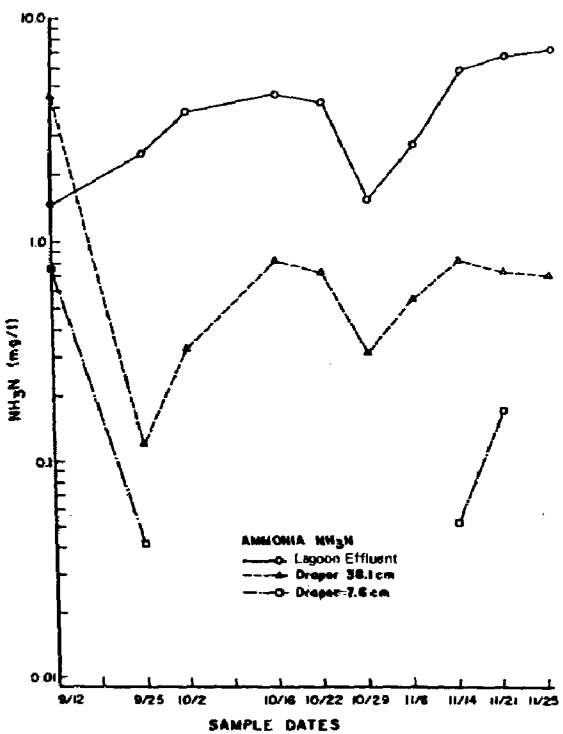


Figure A-11. Ammonia-N concentration in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

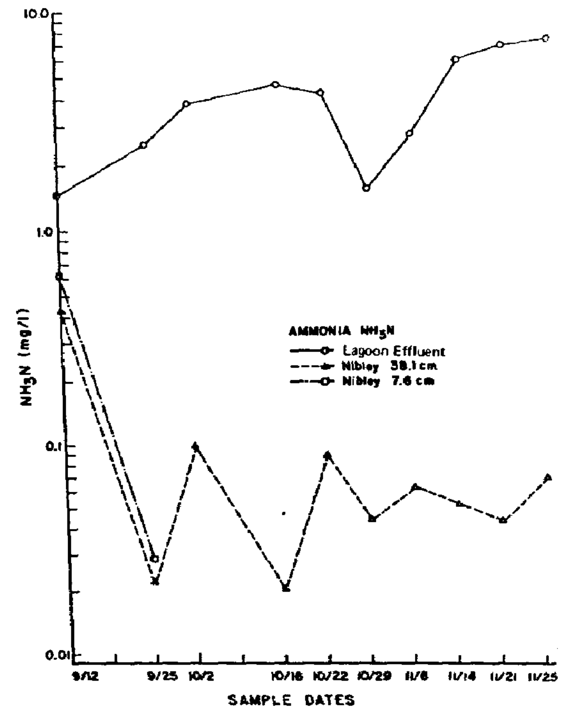


Figure A-12. Ammonia-N concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

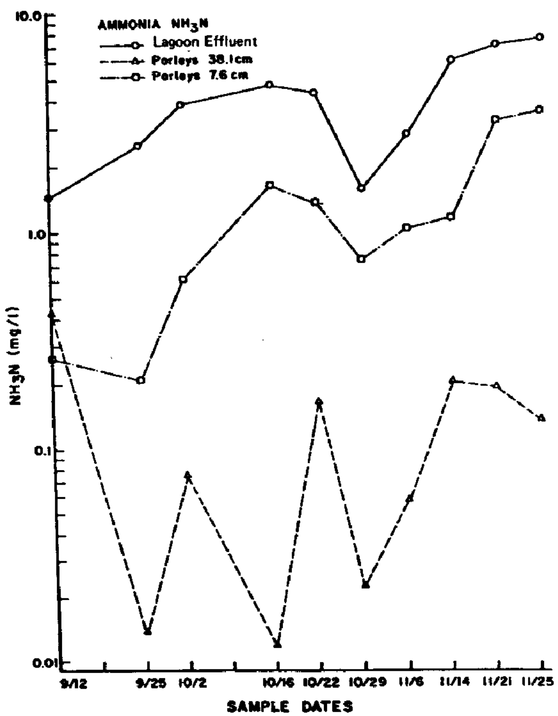


Figure A-13. Ammonia-N concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

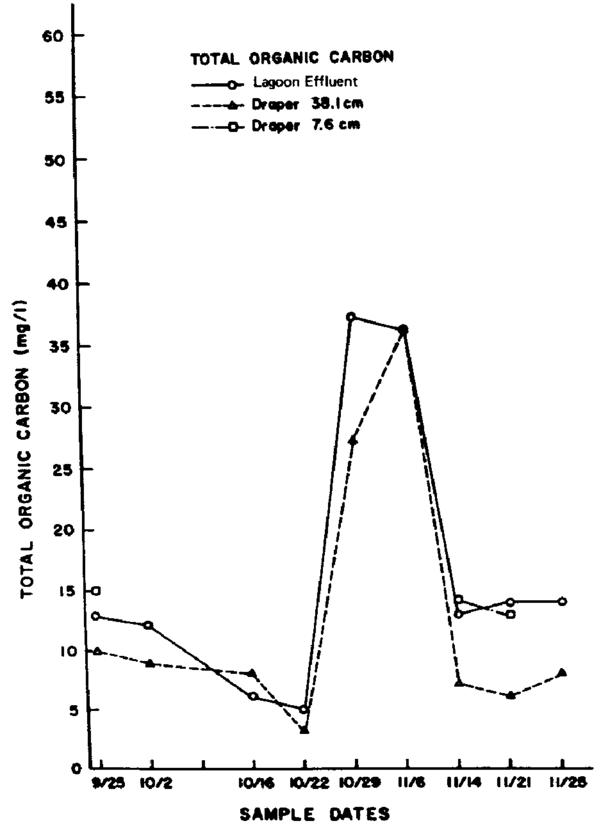


Figure A-14. Total organic carbon concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

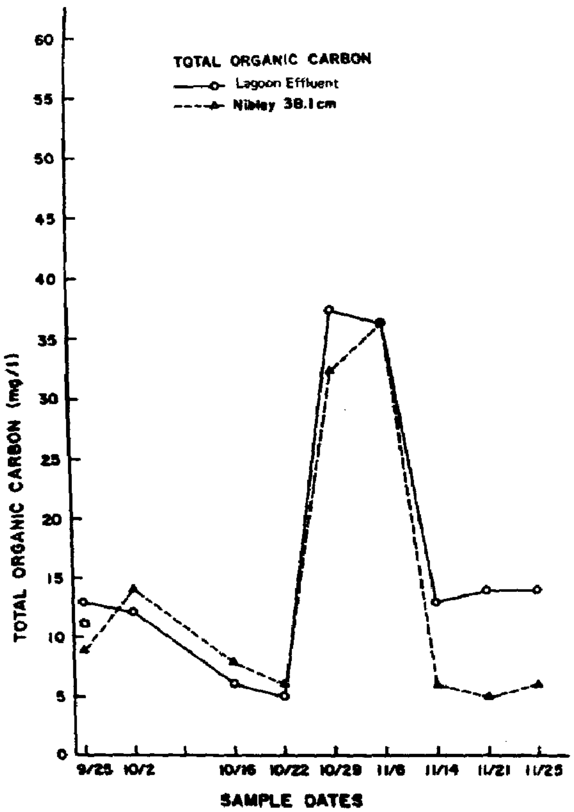


Figure A-15. Total organic carbon concentrations in the influent and effluent samples collected at the 38.1 cm sampling depths for the lysimeters containing Nibley soil.

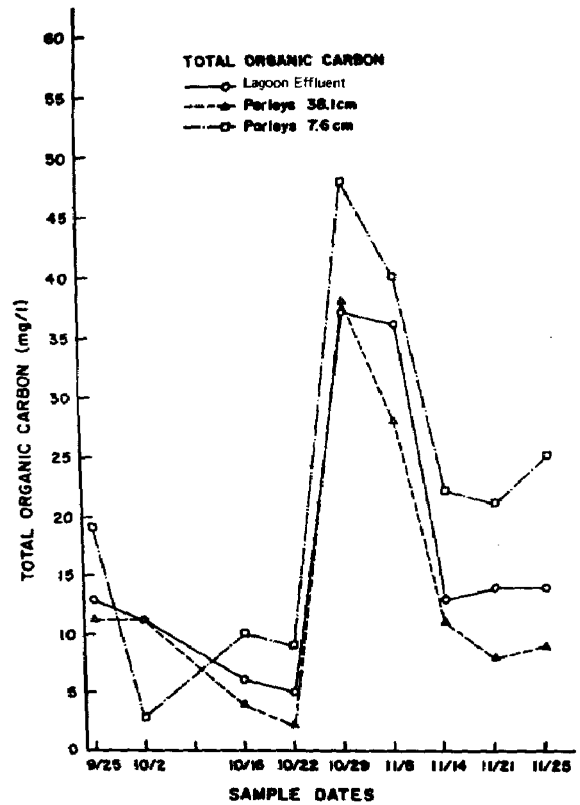


Figure A-16. Total organic carbon concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

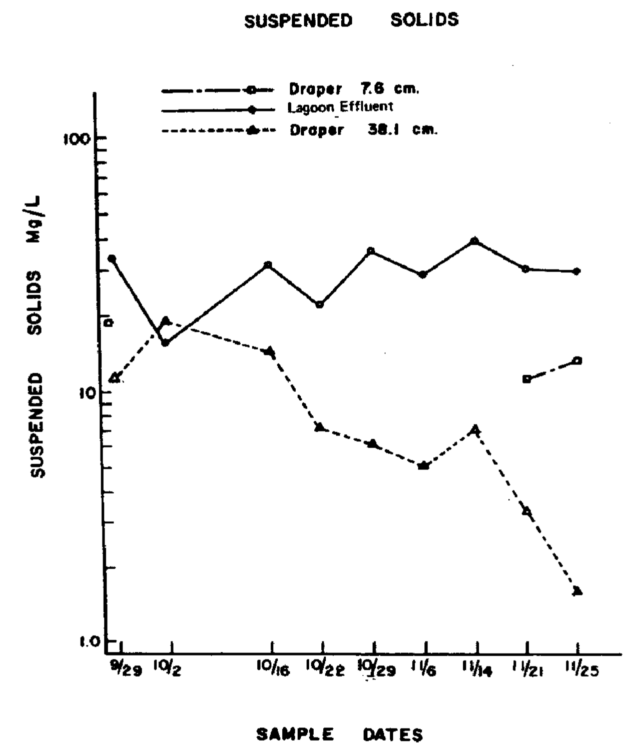


Figure A-17. Suspended solids concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

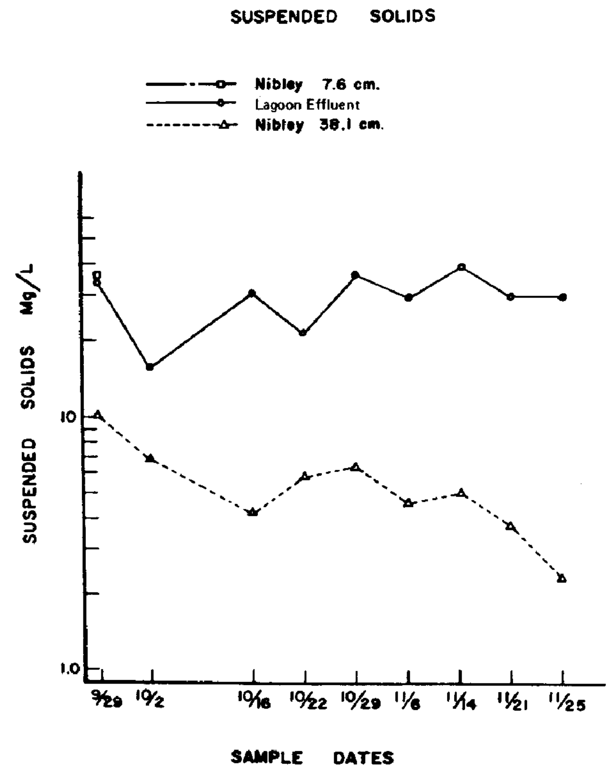


Figure A-18. Suspended solids concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

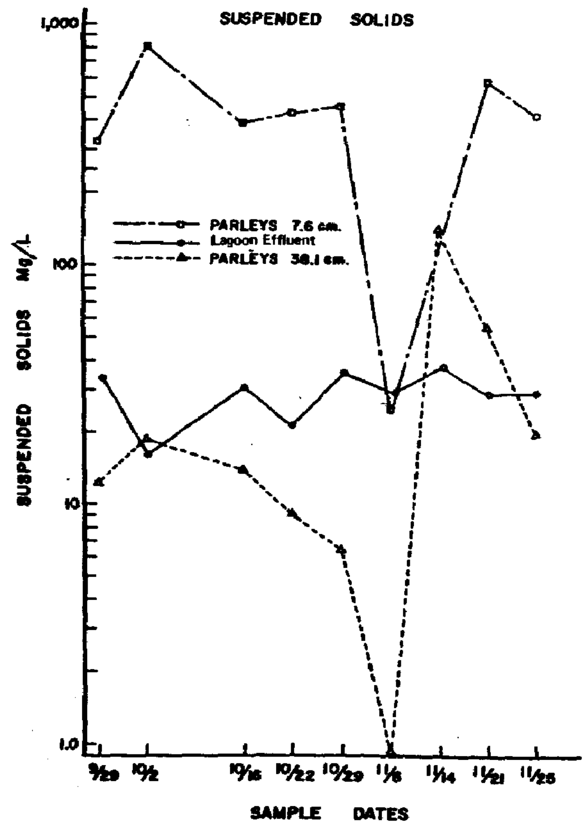


Figure A-19. Suspended solids concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

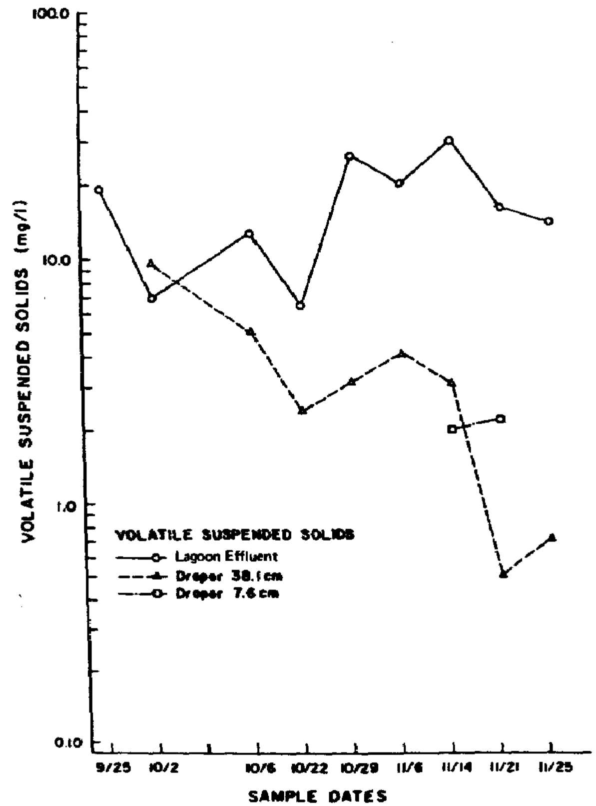


Figure A-20. Volatile suspended solids concentrations in the influent and the effluent samples collected at the 7.6 and 38.1 cm sampling depths fo the lysimeters containing Draper soil.

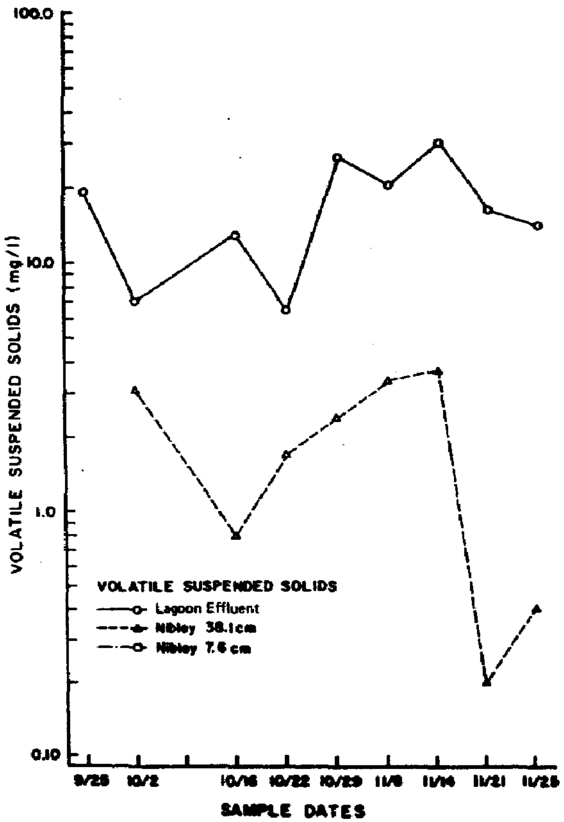


Figure A-21. Volatile suspended solids concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

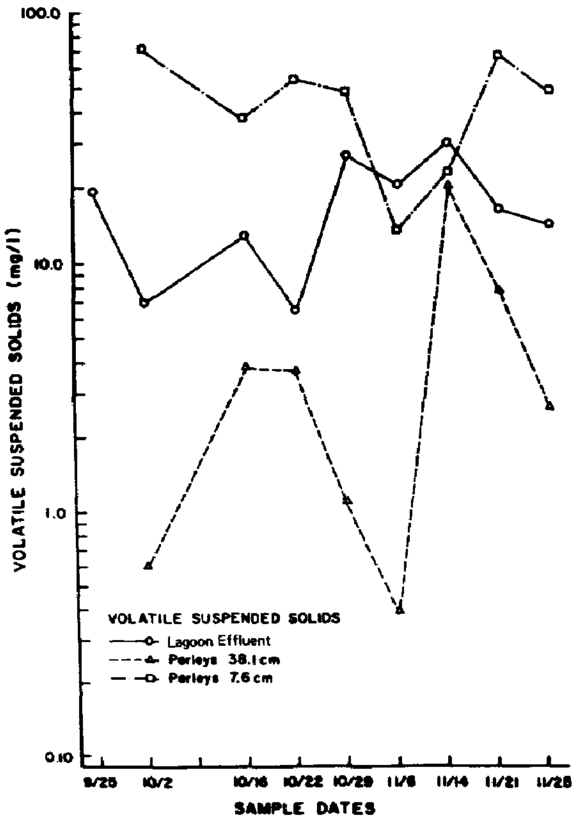


Figure A-22. Volatile suspended solids concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

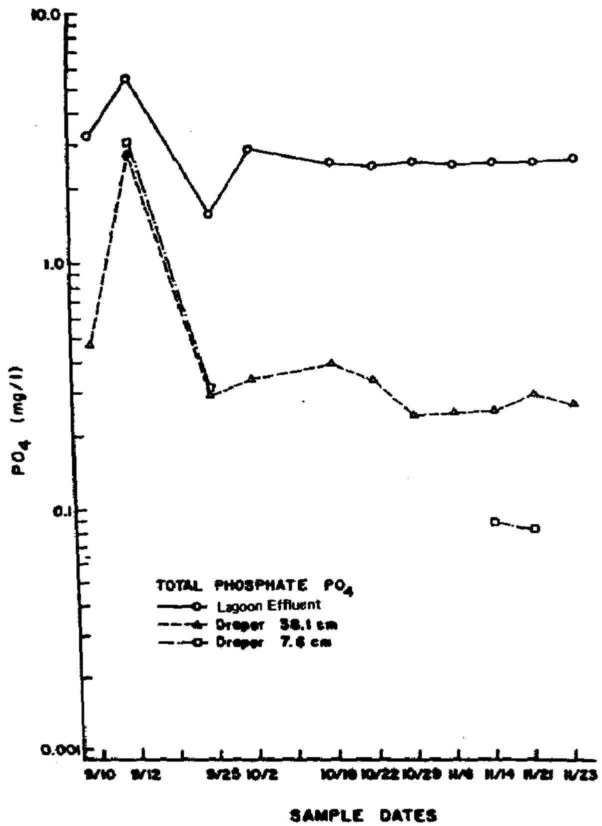


Figure A-23. Total phosphate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

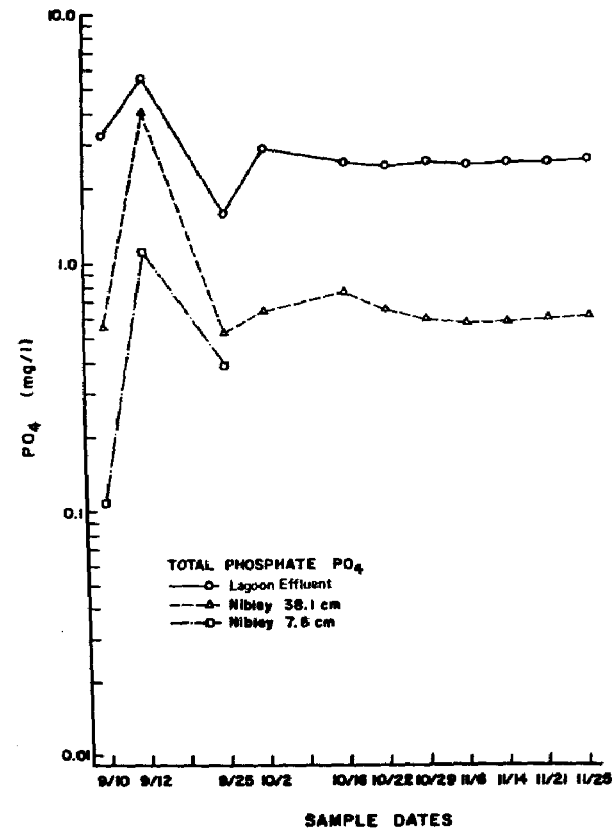


Figure A-24. Total phosphate concentration in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

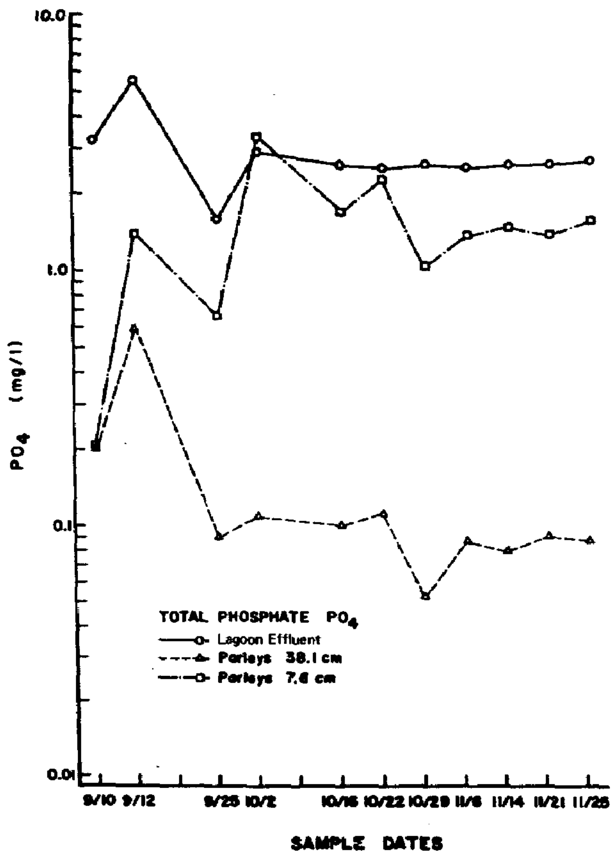


Figure A-25. Total phosphate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

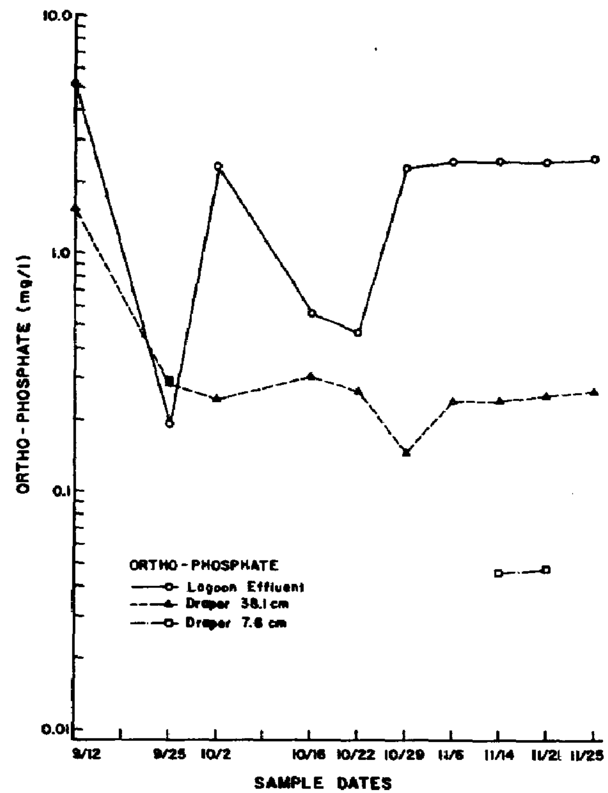


Figure A-26. Ortho-phosphate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

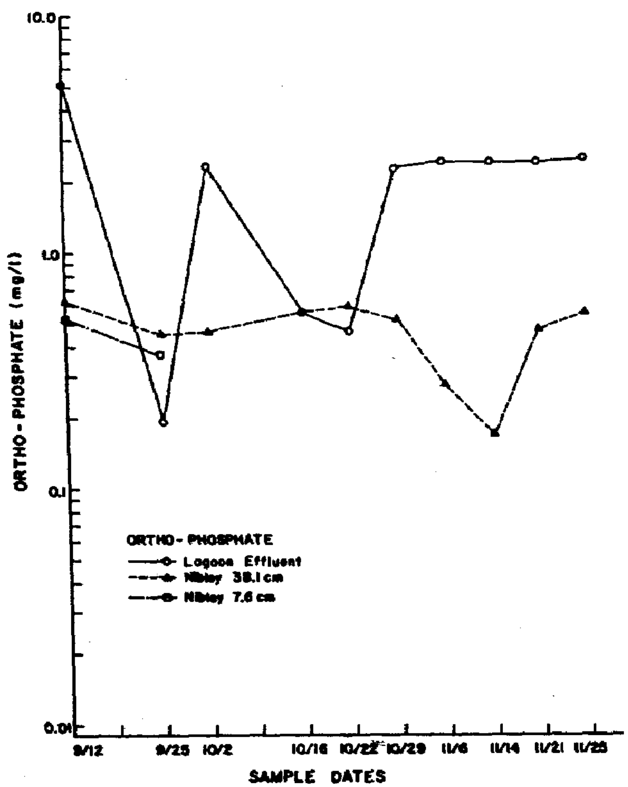


Figure A-27. Ortho-phosphate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

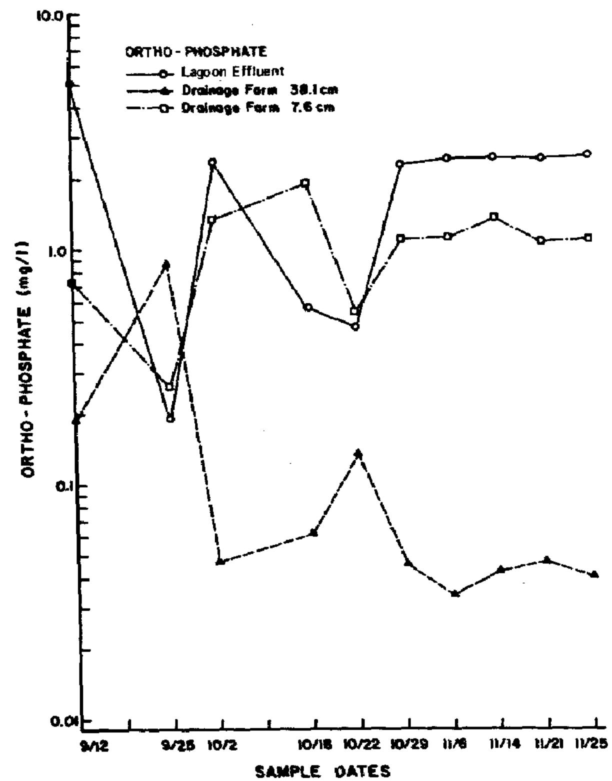


Figure A-28. Ortho-phosphate concentrations in the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

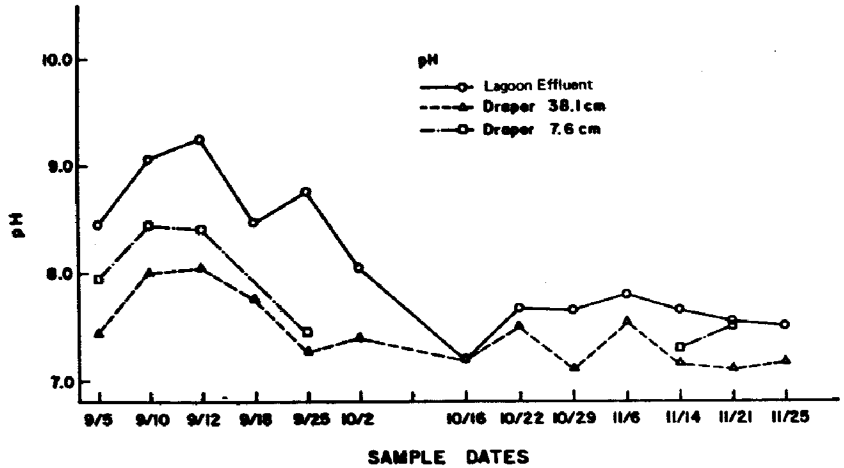


Figure A-29. The pH values for the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

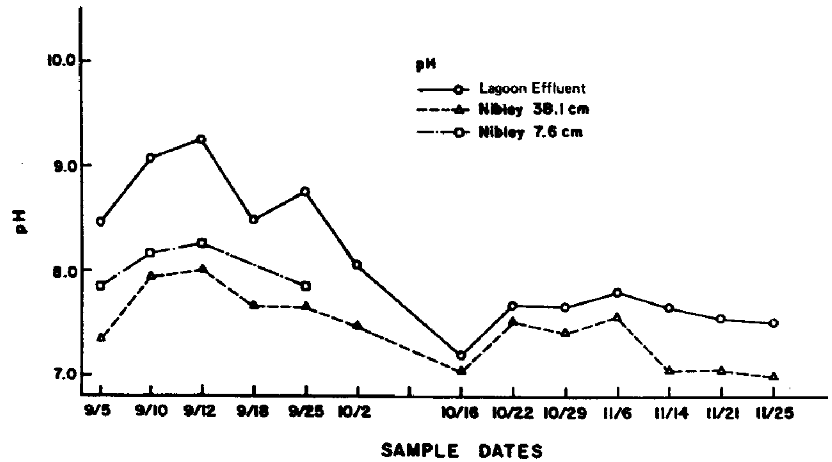


Figure A-30. The pH values for the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

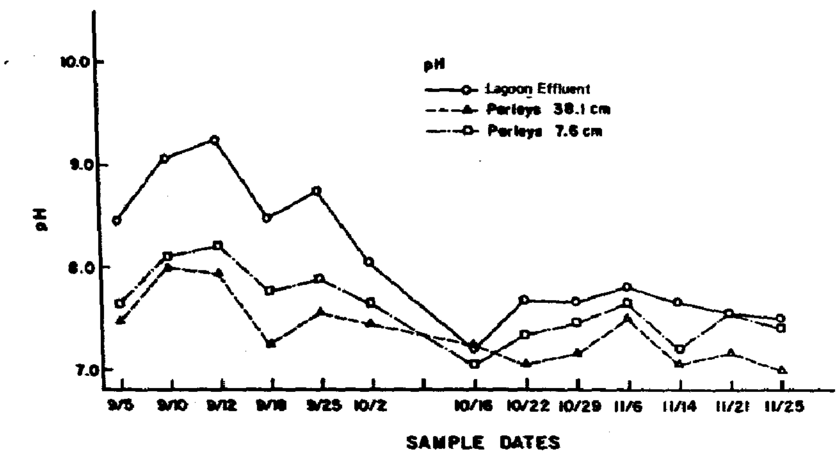


Figure A-31. The pH values for the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

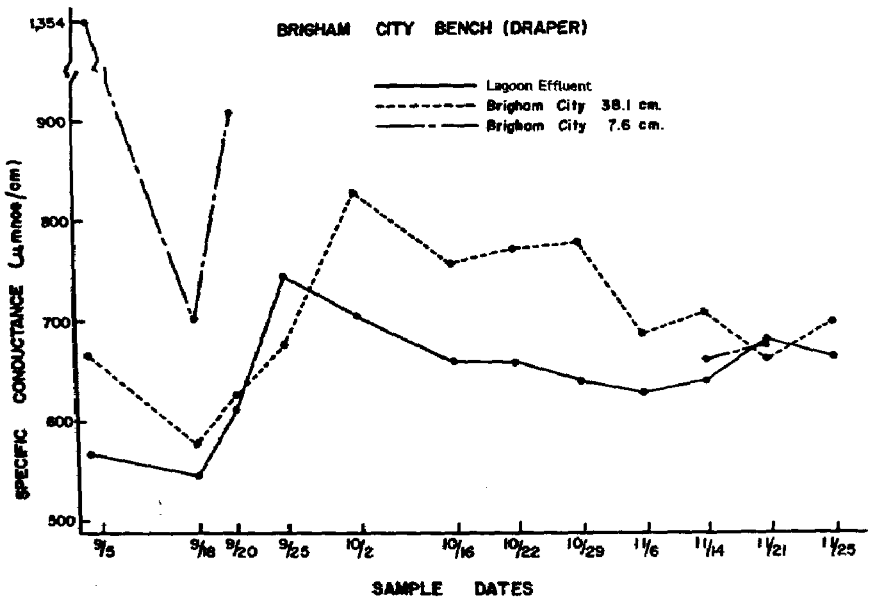


Figure A-32. Specific conductance values for the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Draper soil.

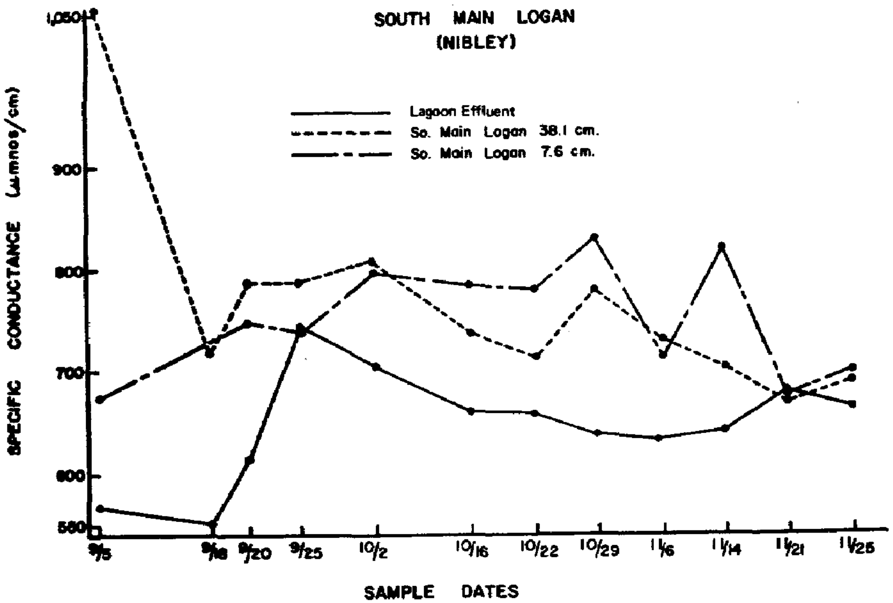


Figure A-33. Specific conductance values for the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Nibley soil.

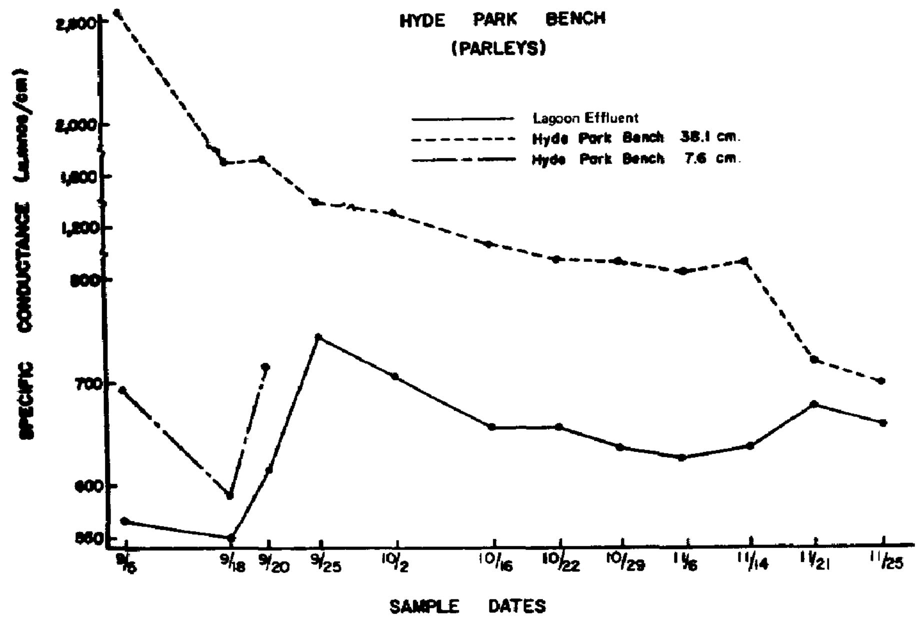


Figure A-34. Specific conductance values for the influent and effluent samples collected at the 7.6 and 38.1 cm sampling depths for the lysimeters containing Parleys soil.

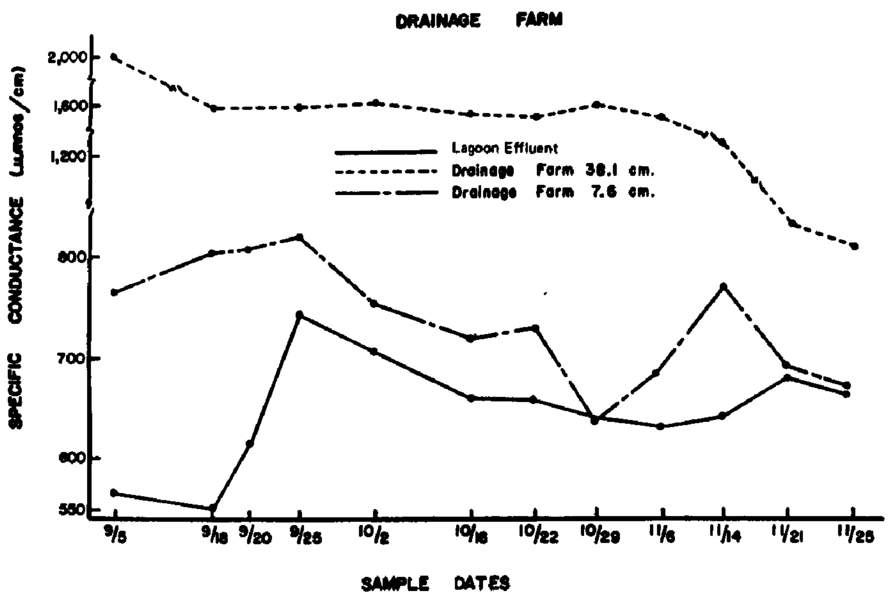


Figure A-35. Specific conductance values in the influent and effluent samples collected at the 7.6 cm sampling depths for the lysimeters containing Drainage Farm soil.

TABLE A-1. RESULTS OF NITRATE (NO_3-N MG/L) ANALYSES

	Sample Date (1974)									
	9/12	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	0.1	0.1	0.1	0.2	0.3	0.2	0.2	0.2	0.1	0.1
Draper										
7.6 cm	7.0	17.8						9.1	8.8	
38.1 cm	3.9	2.0	2.7	3.1	3.0	3.6	3.8	2.8	3.6	3.8
Nibley										
7.6 cm	5.2	5.0								
38.1 cm	175.4	98.8	230.4	101.1	74.9	25.8	17.5	34.6	28.4	25.4
Parleys										
7.6 cm	2.2	2.2	6.1	3.7	3.5	4.2	4.7	4.6	2.0	2.4
38.1 cm	11.4	6.8	48.2	21.8	21.4	19.1	16.2	6.0	5.4	4.7
Drainage Farm										
7.6 cm	2.0	6.5	5.2	3.7	3.6	3.5	4.6	5.2	2.8	2.5
38.1 cm	48.3	69.2	126.0	41.0	36.3	50.2	40.8	34.4	24.4	17.2

TABLE A-2. RESULTS OF NITRITE (NO_2-N MG/L) ANALYSES

	Sample Date (1974)									
	9/12	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Draper										
7.6 cm		<0.1						<0.1	<0.1	
38.1 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nibley										
7.6 cm	<0.1	<0.1								
38.1 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Parleys										
7.6 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
38.1 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Drainage Farm										
7.6 cm	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
38.1 cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

TABLE A-3. RESULTS OF AMMONIA (NH_3-N MG/L) ANALYSES

	Sample Date (1974)									
	9/12	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	1.5	2.5	3.8	4.7	4.3	1.6	2.8	5.9	6.9	7.4
Draper										
7.6 cm	0.8	< 0.1						< 0.1	0.2	
38.1 cm	4.5	0.1	0.3	0.8	0.7	0.3	0.6	0.8	0.8	0.7
Nibley										
7.6 cm	0.6	< 0.1								
38.1 cm	0.4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Parleys										
7.6 cm	0.3	0.2	0.6	1.6	1.4	0.8	1.0	1.2	3.2	3.5
38.1 cm	0.4	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.2	0.2	0.1
Drainage Farm										
7.6 cm	1.5	0.2	1.0	2.7	2.9	1.2	1.3	1.6	2.5	3.5
38.1 cm	0.4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

TABLE A-4. RESULTS OF TOTAL ORGANIC CARBON (UNFILTERED MG/L) ANALYSES

	Sample Date (1974)								
	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	13	12	6	5	37	36	13	14	14
Draper									
7.6 cm	15						14	13	
38.1 cm	10	9	8	4	27	36	7	6	8
Nibley									
7.6 cm	11								
38.1 cm	9	14	8	6	32	36	6	5	6
Parleys									
7.6 cm	19	3	10	9	48	40	22	21	25
38.1 cm	12	12	4	2	38	28	11	8	9
Drainage Farm									
7.6 cm	16	16	8	4	56	32	18	18	17
38.1 cm	7	4	3	2	36	36	5	4	7

TABLE A-5. RESULTS OF TOTAL CARBON (UNFILTERED MG/L) ANALYSES

	Sample Date (1974)								
	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	67	69	56	55	103	106	69	75	72
Draper									
7.6 cm	79						78	81	
38.1 cm	72	80	68	64	107	106	70	73	73
Nibley									
7.6 cm	70								
38.1 cm	89	82	72	67	116	112	87	89	91
Parleys									
7.6 cm	93	88	77	72	134	108	94	97	100
38.1 cm	82	68	58	58	102	100	82	83	86
Drainage Farm									
7.6 cm	82	76	72	63	144	104	85	87	88
38.1 cm	127	102	98	96	118	162	123	125	128

TABLE A-6. RESULTS OF TOTAL INORGANIC CARBON (UNFILTERED MG/L) ANALYSES

	Sample Date (1974)								
	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	54	57	50	50	66	70	56	61	58
Draper									
7.6 cm	64						64	68	
38.1 cm	62	71	60	60	80	70	63	67	65
Nibley									
7.6 cm	59								
38.1 cm	80	68	64	61	84	76	81	84	85
Parleys									
7.6 cm	74	85	67	63	86	68	72	76	75
38.1 cm	70	56	54	56	64	72	71	75	77
Drainage Farm									
7.6 cm	66	60	64	59	88	72	67	69	71
38.1 cm	120	98	95	94	152	126	118	121	121

TABLE A-7. RESULTS OF SUSPENDED SOLIDS (MG/L) ANALYSES

	Sample Date (1974)								
	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	33	16	31	21	36	28	38	29	29
Draper									
7.6 cm	19						11	13	
38.1 cm	11	19	14	7	6	5	7	3	2
Nibley									
7.6 cm	35								
38.1 cm	10	7	4	6	6	4	5	4	2
Parleys									
7.6 cm	323	800	388	423	458	25	131	588	423
38.1 cm	12	19	14	9	6	1	144	55	20
Drainage Farm									
7.6 cm	80	142	328	208	443	56	246	82	212
38.1 cm	10	10	2	4	3	2	8	1	2

TABLE A-8. RESULTS OF VOLATILE SUSPENDED SOLIDS (MG/L) ANALYSES

	Sample Date (1974)								
	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	19	7	13	7	27	20	30	16	14
Draper									
7.6 cm	0						2	2	
38.1 cm	0	10	5	2	3	4	3	1	1
Nibley									
7.6 cm	0								
38.1 cm	0	3	1	2	2	3	4	0	0
Parleys									
7.6 cm	0	70	36	53	48	13	23	66	46
38.1 cm	0	1	4	4	1	0	20	8	3
Drainage Farm									
7.6 cm	14	21	53	35	63	21	29	14	25
38.1 cm	2	3	1	2	2	1	1	1	0

TABLE A-9. RESULTS OF TOTAL PHOSPHATE (PO_4-P MG/L) ANALYSES

	Sample Date (1974)										
	9/10	9/12	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	3.3	5.5	1.6	2.9	2.6	2.4	2.6	2.5	2.6	2.5	2.6
Draper											
7.6 cm		3.0	0.3						< 0.1	< 0.1	
38.1 cm	0.5	2.8	0.3	0.4	0.4	0.3	0.2	0.2	0.1	0.1	0.3
Nibley											
7.6 cm	0.1	1.1	0.4								
38.1 cm	0.6	4.0	0.5	0.6	0.8	0.6	0.6	0.6	0.6	0.6	0.6
Parleys											
7.6 cm	0.2	1.4	0.7	3.2	1.7	2.2	1.0	1.3	1.4	1.4	1.5
38.1 cm	0.2	0.6	< 0.1	0.1	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Drainage Farm											
7.6 cm	0.4	1.8	0.4	1.7	2.1	2.1	1.3	1.4	1.5	1.6	1.6
38.1 cm	0.2	0.4	0.4	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

TABLE A-10. RESULTS OF ORTHOPHOSPHATE ($O\text{-}PO_4\text{-}P$ MG/L) ANALYSES

	Sample Date (1974)									
	9/12	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	5.1	0.2	2.3	0.6	0.5	2.3	2.5	2.5	2.5	2.5
Draper										
7.6 cm		0.3						< 0.1	< 0.1	
38.1 cm	1.6	0.7	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.3
Nibley										
7.6 cm	0.5	0.4								
38.1 cm	0.6	0.5	0.5	0.6	0.6	0.5	0.3	0.2	0.5	0.6
Parleys										
7.6 cm	0.2	0.5	0.6	1.2	1.7	1.0	1.3	1.3	1.2	1.4
38.1 cm	0.2	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Drainage Farm										
7.6 cm	0.7	0.3	1.4	1.9	0.6	1.1	1.1	1.4	1.1	1.1
38.1 cm	0.2	0.8	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

TABLE A-11. RESULTS OF pH ANALYSES

	Sample Date (1974)												
	9/5	9/10	9/12	9/18	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	8.5	9.1	9.2	8.5	8.7	8.0	7.2	7.7	7.6	7.8	7.6	7.6	7.5
Draper													
7.6 cm	7.9	8.4	8.4		7.4						7.3	7.5	
38.1 cm	7.4	8.0	8.0	7.8	7.3	7.4	7.2	7.5	7.1	7.5	7.2	7.1	7.2
Nibley													
7.6 cm	7.8	8.2	8.3		7.8								
38.1 cm	7.3	7.9	8.0	7.6	7.6	7.5	7.0	7.5	7.4	7.6	7.0	7.0	7.0
Parleys													
7.6 cm	7.6	8.1	8.2	7.8	7.9	7.6	7.0	7.3	7.4	7.6	7.2	7.5	7.4
38.1 cm	7.5	8.0	7.9	7.2	7.6	7.5	7.2	7.0	7.2	7.5	7.0	7.2	7.0
Drainage Farm													
7.6 cm	7.8	8.3	8.5	8.0	8.1	8.0	7.8	7.7	7.8	7.8	7.6	7.6	7.5
38.1 cm	7.5	8.0	8.0	7.5	7.7	7.6	7.9	7.4	7.6	7.6	7.2	7.2	7.4

TABLE A-12. RESULTS OF SPECIFIC CONDUCTANCE (μmhos/cm) ANALYSES

	Sample Date (1974)											
	9/5	9/18	9/20	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	566	545	610	742	702	655	653	639	626	637	676	660
Draper												
7.6 cm	1,354	697		903						658	670	
38.1 cm	662	578	627	672	828	751	759	761	683	704	668	647
Nibley												
7.6 cm	691	596		712								
38.1 cm	2,880	1,717	1,725	1,428	1,314	1,047	979	935	851	935	712	698
Parleys												
7.6 cm	672		747	726	793	784	779	821	713	812	672	698
38.1 cm	1,056	717	786	784	804	733	711	773	725	701	670	687
Drainage Farm												
7.6 cm	768	808	813	947	750	717	724	646	680	763	689	666
38.1 cm	2,016	1,515	1,497	1,549	1,565	1,456	1,442	1,503	1,438	1,215	1,060	840

TABLE A-13. TOTAL ALGAL CELL COUNTS (NUMBER/ML)

	Sample Date (1974)								
	9/25	10/2	10/16	10/22	10/29	11/6	11/14	11/21	11/25
Lagoon Effluent	3,378	5,226	5,889	17,476	57,684	37,365	34,874	19,140	23,496
Draper									
7.6 cm	2,706						894	690	
38.1 cm	792	725	712	713	1,626	1,115	562	545	682
Nibley									
7.6 cm	2,746								
38.1 cm	554	462	461	396	1,770	1,327	528	418	316
Parleys									
7.6 cm	1,664	1,135	1,056	1,477	15,897	10,568	11,766	12,411	15,768
38.1 cm	607	529	422	449	895	2,313	6,436	1,931	1,905
Drainage Farm									
7.6 cm	4,249	4,314	1,622	1,387	47,856	54,901	18,182	23,427	27,855
38.1 cm	1,121		370	343	401	316	367	307	247

TABLE A-14. RESULTS OF PHEOPHYTIN "A" (MG/L) ANALYSES

	Sample Date (1974)			
	9/25	10/2	10/16	10/22
Lagoon Effluent	0	0	0	0
Draper				
7.6 cm	0			
38.1 cm	0	0	0	0
Nibley				
7.6 cm	0			
38.1 cm	0	0	0	0
Parleys				
7.6 cm	0	0.016	0	0
38.1 cm	0	0	0	0
Drainage Farm				
7.6 cm	0	0	0	0
38.1 cm	0	0	0	0

Note--Pheophytin "a" tests were not conducted further because levels were too low to make the data reliable.

TABLE A-15. RESULTS OF CHLOROPHYLL "A" (MG/L) ANALYSES

	Sample Date (1974)			
	9/25	10/2	10/16	10/22
Lagoon Effluent	0.057	0.026	0.045	0.026
Draper				
7.6 cm	0			
38.1 cm	0	0	0.003	0.002
Nibley				
7.6 cm	0			
38.1 cm	0	0	0.001	0.001
Parleys				
7.6 cm	0.010	0.003	0.025	0.012
38.1 cm	0	0	0.002	0.002
Drainage Farm				
7.6 cm	0	0.025	0.012	0.007
38.1 cm	0	0	0.001	0.002

APPENDIX B

RESULTS OF FIELD INVESTIGATIONS

TABLE B-1. SPECIFIC CONDUCTANCE, μmhos/cm

Test Site	Depth	Date–1975							
		8/2	8/9	8/16	9/20	10/4	10/18	10/25	Avg.
Vegetated 6"/wk	4"	828	940		598	1050	749	697	810
	1'	1000	1350		930	1090	1230	1180	1130
	2'	27400	12500		3590	3720	1720	1370	8380
	3'	8430	4740		2390	3650	1970	1860	3840
Bare 6"/wk	4"	909	934		571	3340	707	634	1180
	1'	3850	1481		934		1060	747	1620
	2'	1760	1870			1530	1360	1140	1530
	3'	3150	3010			1560		870	2650
Vegetated 4"/wk	4"			826	560	828	1100		829
	1'	4870	2850	1350	1540		1920	1260	2300
	2'	8340	3760	2160	1650			1670	3530
	3'			9220					
Bare 4"/wk	4"			877	591	776			748
	1'	2710	5240	2620	1700		1500	820	2430
	2'	4090	6840	5280	2840	3150	4950	2360	4210
	3'	12300	7750	10000	8900	13400	20200	14700	12500
Vegetated 2"/wk	4"						42700	1000	21900
	1'						9360	3900	6630
	2'							38100	
	3'						4240	16400	2940
Bare 2"/wk	4"		1640					969	1300
	1'		21600	8100		11600		4170	11400
	2'		9110	20200			8660	2820	10200
	3'		45600	39400			42600	39700	41800
Oxidation Pond Effluent		780		730	465	665	706	604	658

TABLE B-2. SPECIFIC CONDUCTANCE, μmhos/cm

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated	4"		1100	980	1150	1290	1290	3070	1390	1230	1180	1260	1210	1230	1160	1350
6"/wk.	1'			1200	1490	1180	1260	1200	1290	1320	1140	1170	1210	1210	1180	1240
	2'			2110	2010	2050		1690	1680	2130	1450	1310	1310	1250	1770	1710
	3'			31700	4430	4170	3220	2680	2590	3550	2260	2220	1560	2220	2030	5140
Bare	4"			726	830	824	790	2150	791	856	725	672	730	717	720	910
6"/wk.	1'		1270	760	920	970	1090	1690	1040	1050	1050	1030	1280	1080	900	1090
	2'		2520	2090	1500	2000	1830	1900	1940	1890	1940	2300	1850	1950	1880	1970
	3'		1910	1860	2490	1700	1710	1590	1690	1650	1600	1870	2470	2500	2230	1940
Vegetated	4"			920	970	1050	1070	950	1020	1010	858	950	906	994	936	970
4"/wk.	1'			1300	1300	1030	960	854	1000	1120	909	944	893	1490	942	1060
	2'			1790	1610	1560	1350	1320	1440	1350	1280	1360	1260	1322	1420	1420
	3'			4840	3950	4370	4050	4320	3120	3220	2830	2610	3610	4180	4130	3770
Bare	4"			961	1140	1110		1070	1120	953	903	933	910	1050	992	1010
4"/wk.	1'			2270	1930	1910	1711	1690	1790	1730	1940	1810	1840	1930	1800	1860
	2'			—	1930	1740	1720	1560	1730	1600	1530	1480	1500	1440	1250	1590
	3'			6920	7020	10200	9640	9390	9850	8810	10200	9820	9600	9900	8310	9180
Vegetated	4"			—	2450		1360	1220	2590	1480	1180	3030	3640	4050	4580	2560
2"/wk.	1'			4520	6040	5000	4050	2280	2600	2000	1940	1850	2040	2290	2140	3060
	2'			7560	8930			7810			5630	4890	5050	6230	5670	6470
	3'			13300	12300		11800	18900	21700	19200	18700	17200	17900	18200	17000	16900
Bare	4"		1420	922	806	916	950	932	990	987	1010	1170	1000	1150	1100	1030
2"/wk.	1'			1920	2290	2250	2070	1540	1870	1630	1640	1710	1700	1700	1670	1830
	2'				5320	6720	8200	8280	9930	4840	7880	2870	6600	2220	6040	6260
	3'			12000	14100	14900	13300	13500	12100	11000	12000	11500	11000	10700	9410	12100
Vegetated	4"		976	1040	1050		1200	1040	1290	1220	1220	1360	1360	1520	1270	1210
Control	1'			1500	1590	1510	1540	1360	1570	1540	1620	1490	1430	1630	1320	1500
4"/wk.	2'		1910	1560	1770	1680	1790	1690	1730	1680	1550	1550	1470	1530	1360	1640
	3'		3060	3410	5120	4700	3940	4360	2610	2470	2550	2400	2950	2210	3020	3290
Bare	4"			1670	1540	1050	1230	1190	1240	1125	864	1100	726	1220	1100	1170
Control	1'		1810	1720	1560		1940	1880	1780	1820	1940	1860	1870	1940	1650	1810
4"/wk.	2'			2780	3000	4900	3100	2600	2970	3000	2810	2810	2770	2900	2600	3020
	3'			10700	12000	9280	12200	14100	14400	14100	13000	11800	11500	12000	10400	12100
Oxidation Pond Effluent		536	623	567	561	592	600	599	603	602	610	546	526	502	508	570
Control Water		474	500	490	496	514	486	487	481	463	479	502	455	484	455	483

TABLE B-3. AMMONIA-N, µg/l

Test Site	Depth	Date–1975					
		8/2	8/9	8/16	10/18	10/25	Avg.
Vegetated 6"/wk	4"	28	38		40	26	33
	1'	<1	12		21	45	19
	2'	<1	5		113	34	38
	3'	14	44		52	22	33
Bare 6"/wk	4"	<1	<1		85	120	51
	1'	<1	17		134	18	42
	2'	<1	17		66	62	36
	3'	<1					
Vegetated 4"/wk	4"			17	39		29
	1'	14	6	<1	112		33
	2'	<1	<1	<1		16	4
	3'			<1			
Bare 4"/wk	4"			24			
	1'	<1	<1	10	77	111	40
	2'	56	<1	435	88	52	126
	3'	<1	4	222	375	882	297
Vegetated 2"/wk	4"				66	34	50
	1'				112	47	80
	2'					43	
	3'				260	36	148
Bare 2"/wk	4"		76		102	48	75
	1'		10	<1		59	23
	2'			263	184	18	76
	3'		142	124	134	40	85
Oxidation Pond Effluent		2040		117	3620	3560	2330

TABLE B-4. AMMONIA-N, μg/1

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"	90	79	30	25	31	37	29	10	<1	28	34	62	40		41
	1'			73	21	17	45	30	15	<1	12	26	41	48	49	34
	2'			193	209	113	224		208	<1	378	228	484	254		255
	3'				106	49	124	80	115	<1	223	195	127	85		122
Bare 6"/wk	4"			77	<1	36	73	27	22	9	42	44	60	35		39
	1'		40	30	28	36	24	60	53	56	72	45	47	33		44
	2'		32	55	101	75	43	170	109	51	131	164	120	129		98
	3'		43	31	<1	82	66	90	78	38	116	119	121	108		74
Vegetated 4"/wk	4"			37	28	24	23	21	22	22	69	17	42	45	52	34
	1'			48	34	12	42	21	15	24	51	32	28	101	54	38
	2'			89	26	24	18	17	41	34	39	84	97	104	114	57
	3'			195	208	286	765		120	175	292	222	209	254	283	274
Bare 4"/wk	4"			24	251	138	15	38	22	<1	31	40	43	46	24	61
	1'			155	16	40	40	29	20	<1	32	33	40	25	32	42
	2'				129	8	7	21	15	<1	47	74	65	83	59	51
	3'				7320	2710	887		134	<1	159	76	356	224	74	1330
Vegetated 2"/wk	4"				89	64	44	39	29	34	32	36	88	44		50
	1'			1060	190	197	113	28	32	43	51	50	58	42	32	76
	2'			108	246		799	268	171		168	151	222	214	261	261
	3'				1450	2450	2410	549	454	431	515	445	366	283		935
Bare 2"/wk	4"		53	35	43	16	29	29	12	20	36	32	30	28	36	31
	1'				54	38	9	26	21	32	31	27	29	41		31
	2'				58	30	4	64	64	64	111	47	111	35	119	64
	3'		54	30	254	79	144	110	122	185	227	190	213	171	183	151
Vegetated Control 4"/wk	4"		90	36	44	27	36	44	22	38	34	34	48	36		41
	1'			52	<1	30	27	43	28	24	48	29	33	29		31
	2'	196	47	38	<1	145	163	133	90	106	117	60	102	112		101
	3'			739	1020	581	756	459	402	216	337	243	90	90		449
Bare Control 4"/wk	4"			29	39	24	12	23	28	21	32	30	34	25	26	27
	1'		26	32	49	28	4	29	22	24	25	24	35	28	29	27
	2'			69	28	55	52	30	28	28	25	70	66	43	40	45
	3'			333	222	87	141	189	173	186	199	150	216	141	152	182
Oxidation Pond Effluent		82	178	492	1170	2160	1950	1020	640	1830	1450	170	279	131	99	832
Control Water		218	168	168	170	204	178	201	159	197	185	153	189	168	173	181

TABLE B-5. NITRATE NO_3-N, µg/l

Test Site	Depth	Date–1975							
		8/2	8/9	8/16	9/20	10/4	10/18	10/25	Avg.
Vegetated 6"/wk	4"	3750	2070		7	6	22	22	979
	1'	12000	1590		23	6	19	23	2280
	2'	14800	2080		47	17	5	20	2830
	3'	16800	227		886	< 1	6	22	2990
Bare 6"/wk	4"			2950	28		23		1000
	1'	12600	945	253	6		31		2770
	2'	16900	2160	16				5	4770
	3'			6110					
Vegetated 4"/wk	4"						1220	35	627
	1'						9810	9200	9510
	2'							3370	
	3'						10800	155	5480
Bare 4"/wk	4"		5360				53400	13800	24200
	1'		7940	269000				87900	122000
	2'		18200	7940				65600	30600
	3'		3110	8080			47800	38500	24400
Vegetated 2"/wk	4"			872	6250	2220			3110
	1'	30400	3380	7750	8520		6680	1240	5060
	2'	37600	6450	118000	25300	20700	29900	26200	22600
	3'	15700	4260	5150	19300	32800	4510	5737	12500
Bare 2"/wk	4"		4690		4240		4470	1790	3800
	1'	101000			20300	15300	4400	2320	28700
	2'	24200	213			9800	4700	2380	8260
	3'	8770	664			18700			9380
Oxidation Pond Effluent		2390		306	372	719	39	106	655

TABLE B-6. NITRATE-N, μg/l

Test Site	Depth	Date–1976														
		7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"	265	2450	814	<1	5	14		5	6	11	5	26	15	8	10
	1'			64	7	9	6	17	5	<1	8	16	19	6	8	14
	2'			1210	<1	7	27	7	6	20	10	10	6	124	28	22
	3'			88	<1	5	4	4	14	3	5	6	10	21	8	14
Bare 6"/wk	4"			2540	4		13	<1	<1	54	77	35	12	9	54	26
	1'		70	104	167	244	219	353	260	661	197	131	88	15	117	202
	2'		5190	989	600	981	2620	<1	628	1750	352	405	376	91	14	734
	3'		1930	72	35	2	21	10	62	159	44	43	204	121	195	81
Vegetated 4"/wk	4"			12	29	9	10	5	28	2	6	38	39	19	16	18
	1'			1170	<1	4	6	8	4	3	3	8	9	4	6	5
	2'			855	5	13	7	5	31	4	5	11	14	12	7	10
	3'			916	22	6	4	<1	3	<1	2	1	1	1	3	4
Bare 4"/wk	4"			3110	<1	<1	213	14	9	75	13	17	11	136	32	303
	1'			34600	37200	18300	16000	9980	7370		763	4270	4420	4820	4740	13000
	2'				29800	22000	20700	10300	13300	14500		7650	2010	1100	2470	32200
	3'			8640	9910	9840	11100	14300	7900	5620	10200	11500	12400	12500	17400	10900
Vegetated 2"/wk	4"				310	397	448	4	7	12	5	5	10	5	9	110
	1'				178	86	5	14	8	11	2	3	18	<1	<1	29
	2'			12		78	290	224		14		10	102		14	93
	3'			935	54	38	<1	<1	10	2	1	1	3	3	3	10
Bare 2"/wk	4"		26300	11300	8470	6920	4030	2860	1160	5240	1110	2800	438	1030	262	5530
	1'			16200	25300	30000	40000	3710	15200	16900	5040	5490	4310	4650	2350	14600
	2'			8900	38900	46400	69200		24300	29000	21300	12600	5960	6490		24100
	3'			11500	15100	14400	18000	19200	13600	39800	22700	29400	25900	2450	15600	19000
Vegetated Control 4"/wk	4"		186	18	70	10	32	<1	2	5	3	14	13	38	8	18
	1'			2090	3	6	9	92	1	14	2	6	9	6	13	15
	2'	508	7060	2110	769	36	6	<1	42	40	<1	3	3	37	14	18
	3'		221	16	28	1	<1	<1	<1	1	3	2	2	130	5	16
Bare Control 4"/wk	4"			59000	61500	15300	9810	6410	3330	3060	1280	405	8	14	16	13300
	1'		19500	21300	1040		13900	2080	1550	324	285	321	519	2950	493	5360
	2'			9500	9680	4930	13600	4460	1680	2420	172	1710	1430	171	1	4150
	3'			40900	71400	40400	43500	42900	39800	42200	39800	34200	9020	23600	28100	38000
Oxidation Pond Effluent		18	226	13	32	11	19	8	3	18	33	185	218	34	262	69
Control Water			117	8	18	6	5	1	2	10	13	5	37	4	16	20

TABLE B-7. NITRITE NO_2-N, μg/l

Test Site	Depth	Date–1975							
		8/2	8/9	8/16	9/20	10/4	10/18	10/25	Avg.
Vegetated 6"/wk	4"	6	12		<1	<1	<1	<1	3
	1'	53	85		3	<1	<1	<1	24
	2'	342	639		3	<1	1	<1	164
	3'	345	173		26	2	<1	<1	91
Bare 6"/wk	4"	6	106		6		8	8	27
	1'	9	209			15	4	4	48
	2'	94	213			40	23	24	79
	3'	31	136			109		56	83
Vegetated 4"/wk	4"			7	2	<1	<1		3
	1'	3	55	7	2		1	2	12
	2'	31	2220	284	8			<1	509
	3'			14					
Bare 4"/wk	4"			27	26	22			25
	1'	351	1220	93	7		4	3	280
	2'		2230	341	58	82	91	25	471
	3'	490	3900	1388	451	3	930	583	1090
Vegetated 2"/wk	4"						2	1	1
	1'						11	5	8
	2'							150	
	3'						5	5	5
Bare 2"/wk	4"		441				15	16	157
	1'		304	65		10		469	212
	2'		125	62			24	7	54
	3'		88	1720			156	1100	769
Oxidation Pond Effluent		14		336	103	89	26	49	103

TABLE B-8. NITRITE NO_2-N, μg/l

Test Site	Depth	7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
		Date–1976														
Vegetated 6"/wk	4"	14	3	4	1	<1	<1	1	2	1	<1	<1	9	<1	<1	3
	1'			29	<1	<1	2	3	1	6	3	<1	12	1	2	5
	2'			4	2	2	6	3	6	6	3	4		<1	3	4
	3'			7	1	1	<1	<1	2	<1	<1	1	3	<1	<1	2
Bare 6"/wk	4"			32	3		6	2	3	27	8	14		3	<1	9
	1'		38	103	58	30	56	20	19	46	29	19	24	14	14	36
	2'		201	41	3	39	31	27	29	19	14	20	20	5	3	35
	3'		151	54	12	2	2	4	15	85	3	10	24	13	10	30
Vegetated 4"/wk	4"			4	<1	<1	<1	<1	4	2	1	2	<1	1	<1	1
	1'			5	7	1	<1	1	2	<1	1	2	<1	<1	<1	2
	2'			14	7	1	<1	<1	8	<1	<1	1	<1	<1	<1	3
	3'			644	<1	1	<1	1	<1	2	<1	2	<1	<1	<1	55
Bare 4"/wk	4"			155	6	5	13	17	13	7	119	1		5	2	31
	1'			6	16	148	204	325	218	198	112	340	107	67	60	150
	2'				960	2510	1760	1270	897	527	380	377	243	200	129	841
	3'			2160	3390	3060	2820	3440	3200	1970	1130	589	453	297	256	1900
Vegetated 2"/wk	4"			4	5	2	21	<1	2	1	<1	2	1	1	1	4
	1'			170	7	6	3	2	2	14	2	<1	<1	2	10	18
	2'			58	3	48		3	2	3	3	2		<1	3	13
	3'			7	2	3	4	1	2	1	2	3	<1	1	<1	2
Bare 2"/wk	4"		720	26	14	22	4	24	22	14	8	4	4	3	<1	66
	1'			32	32	35	11	75	22	41	59	10	40	33	6	40
	2'				112	1210	580	1220	658	537	1260	444		183		689
	3'		951	80	658	681	1000	602	934	509	780	572	49	442	53	517
Vegetated Control 4"/wk	4"		<1	3	1	2	1	3	<1	<1	<1	1	<1	<1	<1	1
	1'			17	2	2	<1	4	2	<1	<1	<1	<1	<1	<1	2
	2'	2	8	6	1	2	<1	3	2	9	<1	<1	<1	2	<1	3
	3'		<1	5	2	3	3	3	1	<1	<1	2	<1	1	<1	2
Bare Control 4"/wk	4"			290	17	25	9	24	12	14	5	8	<1	2	2	34
	1'		280	1910	761	2960	606	610	333	59	21	79	24	22	32	592
	2'			29	6	17	44	20	<1	10	7	4	21	22	1	15
	3'			50	188	643	402	879	572	613	1130	835	700	590	472	589
Oxidation Pond Effluent		7	13	12	3	14	49	19	28	14	64	71	40	43	428	58
Control Water		<1	<1	<1	<1	<1	2	5	4	<1	<1	3	1	<1	<1	1

TABLE B-9. TOTAL-P, µg/1

Test Site	Depth	Date–1975						
		8/2	8/9	8/16	10/4	10/18	10/25	Avg.
Vegetated 6"/wk	4"					22	46	34
	1'	540					82	311
	2'	613				80	92	221
	3'	396				86	87	167
Bare 6"/wk	4"	523				121	97	247
	1'	126			32	134		97
	2'	512			61	103	110	196
	3'	332			147			240
Vegetated 4"/wk	4"			49	45		38	44
	1'	432		49			114	198
	2'	486		61		142	97	196
	3'							
Bare 4"/wk	4"			92	74			
	1'	541		92		104	100	209
	2'	587		134	202	172	190	257
	3'	505		189	282	207	223	281
Vegetated 2"/wk	4"					70	84	77
	1'					118	245	182
	2'						61	
	3'					271	287	279
Bare 2"/wk	4"					171	129	150
	1'			98	131		71	100
	2'			171		89	129	130
	3'			64		449	187	233
Oxidation Pond Effluent		4320		1270	909	2270	2020	2160

TABLE B-10. TOTAL-P, μg/1

Test Site	Depth	Date–1976 7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"		222	353		56			82	69	54	85	64	78	92	116
	1'			1010	948	135		162	148	156	127	257	134	169	172	311
	2'			1360	754	667					360	345	272	260	259	535
	3'				212	247		139	167	119	182	206	176	151	157	176
Bare 6"/wk	4"			337	68	101						124	110	115		142
	1'		623		89	134		120	129	62	91	91	113	118	98	152
	2'	592	1100		372	311		269	201	159	273	448	215	229	215	365
	3'		623		111	155		153	151		124	188	149	160	135	195
Vegetated 4"/wk	4"			160	68	110		72	86	84	85	94	72	69	77	98
	1'			159	68	74		61	98		94	118	98	100	126	100
	2'			178	90	149		125	114	116	88	121	925	100	98	111
	3'				134	295		224	139	181	206	185	245	238	175	202
Bare 4"/wk	4"				622							136	152		175	271
	1'			171	92	134		126	132	97	152	176	110	118	98	128
	2'				89	114		106	114	94	118	252	116	121	108	123
	3'			3430		523		433	304	184		275	546	305	265	696
Vegetated 2"/wk	4"							46	98	59	76	152	98	115	111	94
	1'				923			54	166	69	133	148	113	121	126	206
	2'				363											363
	3'				920			292	297	297	303	409	290	278	274	373
Bare 2"/wk	4"		495	36	62	80		46	79	56	58	76	51	82	74	100
	1'				95	147		61	76	59	64	88	72	66	89	82
	2'				95	241		201				121	—	88		149
	3'			348	683	257		355	372	250	348	333	272	262	308	344
Vegetated Control 4"/wk	4"		774		255	91		72	82	81		64	60	39	49	157
	1'			129	74	101		73	98	91	88	94	84	84	80	95
	2'		774		151	168		113	179	113	121	155	125	121	132	196
	3'	345		714	335	349		244	204	178	124	206	167	157	172	266
Bare Control 4"/wk	4"		757	196		74		52	61	56		64	45	58		152
	1'		454	143	422			61	173	500	61	76	69	66	74	191
	2'			330	178	241		162	207	244	239	215	182	181	191	215
	3'				307	225		21	241	194	267	276	296	211	218	226
Oxidation Pond Effluent		623	359	1690	1330	1740		1260	1460	1220	1980	2000	2360	1530	1410	1460
Control Water		141		101	46	216		54	54	30	42	33	45	88	42	74

TABLE B-11. ORTHOPHOSPHATE-P, μg/1

Test Site	Depth	Date–1975							
		8/2	8/9	8/16	9/20	10/4	10/18	10/25	Avg.
Vegetated 6"/wk	4"	2	21		3	21	31	26	17
	1'	43	17		2	35	46	67	35
	2'	31	57		48	64	69	77	58
	3'	47	67		51	64	64	93	64
Bare 6"/wk	4"	50	60		69		46	88	63
	1'	45	16			18	81	132	58
	2'	63	60			51	73	207	91
	3'	72	121			112			102
Vegetated 4"/wk	4"			30	66	18	8		30
	1'	27	28	32	34		52		35
	2'	54	26	38	64				46
	3'			116					
Bare 4"/wk	4"			49	40	43			44
	1'	2	28	38	64		57	105	49
	2'	90	52	92	139	157	131	141	114
	3'	72	95	119	170	224	136	214	147
Vegetated 2"/wk	4"						20	46	
	1'						74	240	
	2'							24	
	3'						132	210	
Bare 2"/wk	4"		36				16	97	50
	1'		71	64		91		219	111
	2'		93	92			43	86	78
	3'		207	163				135	168
Oxidation Pond Effluent		2320		1030	870	775	2160	2050	1530

TABLE B-12. ORTHOPHOSPHATE-P, μg/1

Test Site	Depth	Date–1976 7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"	276	58	134	212	44	56	50	44	52	40	16	36	48	46	79
	1'			631	830	91	179	143	104	150	153	149	142	149	140	238
	2'			820	665	473	385	280	264	248	224	203	210	195	215	348
	3'				189	156	163	120	137	156	141	118	121	92	126	138
Bare 6"/wk	4"			44	26	63	74	67	60	78	61	74	85	91	89	61
	1'		71	385	46	77	71	58	66	82	64	70	72	76	78	92
	2'		206	252	307	185	151	180	177	184	192	271	199	174	172	204
	3'		94	72	61	81	99	95	101	92	92	110	109	121	103	95
Vegetated 4"/wk	4"			92	52	62	42	39	69	44	63	26	54	45	54	53
	1'			22	41	42	50	35	49	58	63	51	69	71	80	52
	2'			160	36	94	71	49	73	66	51	48	58	60	60	69
	3'			143	86	175	166	157	41	134	129	90	106	165	135	127
Bare 4"/wk	4"			435	310	272	166	111	145	142	130	119	125	121	85	180
	1'			86	70	73	78	79	95	108	101	102	100	89	69	88
	2'				67	54	52	43	73	91	86	96	90	92	83	126
	3'			3133	1350	382	335	210	169	170	204	48	210	254	206	556
Vegetated 2"/wk	4"						36	32	20	45	37	28	30	30	20	31
	1'				453	484	225	38	93	59	87	57	106	94	92	162
	2'				257		323	82	249	297	278	118	255	287	323	224
	3'				670	423	693	251	202	246	233	115	230	243	275	326
Bare 2"/wk	4"		45	29	49	28	21	8	15	16	28	26	54	53	58	33
	1'			137	57	169	58	21	49	50	262	53	55	53	63	86
	2'				78	112	148	135	221	125	242	61	125	54	242	140
	3'			179	229	168	261	234	262	278	109	236	245	240	251	224
Vegetated Control 4"/wk	4"		78	258	83	49	46	48	37	36	38	19	30	41	32	45
	1'			53	69	78	74	54	76	72	74	53	63	68	65	66
	2'	286	127	136	52	108	101	104	76	94	87	73	70	94	91	107
	3'		260	86	197	184	145	154	105	102	116	71	98	107	106	133
Bare Control 4"/wk	4"			8	33	29	25	20	18	27	40	11	39	30	29	26
	1'		9	17	24	38	33	30	64	62	29	42	61	59	54	40
	2'			144	154	148	161	118	151	178	155	166	158	160	155	154
	3'			523	171	136	145	160	168	172	172	169	172	174	185	195
Oxidation Pond Effluent		391	369	768	988	1400	1100	1030	927	1480	1230	829	2090	642	881	1000
Control Water		47	34	41	28	21	30	21	28	29	31	22	19	18	25	28

TABLE B-13. TOTAL ORGANIC CARBON, MG/L

Test Site	Depth	Date–1976 7/16	7/23	8/13	8/20	8/27	9/3	9/17	9/24	10/1	10/8	Avg.
Vegetated 6"/wk	4"		21	<1	32	17	18	18	15	12	<1	15
	1'		8	11	41	6	11	<1	10	27	47	18
	2'	40	3	20	70	4	15	<1	8	33	27	22
	3'		7	32	74	<1	35	48	10	12	11	26
Bare 6"/wk	4"		5	6	23	<1	7	18	<1	12	<1	8
	1'	16	14	10	32	29	14	18	25	<1	<1	16
	2'		3	37	67	12	31	18	5	18	37	25
	3'		<1	31	55	1		18	5	9	23	18
Vegetated 4"/wk	4"	22	<1	4	9	<1	15	6	10	3	2	7
	1'	24	<1	25	18	3	12	6	10	12	2	11
	2'		6	18	41	11	15	6	20	6	8	14
	3'	27	5	30	98	16	22	<1	<1	18	15	23
Bare 4"/wk	4"	26	8	<1	44	3	21	30	15	<1	5	15
	1'		21	40	65	2	22	30	5	18	14	24
	2'			36	54	<1	36	6	5	18	5	20
	3'	25	<1	21	83	25	37	12	10	18	20	25
Vegetated 2"/wk	4"		8	33	41	8	24	<1	50	24	15	22
	1'		<1	64	62	19	95	18	10	6	29	34
	2'	17	44	105	127	30	39	<1	25	30	16	43
	3'		<1	54	56	17	105	29	8	15	28	34
Bare 2"/wk	4"	<1	7	<1	19	2	12	36	45	<1	17	14
	1'	28	22	27	51	11	26	<1	15	<1	18	20
	2'	48		34	104	58	46	66	35	<1	43	48
	3'	6	<1	23	105	<1	48	48	20	12	30	29
Vegetated Control 4"/wk	4"	39	5	13	64	<1	12	36	<1	6	34	21
	1'		3	29	57	<1	21	54	15	9	22	23
	2'	6	2	<1	72	<1	22	<1	15	12	9	14
	3'	<1	<1	63	119	<1	109	<1	5	12	17	32
Bare Control 4"/wk	4"	4	10	29	49	<1	14	6	<1	36	20	17
	1'	32	1	32	67	7	30	30	12	<1	23	24
	2'		18	62	97	24	78	18	<1	<1	26	36
	3'		8	48	62	14	39	24	42	12	35	32
Oxidation Pond Effluent		21	12	<1	22	5	15	18	8	12	1	12
Control Water		19	15	<1	6	<1	<1	<1	<1	3	<1	4

TABLE B-14. RESULTS OF THE SOIL SAMPLE ANALYSES BEFORE AND AFTER IRRIGATION

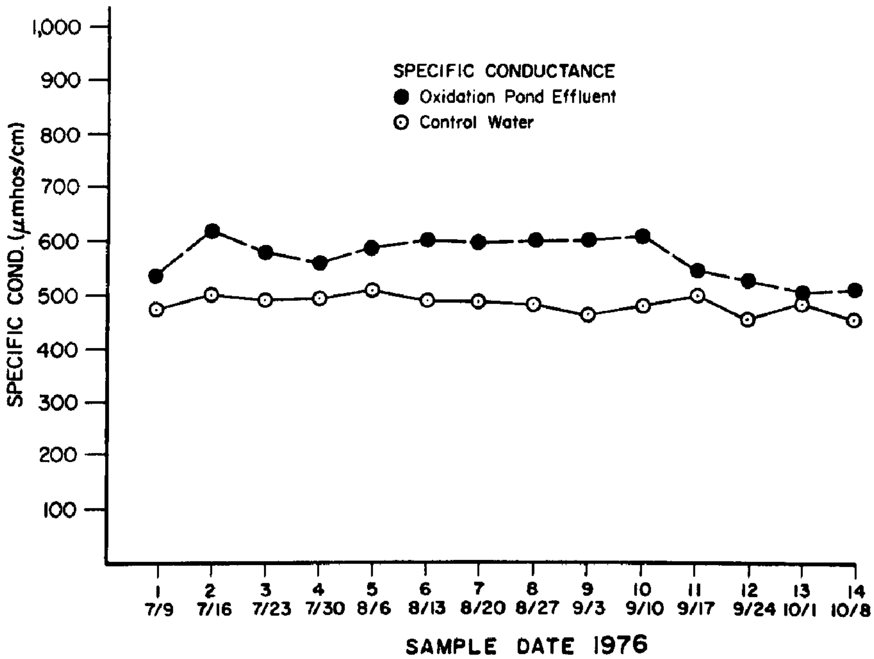
Sample Site	Sample Depth (Inches)	Na meq/l			K meq/l			Ca meq/l			% C			% N		
		Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2	Initial	End of Season 1	End of Season 2
Vegetated 6"/wk	0-6	0.4	0.2	0.2	< 0.1	0.1	< 0.1	< 0.1	0.1	0.2	4.1	3.6	4.2	0.3	0.4	0.4
	9-15	0.5	0.3	0.1	< 0.1	0.1	< 0.1	< 0.1	0.1	0.1	3.2	2.7	3.4	0.3	0.3	0.3
	30-36	4.2	1.0	0.6	0.2	0.1	< 0.1	0.3	< 0.1	< 0.1	0.7	0.8	0.9	0.1	0.1	0.1
Bare 6"/wk	0-6	< 0.1	0.9	0.2	< 0.1	0.1	< 0.1	< 0.1	0.1	0.1	2.7	3.6	3.6	0.3	0.3	0.3
	9-15	< 0.1	1.0	0.2	< 0.1	0.1	< 0.1	< 0.1	< 0.1	0.1	1.9	1.5	3.4	0.2	0.2	0.3
	30-36	4.2	4.9	0.8	0.2	0.1	< 0.1	0.1	0.1	< 0.1	0.7	0.5	0.8	0.1	0.1	0.1
Vegetated 4"/wk	0-6	1.0	0.1	0.2	0.1	0.1	< 0.1	< 0.1	0.1	0.2	2.3	4.4	4.4	0.2	0.4	0.4
	9-15	4.0	0.2	0.1	0.3	< 0.1	< 0.1	< 0.1	0.1	0.1	1.3	2.6	2.3	0.2	0.3	0.2
	30-36	4.3	1.4	0.8	0.2	0.1	< 0.1	0.1	0.1	< 0.1	0.5	0.5	0.6	0.1	0.1	0.1
Bare 4"/wk	0-6	0.2	0.2	0.3	0.1	0.1	< 0.1	0.2	0.1	0.2	6.0	3.9	3.8	0.4	0.3	0.3
	9-15	0.3	0.4	0.4	< 0.1	0.1	< 0.1	< 0.1	0.1	< 0.1	3.0	2.3	1.8	0.2	0.2	0.2
	30-36	8.5	3.3	2.9	0.3	0.1	< 0.1	0.2	< 0.1	< 0.1	0.4	0.5	0.5	0.0	0.1	0.1
Vegetated 2"/wk	0-6	0.7	0.2	0.2	0.1	0.1	< 0.1	0.1	0.1	0.1	3.6	2.4	2.2	0.4	0.2	0.2
	9-15	1.2	0.8	0.4	< 0.1	0.1	0.1	0.2	0.1	< 0.1	2.7	1.4	1.2	0.3	0.1	0.1
	30-36	3.0	4.0	10.5	< 0.1	0.2	0.4	< 0.1	0.1	0.6	0.4	0.5	0.5	0.1	0.1	0.1
Bare 2"/wk	0-6	1.0	1.0	0.3	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	5.1	4.4	4.4	0.3	0.4	0.4
	9-15	8.4	2.3	0.8	0.4	0.1	< 0.1	0.7	0.1	< 0.1	3.1	2.8	2.8	0.3	0.3	0.3
	30-36	10.4	10.4	2.3	0.3	0.4	< 0.1	0.3	0.4	< 0.1	0.5	0.5	0.5	0.1	0.1	0.1
Vegetated Control 4"/wk	0-6	0.2	0.2	-0.2	< 0.1	< 0.1	< 0.1	0.1	0.2	0.1	4.8	4.4	3.8	0.3	0.4	0.3
	9-15	0.2	0.2	-0.2	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	2.1	2.0	1.8	0.2	0.2	0.2
	30-36	1.0	0.7	0.9	< 0.1	0.1	< 0.1	< 0.1	0.1	< 0.1	0.4	0.5	0.4	0.1	0.1	0.1
Bare Control 4"/wk	0-6	0.2	0.2	0.3	< 0.1	0.1	< 0.1	0.1	0.1	< 0.1	4.4	4.0	3.4	0.3	0.4	0.3
	9-15	0.5	0.2	0.7	< 0.1	0.1	< 0.1	< 0.1	0.1	0.8	2.7	2.6	2.5	0.3	0.2	0.3
	30-36	6.7	0.7	1.8	0.2	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.5	0.6	0.8	0.1	0.1	0.1
Non-irrigated	0-6															
	9-15															
	30-36															

TABLE B-14. CONTINUED

Sample Site	Sample Depth (Inches)	NO_3-N, mg/l Initial	NO_3-N, mg/l End of Season 1	NO_3-N, mg/l End of Season 2	P Available, mg/l Initial	P Available, mg/l End of Season 1	P Available, mg/l End of Season 2	EC_e, mmhos/cm Initial	EC_e, mmhos/cm End of Season 1	EC_e, mmhos/cm End of Season 2	pH Initial	pH End of Season 1	pH End of Season 2	Cation Exchange Capacity meq/100 g	Deviation from Non-irrigated meq/100 g
Vegetated 6"/wk	0-6	2.7	2.5	1.3	6.9	5.6	7.2	0.7	0.7	0.8	8.4	8.4	8.0	24.8	+1.2
	9-15	2.8	2.6	2.0	4.7	4.0	4.5	0.8	0.6	0.5	8.7	8.5	8.5	22.1	+1.9
	30-36	0.7	0.2	0.6	3.0	4.8	2.8	6.2	1.4	0.7	8.3	8.7	8.8	18.7	- 0.5
Bare 6"/wk	0-6	4.4	18.9	4.3	14.0	8.3	14.4	0.6	1.7	0.6	8.3	8.5	8.1	24.8	+1.2
	9-15	2.2	13.4	5.4	6.4	5.5	7.2	0.6	1.0	0.7	8.7	8.9	8.2	21.7	+1.5
	30-36	1.5	3.5	1.4	3.3	3.4	2.7	5.0	6.9	0.9	8.5	8.7	8.8	17.2	- 2.0
Vegetated 4"/wk	0-6	0.6	4.2	0.3	25.0	5.9	7.3	1.0	0.5	0.8	8.5	8.3	8.0	24.8	+1.2
	9-15	0.6	0.9	0.6	13.0	3.5	4.4	2.7	0.5	0.5	8.8	8.4	8.4	19.2	- 1.0
	30-36	1.2	< 0.1	0.5	4.4	4.0	3.1	4.2	2.0	1.0	8.4	8.6	8.9	17.2	- 2.0
Bare 4"/wk	0-6	37.7	4.0	7.3	12.0	11.5	15.2	0.8	0.6	0.8	8.1	8.5	8.2	22.7	- 0.9
	9-15	17.2	9.1	4.1	6.3	4.6	7.9	0.7	0.8	0.7	8.3	8.4	8.6	17.7	- 2.5
	30-36	1.7	7.6	4.0	1.4	3.2	5.7	18.9	2.5	2.2	8.3	9.1	9.0	21.2	+2.0
Vegetated 2"/wk	0-6	1.6	1.0	0.6	6.0	19.0	8.7	1.5	0.7	0.8	7.9	8.4	8.3	22.7	- 0.9
	9-15	1.3	0.9	0.7	5.0	6.8	5.0	2.5	0.9	0.7	8.3	8.9	8.6	18.7	- 1.5
	30-36	3.3	0.8	0.6	1.3	3.9	6.9	2.3	4.5	1.2	8.8	8.7	9.2	17.7	- 1.5
Bare 2"/wk	0-6	38.7	3.8	5.8	7.8	9.1	10.6	1.9	1.7	0.6	8.3	8.5	8.3	23.8	+0.2
	9-15	18.2	18.4	3.5	4.6	5.8	5.2	15.0	3.2	1.0	8.0	8.4	8.8	21.7	+1.5
	30-36	1.5	6.2	5.9	3.4	2.9	3.8	18.2	16.3	2.1	8.2	8.4	8.9	18.2	- 1.0
Vegetated Control 4"/wk	0-6	3.3	0.6	0.9	4.1	3.2	3.6	0.7	0.7	0.5	8.2	8.3	8.3	21.2	- 1.4
	9-15	2.2	0.1	0.9	1.6	1.8	2.4	0.4	0.5	0.4	8.6	8.5	8.6	18.7	- 1.5
	30-36	0.6	0.1	0.2	1.5	1.7	3.7	0.9	0.8	0.9	8.8	9.0	8.9		
Bare Control 4"/wk	0-6	26.0	10.9	4.2	10.0	12.3	9.1	0.7	0.8	0.6	8.1	8.3	8.5	22.7	- 0.9
	9-15	6.6	3.3	2.2	4.8	4.9	3.1	0.7	0.7	1.4	8.6	8.4	8.6	26.3	+6.1
	30-36	4.2	3.8	5.7	2.0	2.6	5.0	5.7	1.0	1.6	8.5	8.9	9.0	16.3	- 2.9
Non-irrigated	0-6													23.6	
	9-15													20.2	
	30-36													19.2	

TABLE B-15. SODIUM ADSORPTION RATIOS

Test Site	Depth	Date–1976										
		7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/10	9/17	9/24	Avg.
Vegetated 6"/wk	4"	2	1	1	1	1	1	1	1	1	1	1
	1'			1		1		2	2	1		1
	2'		36	10	9	9				3		8
	3'			13	13	12	11	10	9	8		11
Bare 6"/wk	4"		4			3	2					3
	1'	2		2	2	2	2	2	2	2		2
	2'		31	15	7	5		8	6	11	7	11
	3'		21	9	12	14		15	13	13	10	13
Vegetated 4"/wk	4"			2	1	2	2	2	2	2	1	2
	1'		16	10	6	6		4	2	2	2	6
	2'		8	8	7	8	7	7	6	5	5	7
	3'		5	36	29		37	20	18	13	15	21
Bare 4"/wk	4"		4	4	3	2	3	3	4	2	3	3
	1'		7	4	6	5	5	7	5	4	5	5
	2'		16	11	24	20		29	25	22	19	21
	3'			22	18		8	10	39	47	29	25
Vegetated 2"/wk	4"				2	2	2	3	1	3	4	2
	1'				12	14	5	7	4	3	3	7
	2'									12		12
	3'			20	21		23	20	25	34	27	24
Bare 2"/wk	4"			3	2	2	2	3	2	2	2	2
	1'			11	12	12	9	10	10	6	7	10
	2'			15	20	9	11	27	39	16		19
	3'			25	23	6	13	15	46	46	26	25
Vegetated Control 4"/wk	4"		1	2	1	1	2	2	1	1	1	1
	1'		3	3	2	1	1	2	1	1		2
	2'		17	5	5	4	4	5	3	3	3	6
	3'		20	15	18	17	19	13	12	9	14	15
Bare Control 4"/wk	4"		3	2	2	2			2			2
	1'			4	3	2	3	2	3	2	2	3
	2'			7	8	5	7	8	5	5	5	6
	3'			23	17	11	6	7	17	20	22	15
Oxidation Pond Effluent			1	1	1	1	1	2	2	2	2	1
Control Water			1	2	2	1	2	2	2	2	2	2
Drain				10	12	4	3		14			9



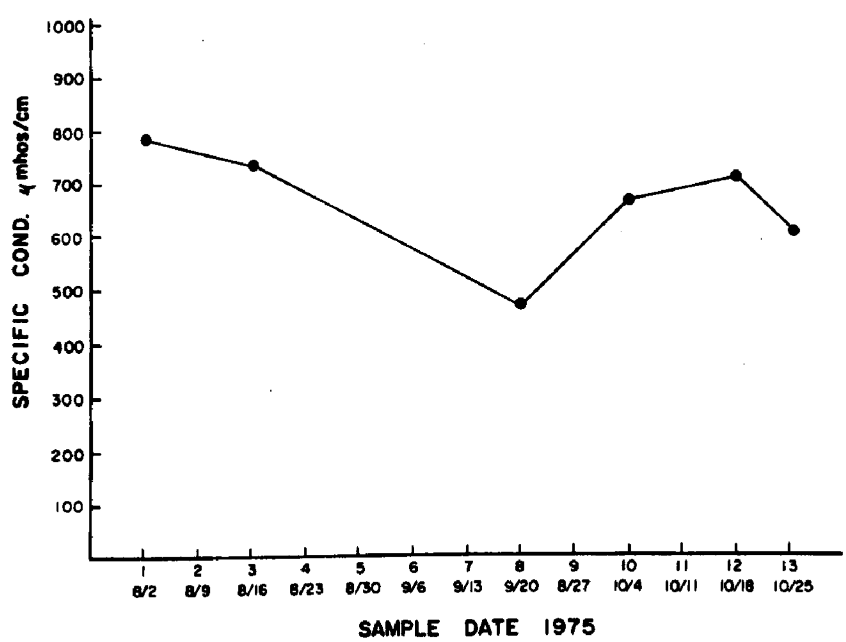


Figure B-1. Specific conductance values of the stabilization pond effluent and control water during 1976 (above), specific conductance values of the stabilization pond effluent during 1975 (below).

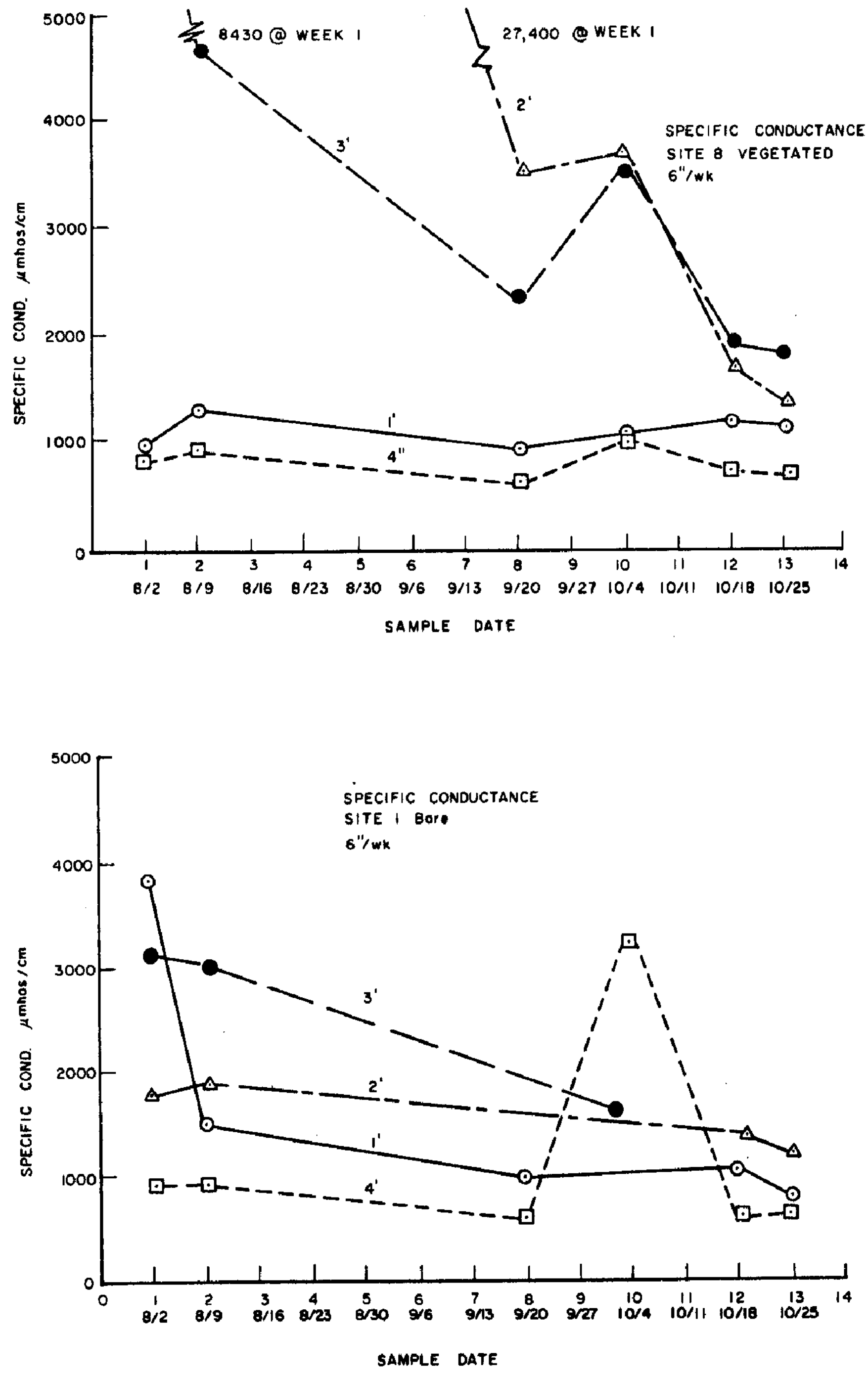
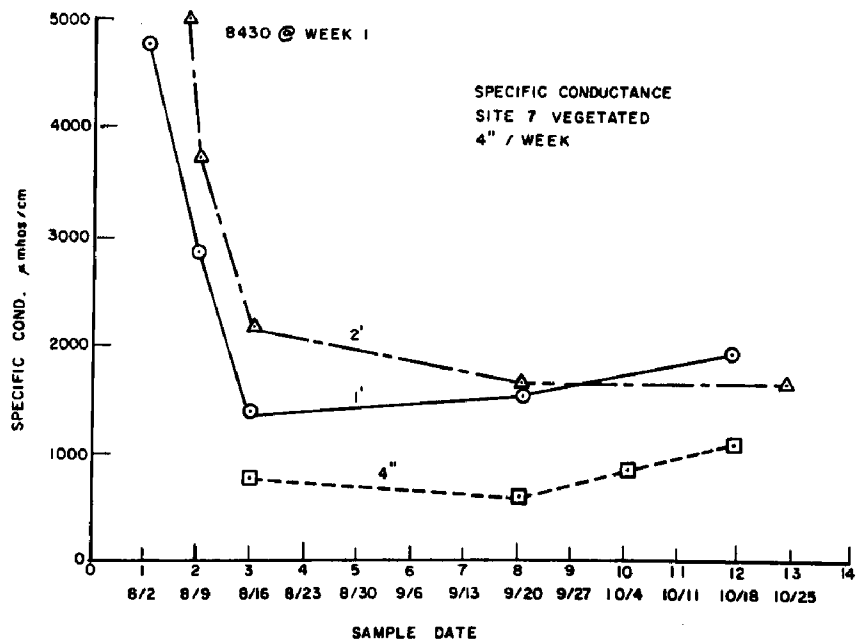


Figure B-2. Specific conductance values of the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites at a 15.2 cm (6 in.) per week irrigation application rate during 1975.



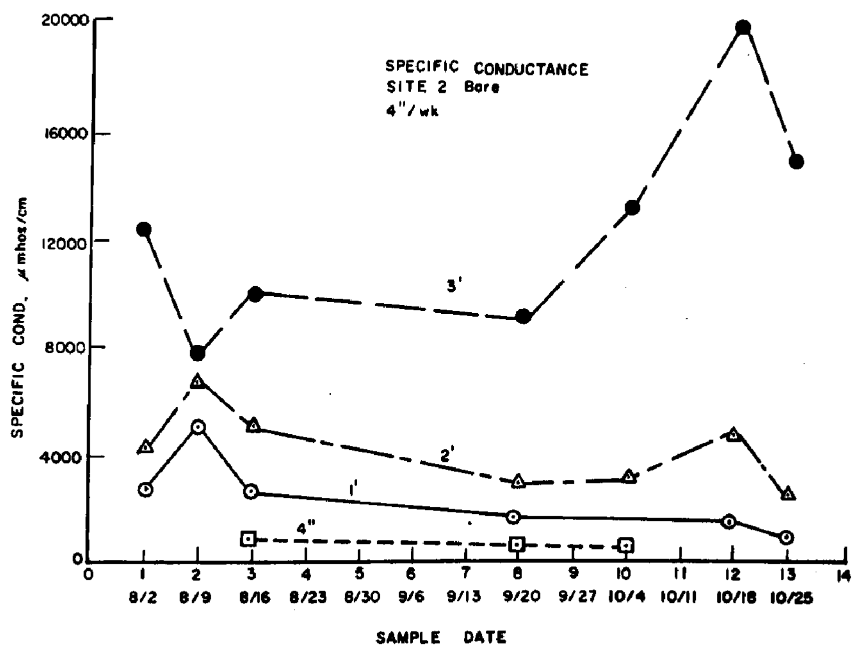
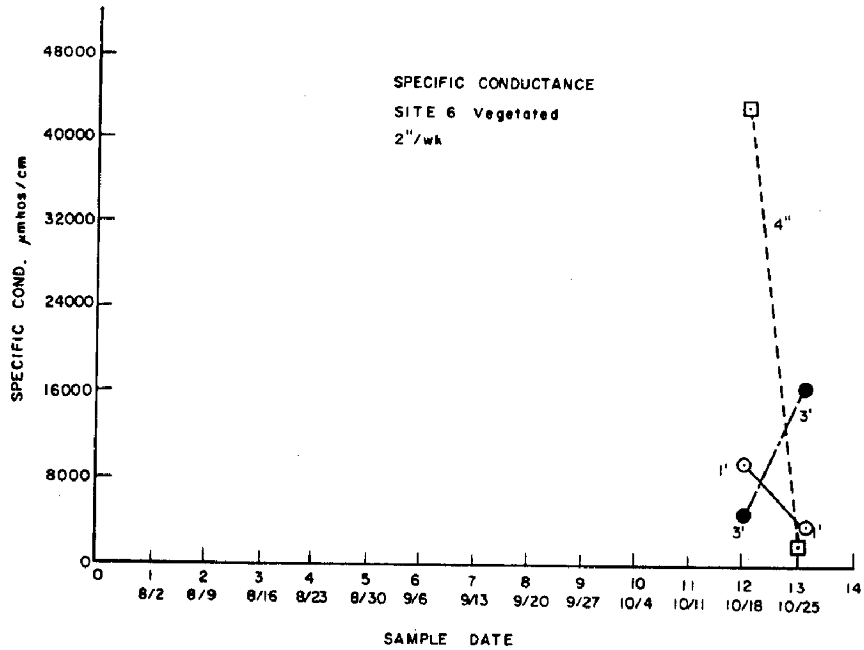


Figure B-3. Specific conductance values of the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites at a 10.2 cm (4 in.) per week irrigation application rate during 1975.



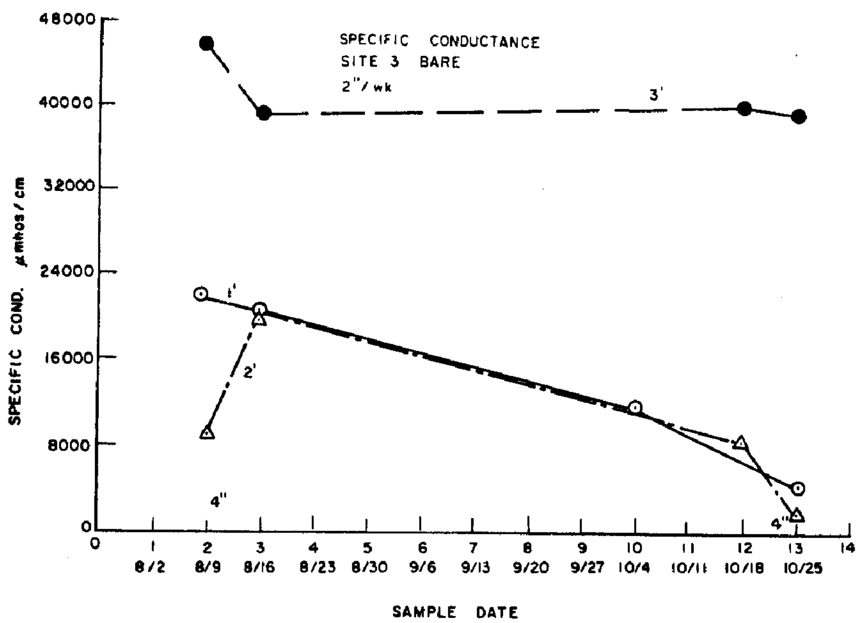
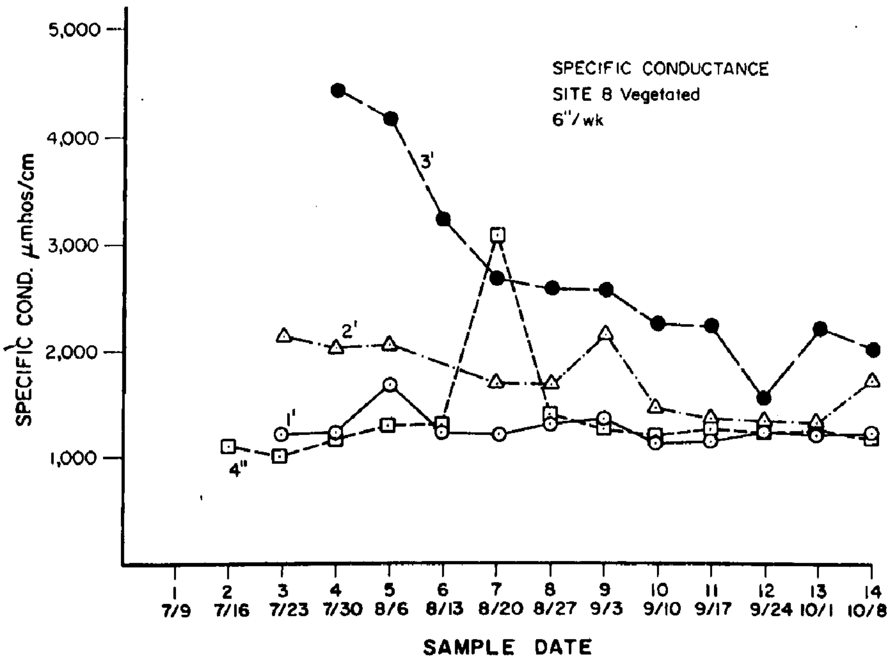


Figure B-4. Specific conductance values of the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites at a 5.08 cm (2 in.) per week irrigation application rate during 1975.



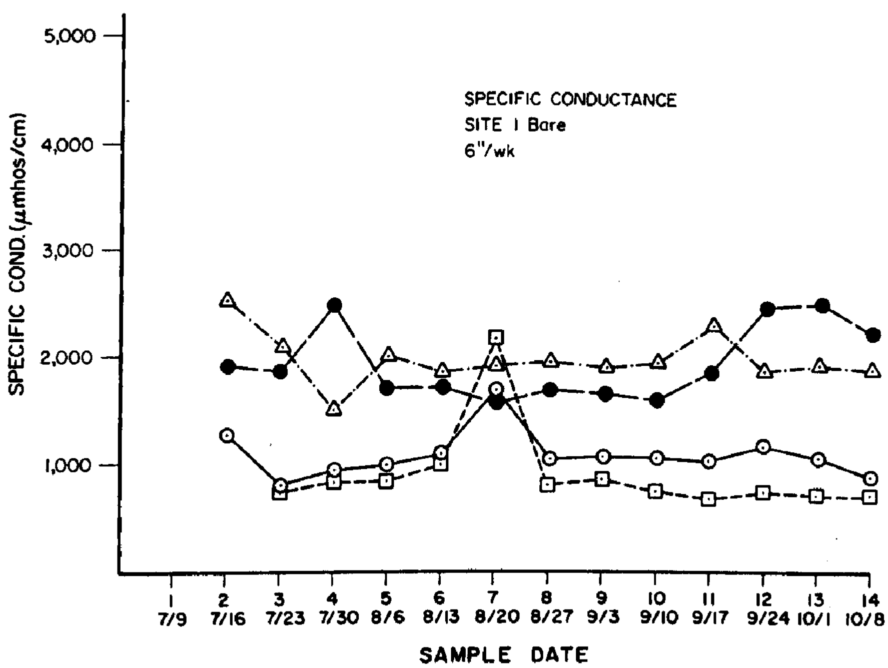
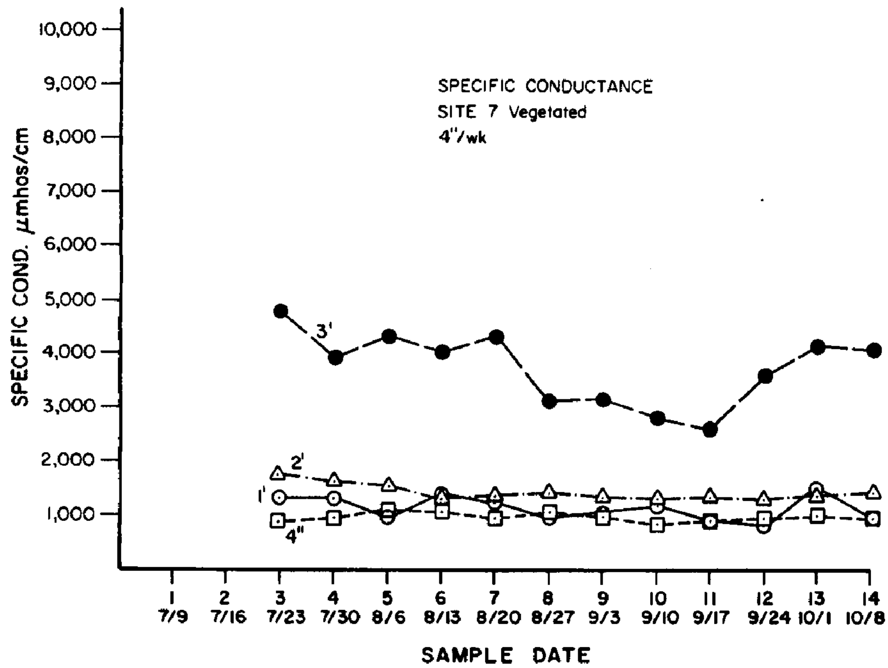


Figure B-5. Specific conductance values of the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites at a 15.2 cm (6 in.) per week irrigation application rate during 1976.



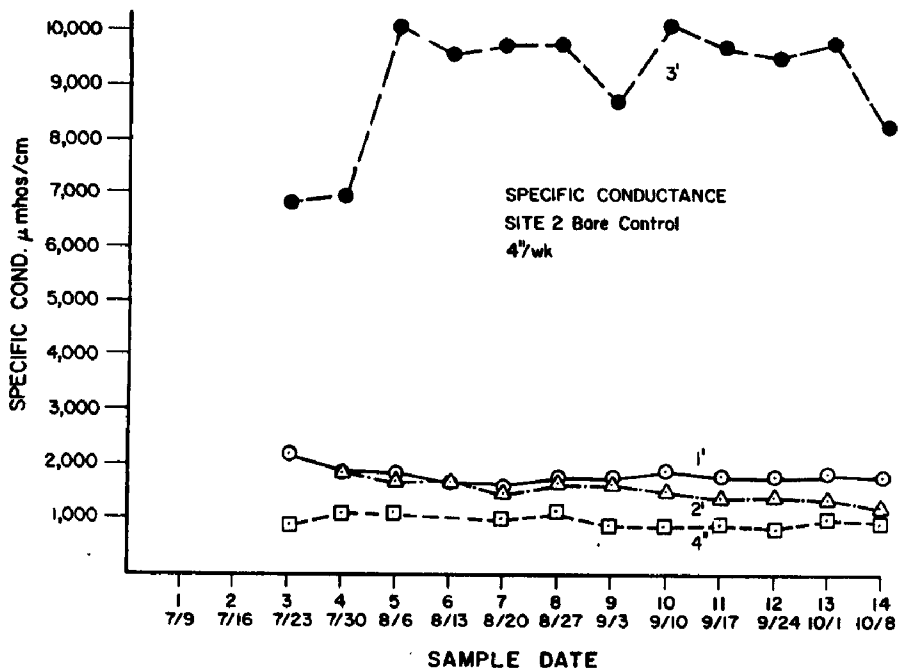
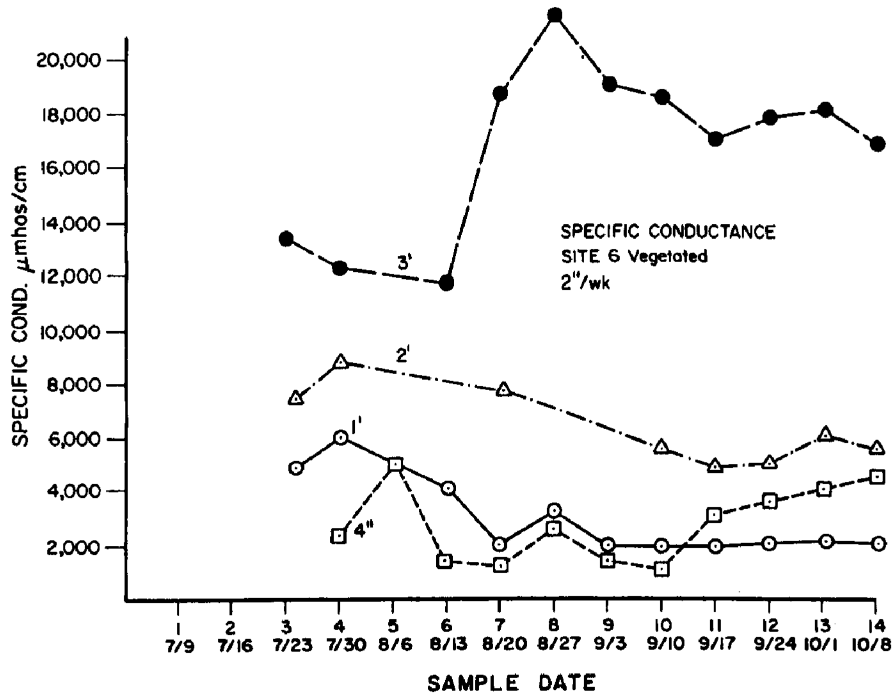


Figure B-6. Specific conductance values of the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites at a 10.2 cm (4 in.) per week irrigation application rate during 1976.



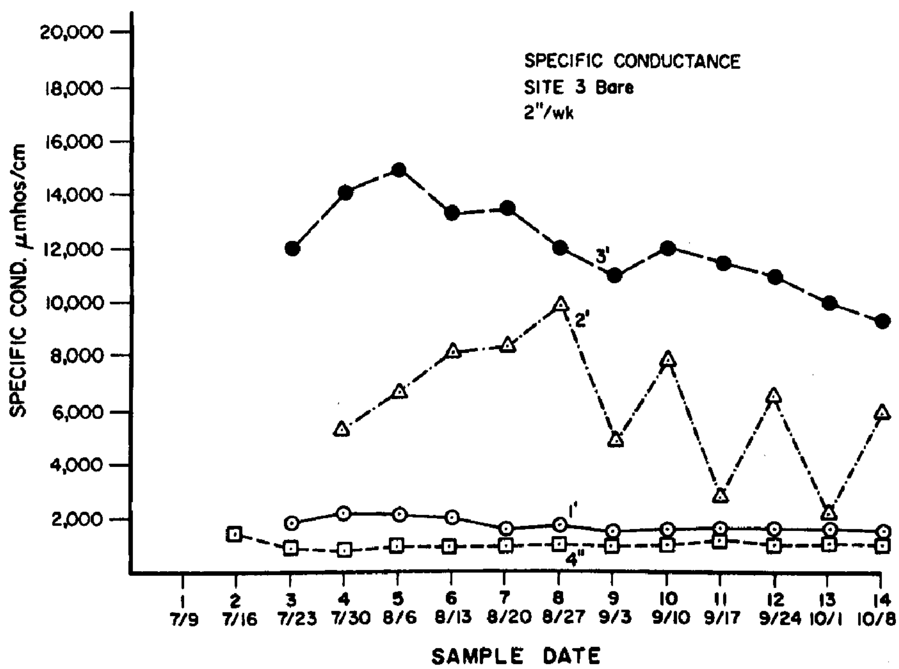
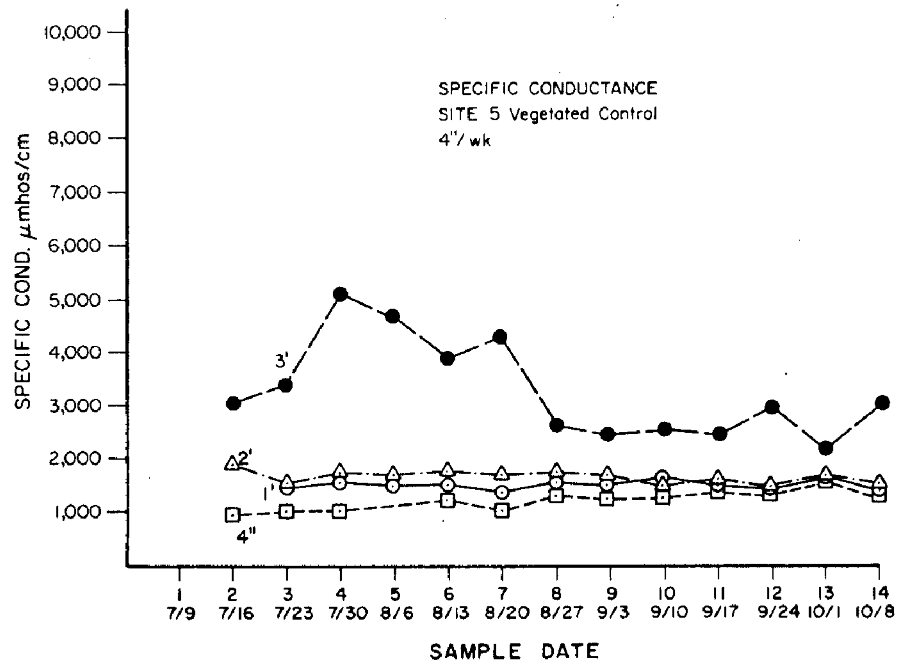


Figure B-7. Specific conductance values of the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.)., 61.0 cm (2 ft.), 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites at a 5.08 cm (2 in.) per week irrigation application rate during 1976.



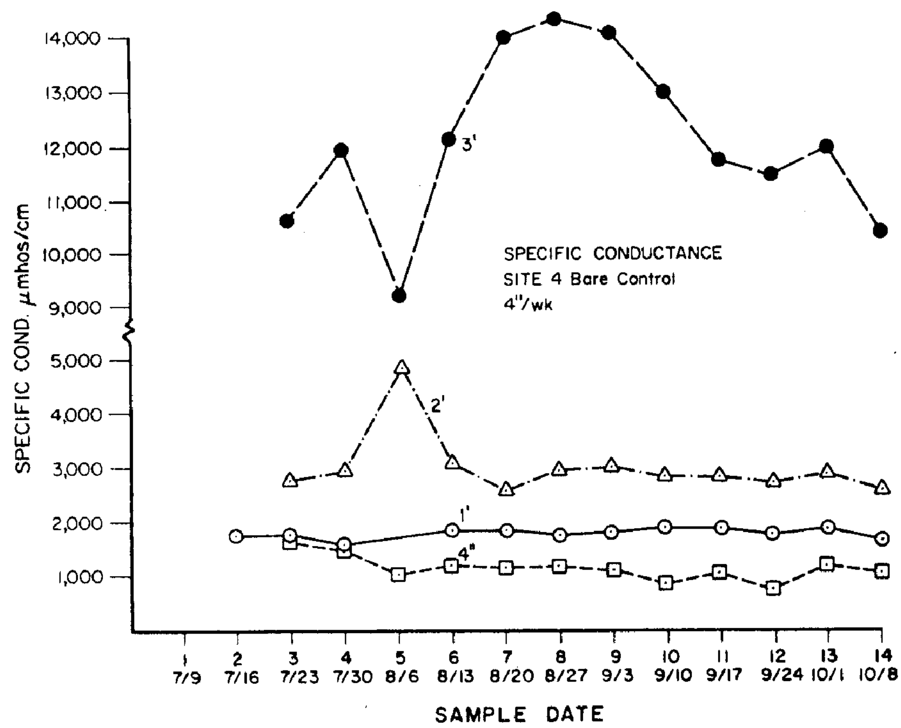


Figure B-8. Specific conductance values of the soil mantle treated control water at a 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites at a 10.2 cm (4 in.) per week irrigation application rate during 1976.

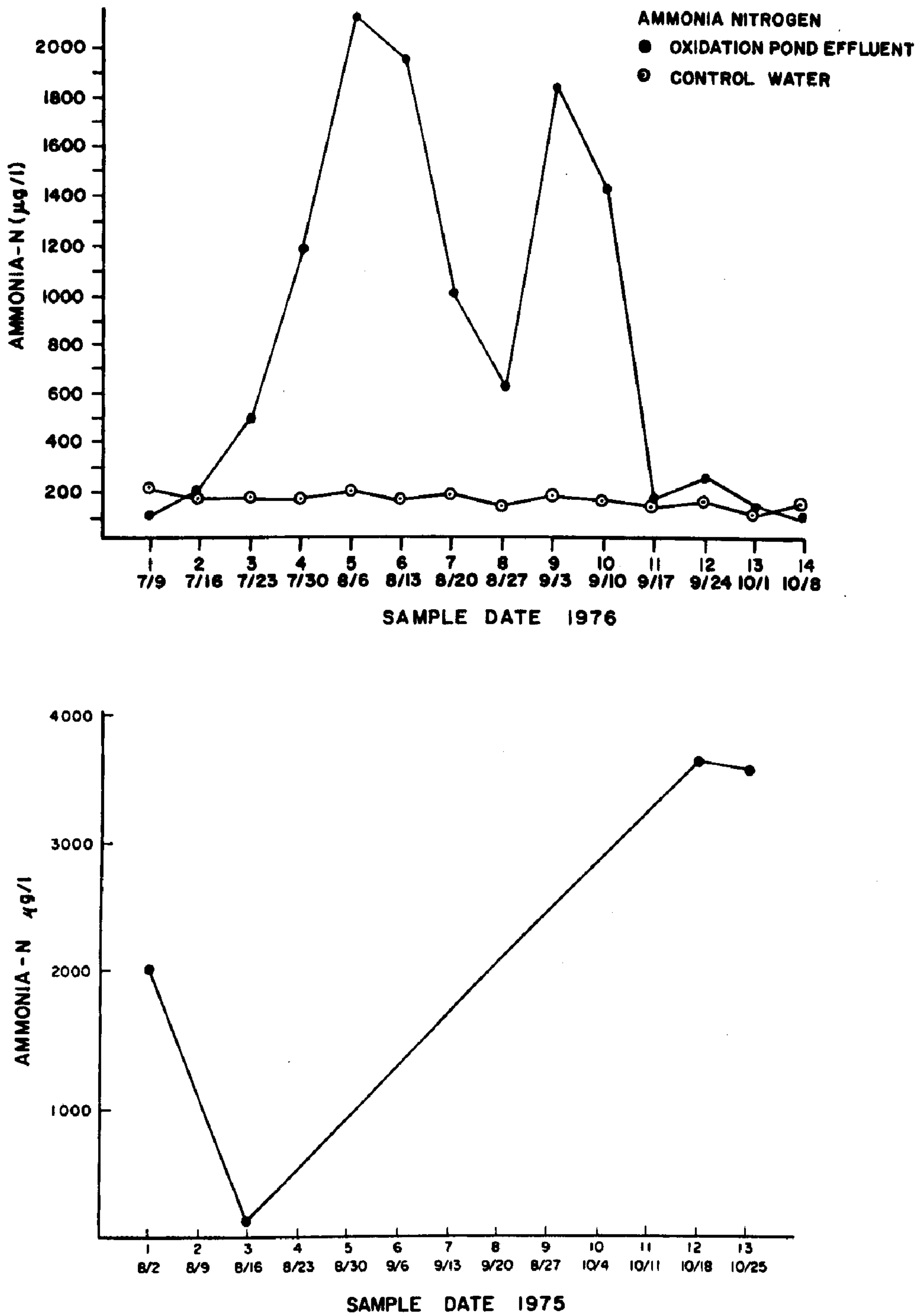


Figure B-9. Ammonia-N concentrations in the stabilization pond effluent and control water during 1976 (above) and ammonia-N concentrations in the stabilization pond effluent during 1975 (below).

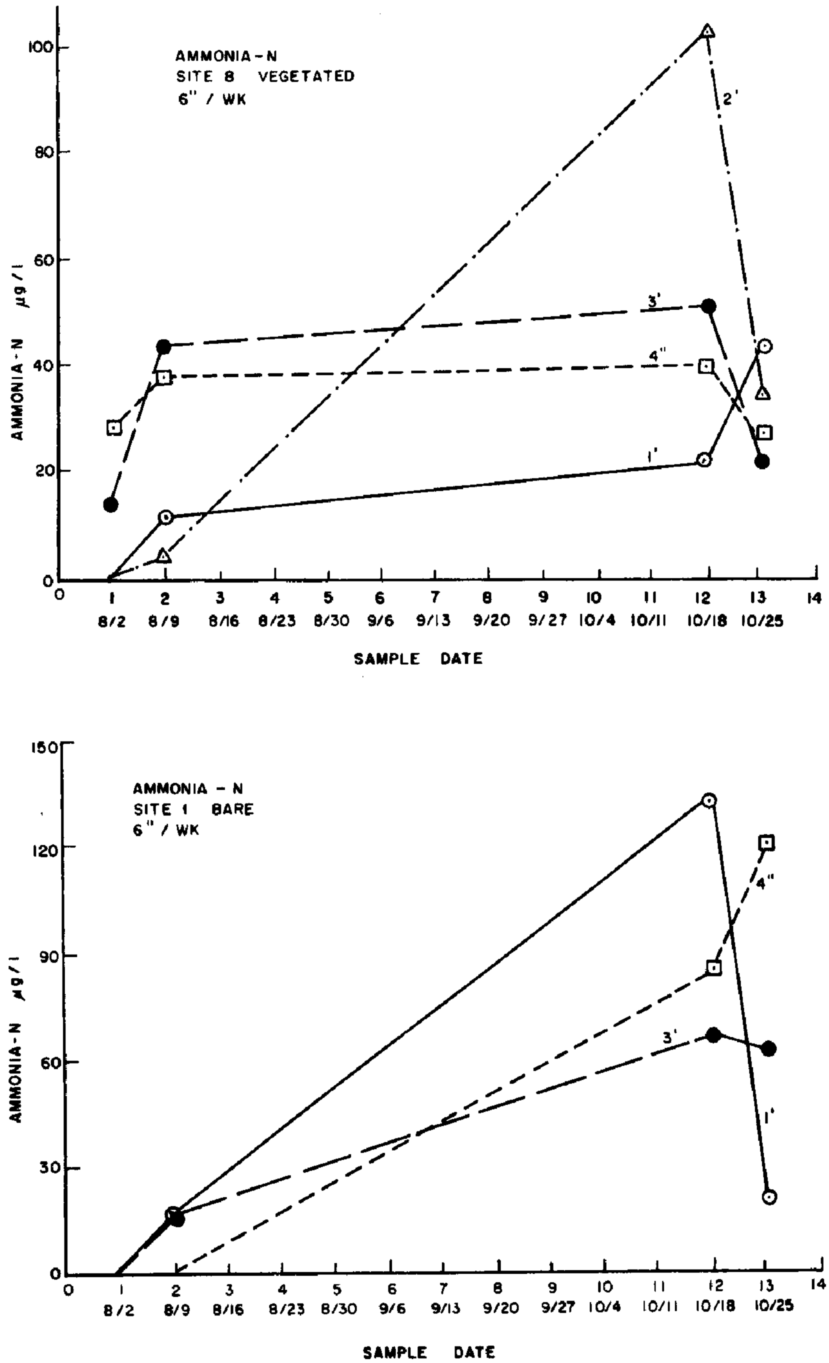


Figure B-10. Ammonia-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1975.

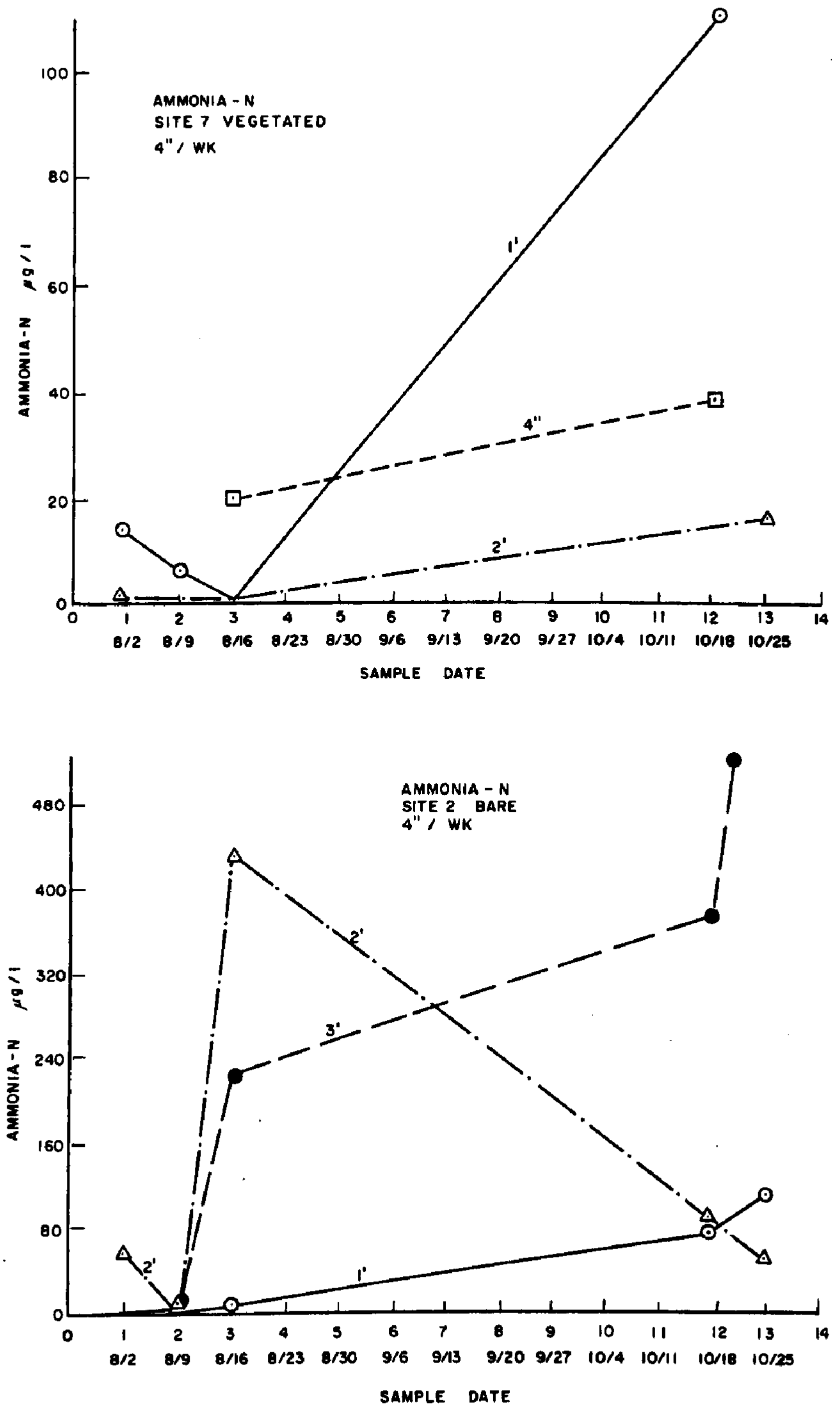


Figure B-11. Ammonia-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1975.

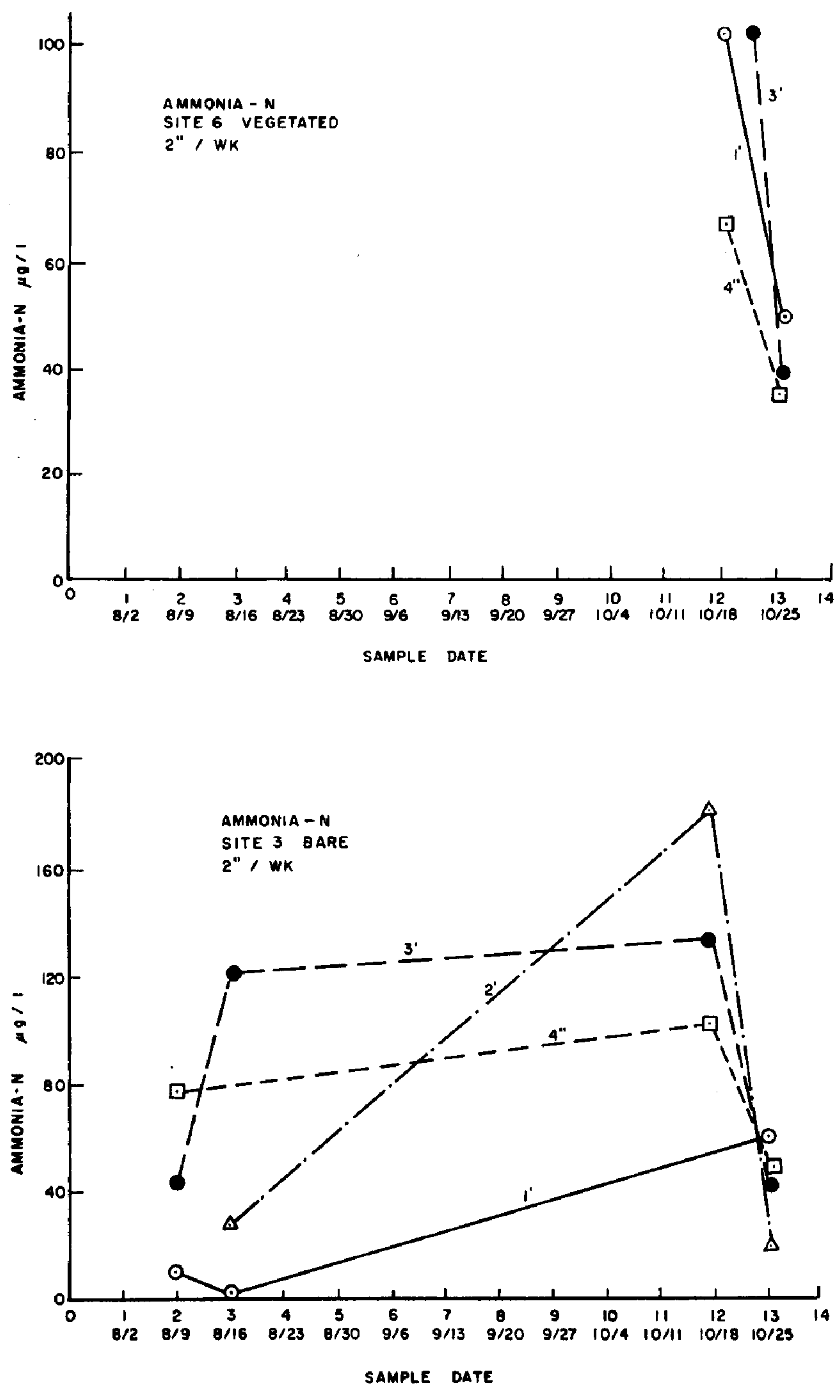


Figure B-12. Ammonia-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1975.

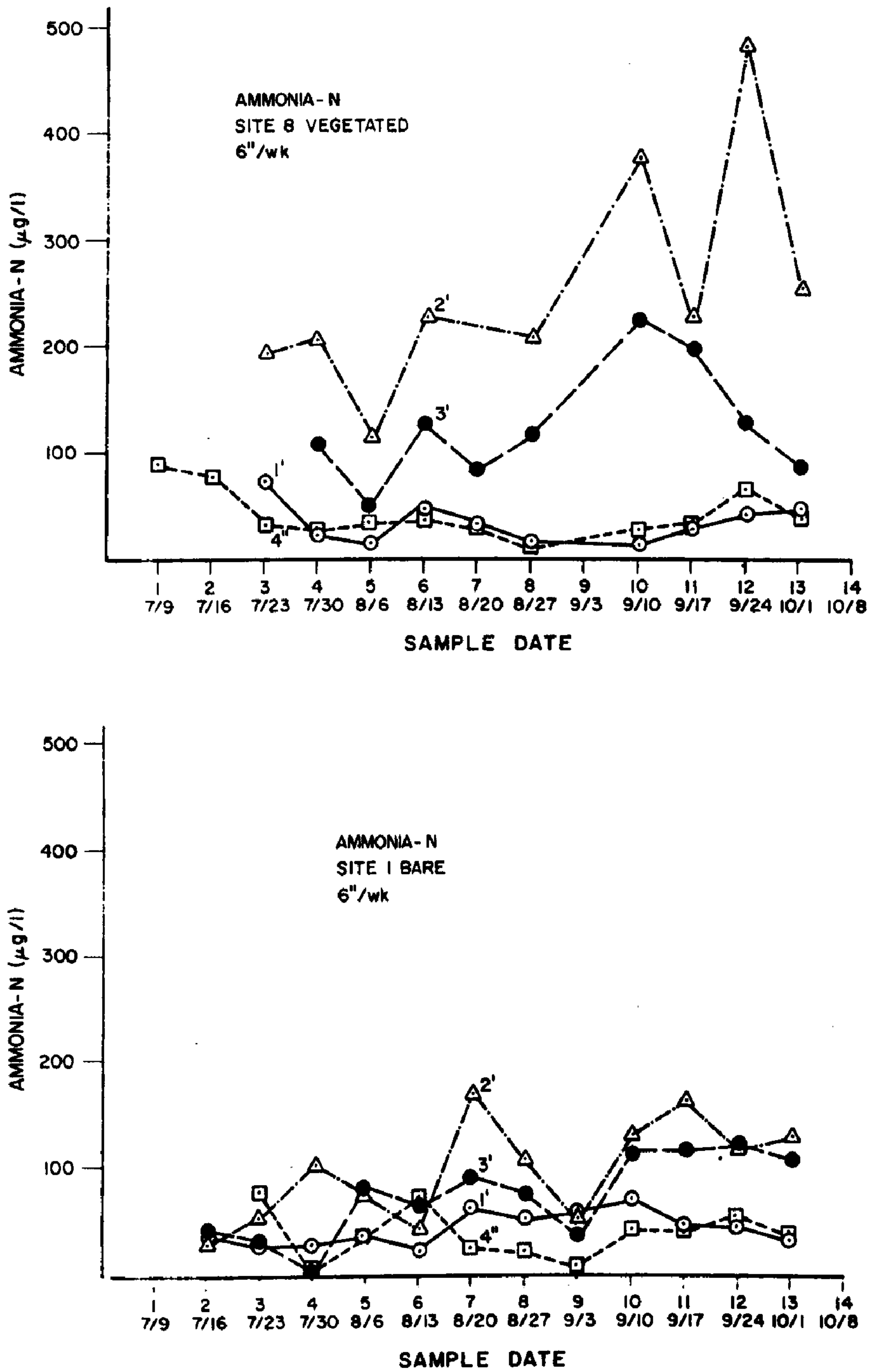


Figure B-13. Ammonia-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1976.

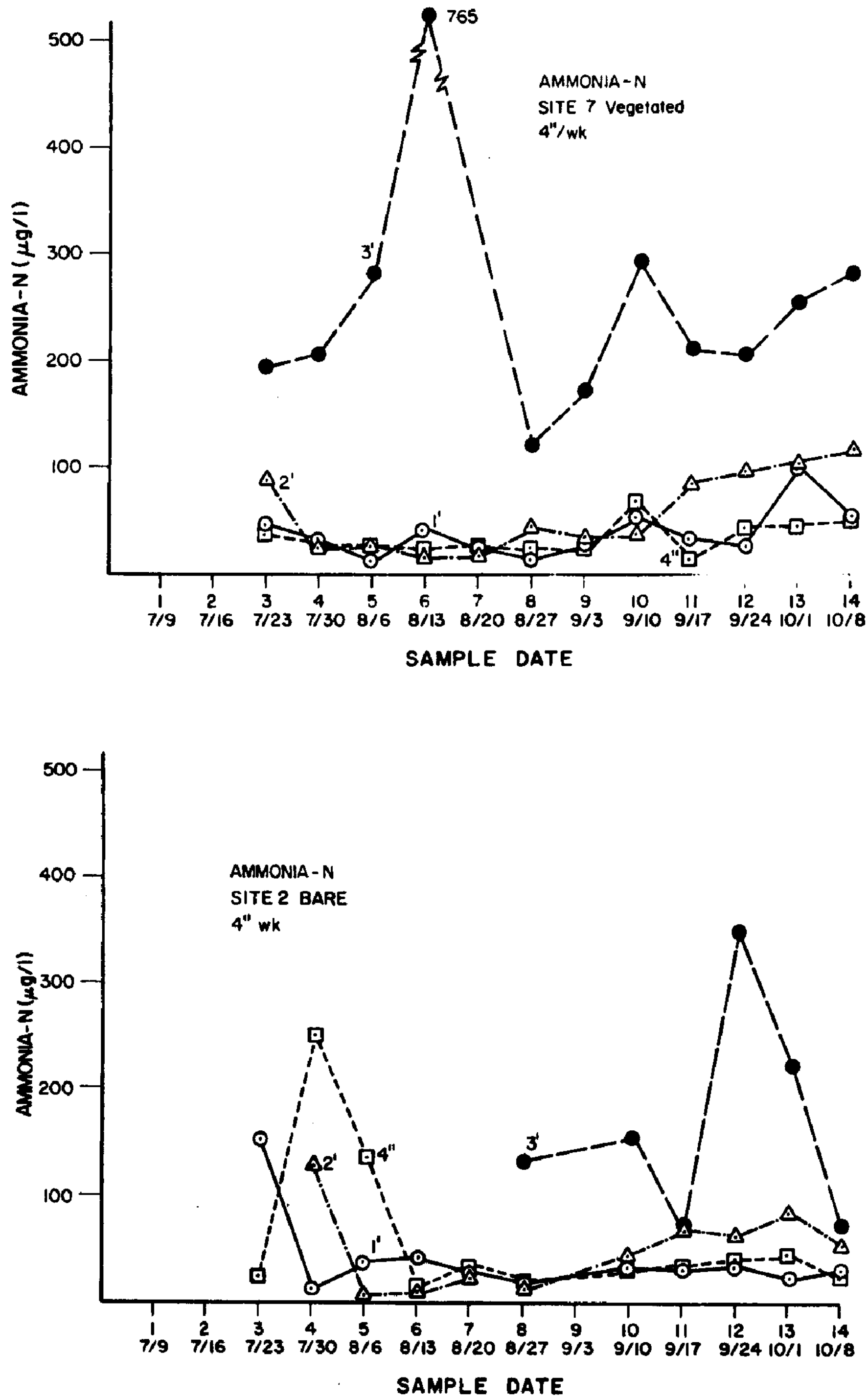


Figure B-14. Ammonia-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.

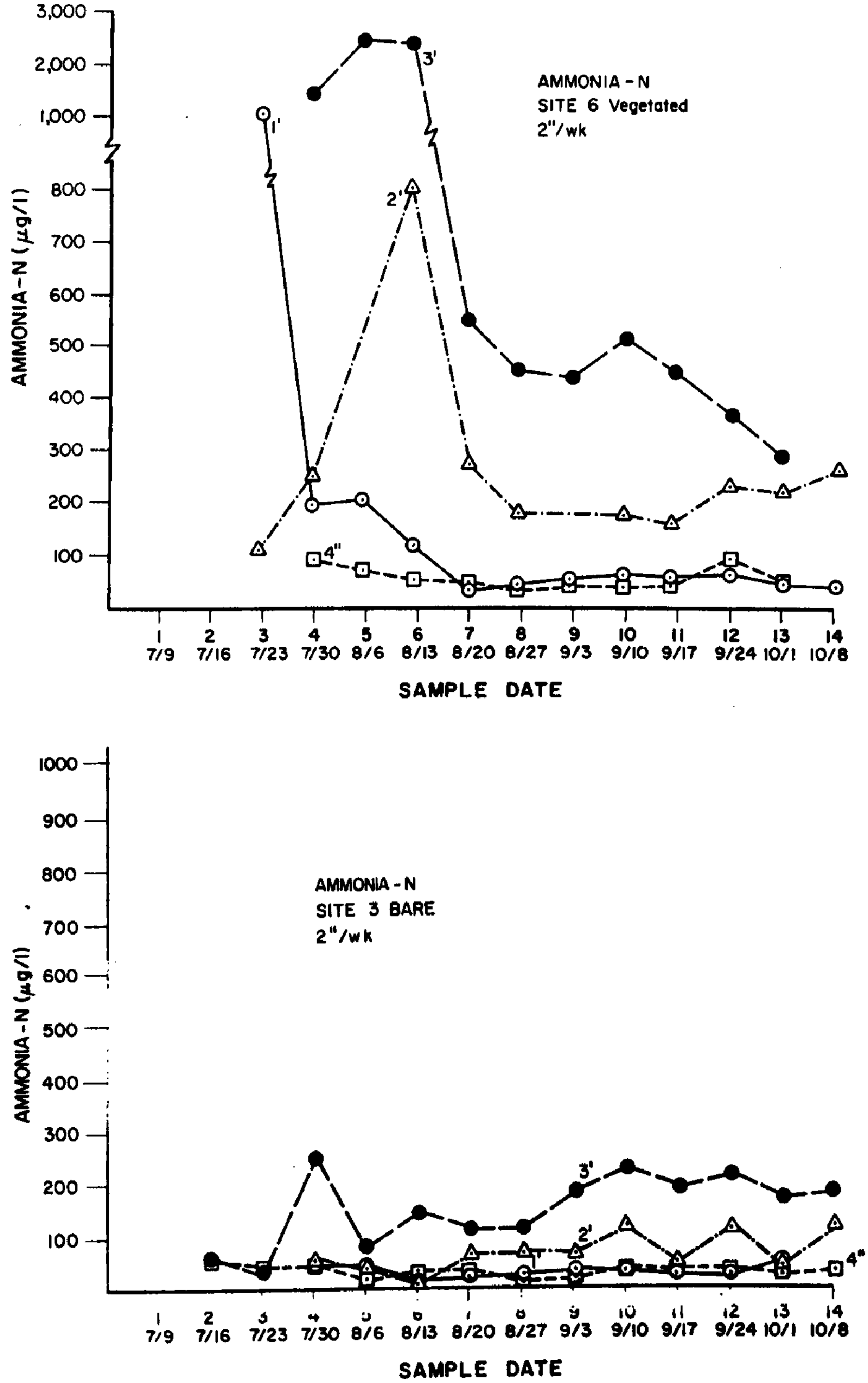
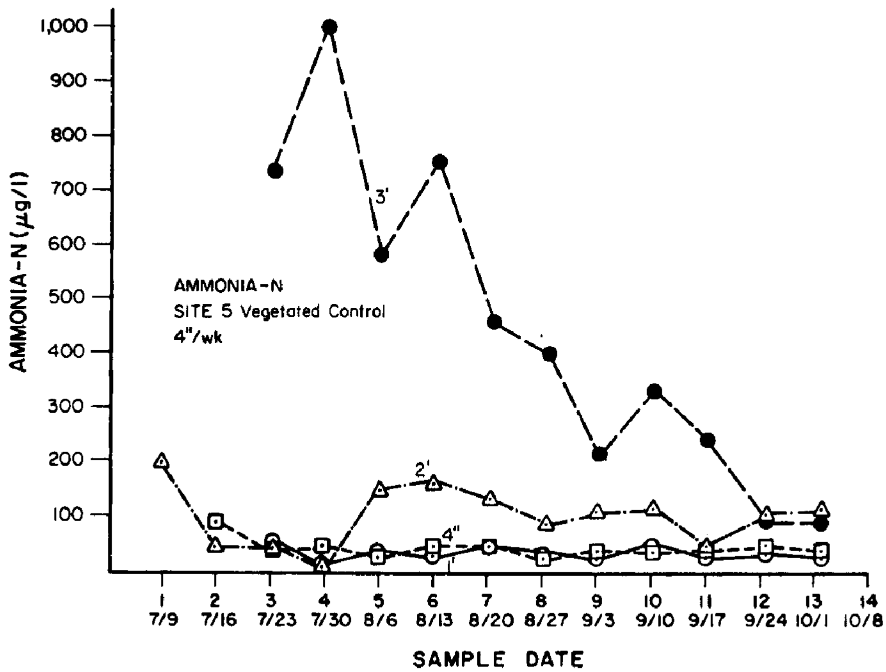


Figure B-15. Ammonia-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1976.



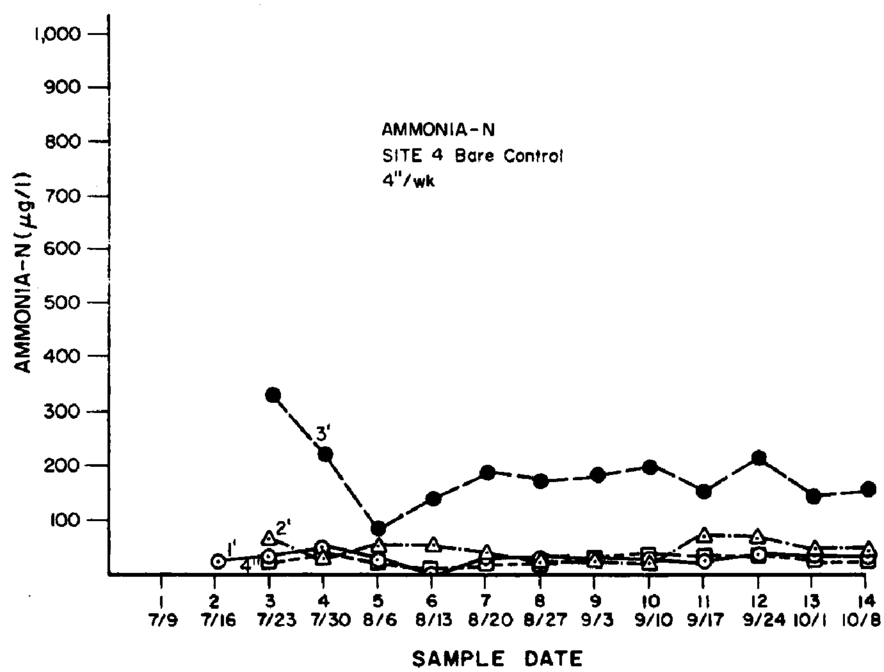
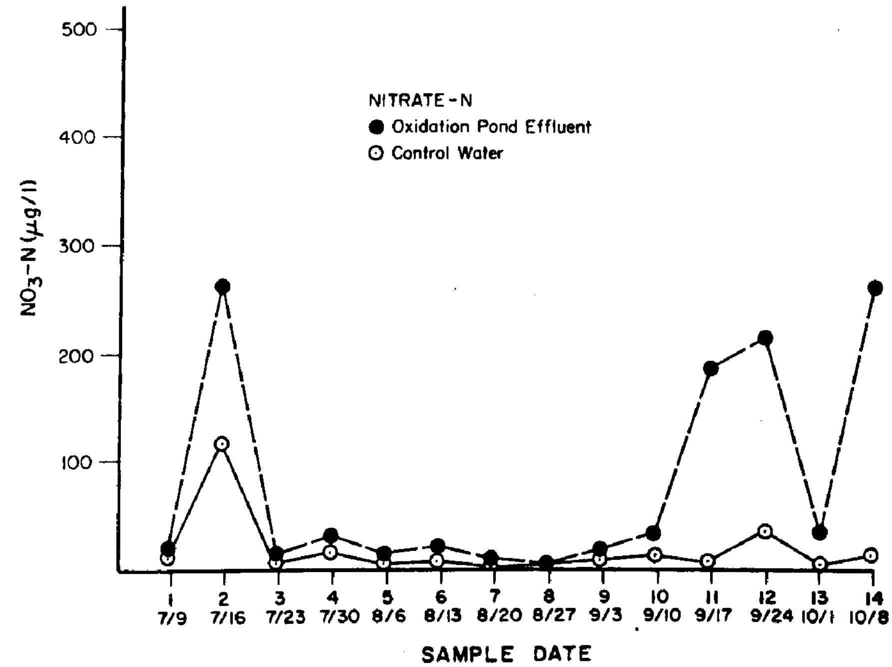


Figure B-16. Ammonia-N concentrations in the soil mantle treated control water at 10.2 cm (4 in.), 30.5 cm (1. ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile and vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.



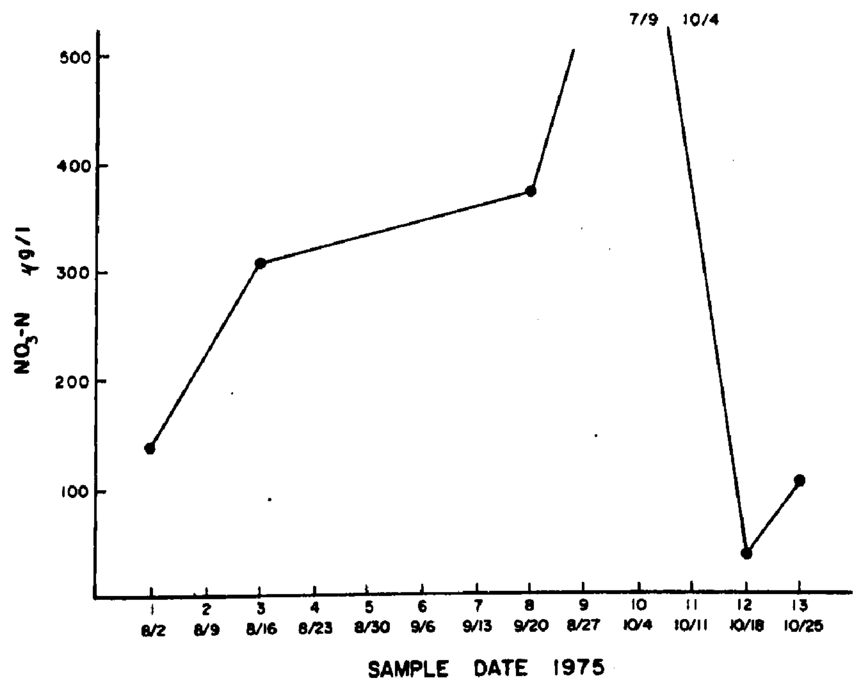
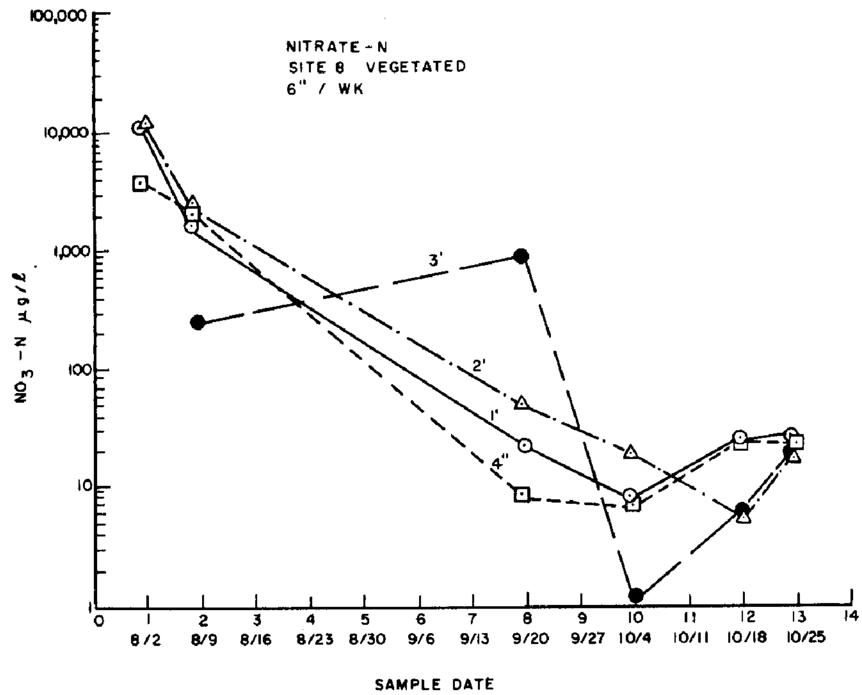


Figure B-17. Nitrate-N concentrations in the stabilization pond effluent and control water during 1976 (above) and nitrate-N concentrations in the stabilization pond effluent during 1975 (below).



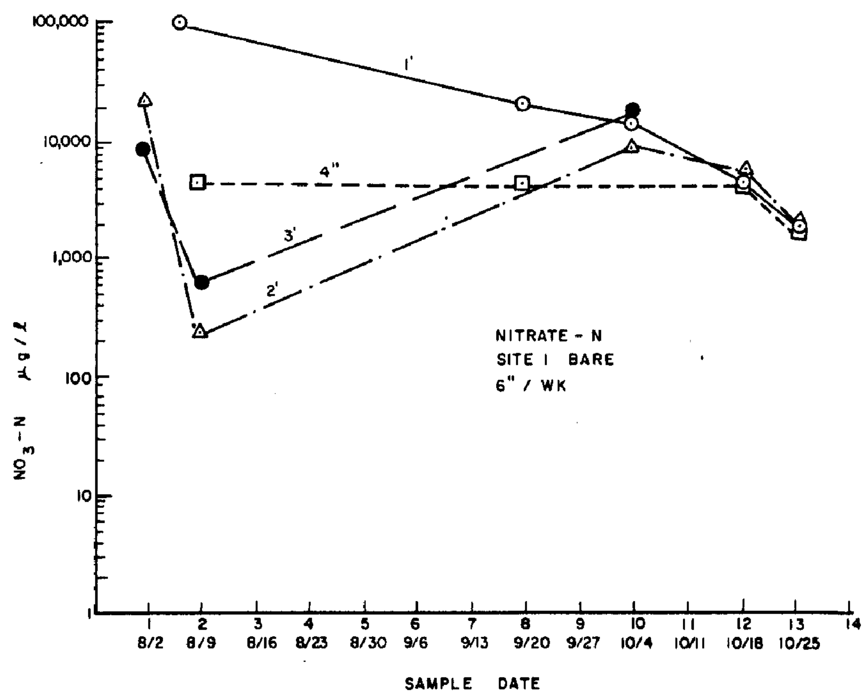


Figure B-18. Nitrate-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1975.

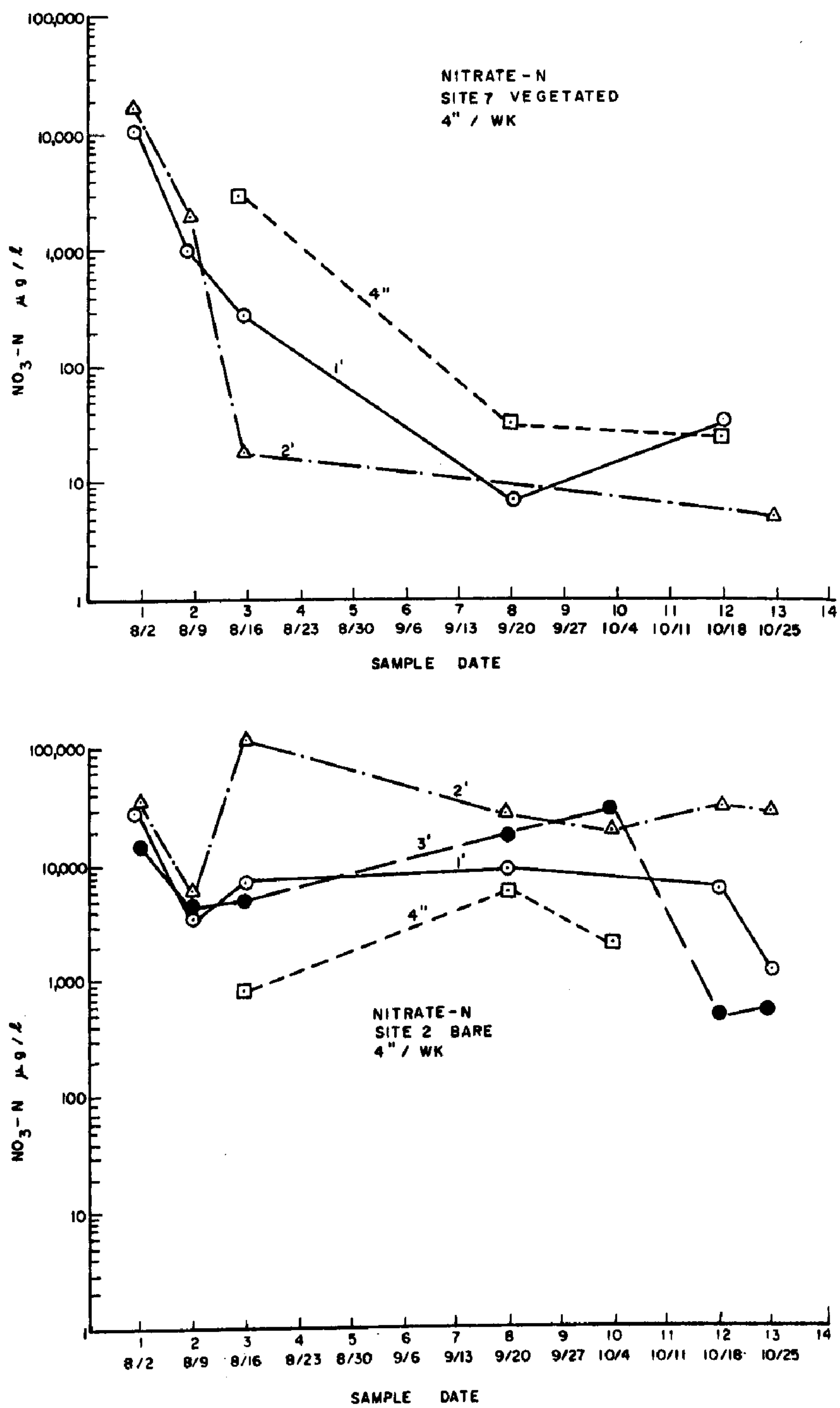


Figure B-19. Nitrate-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1975.

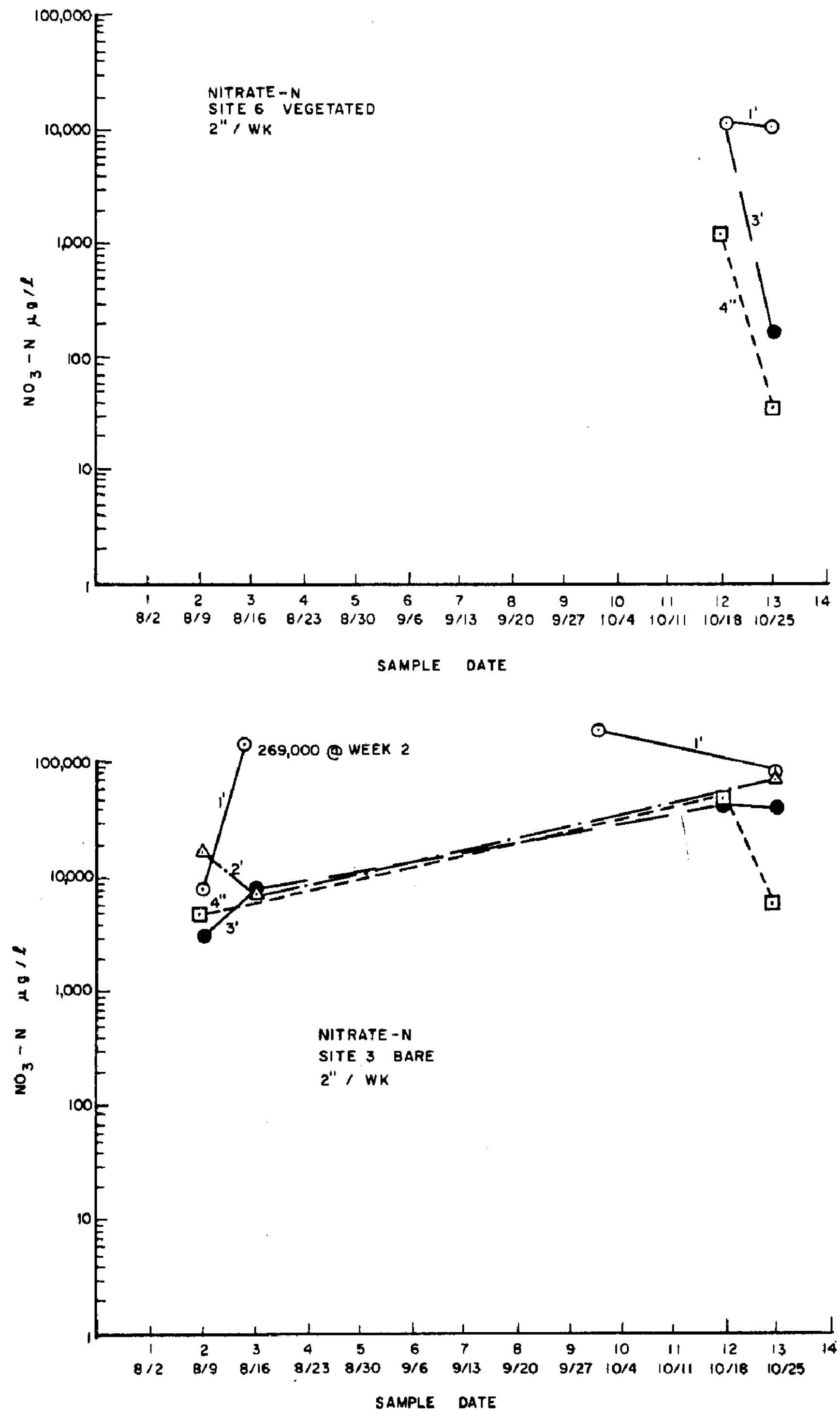
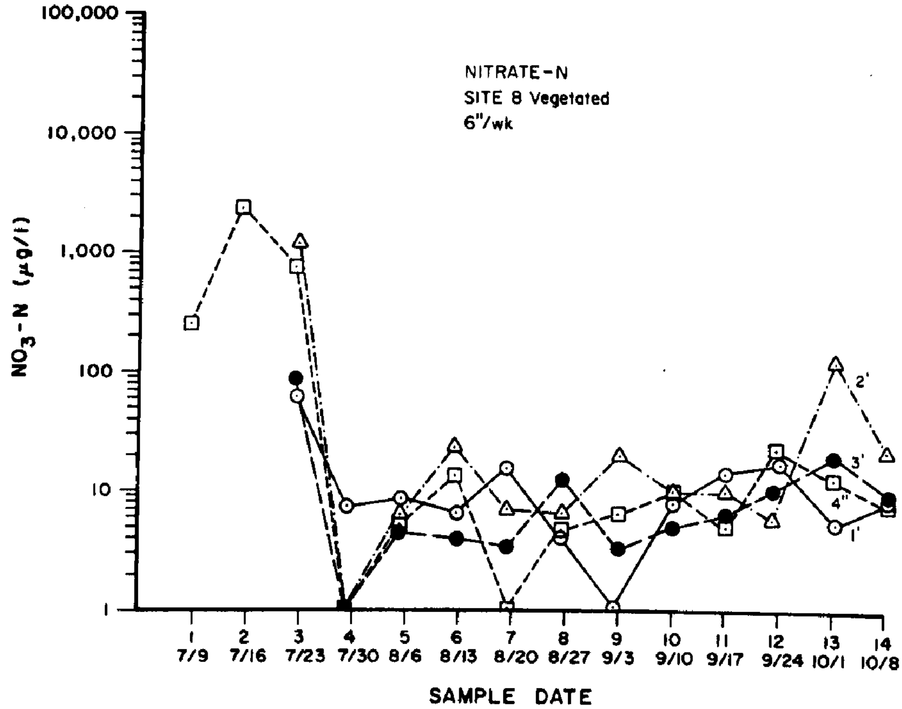


Figure B-20. Nitrate-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1975.



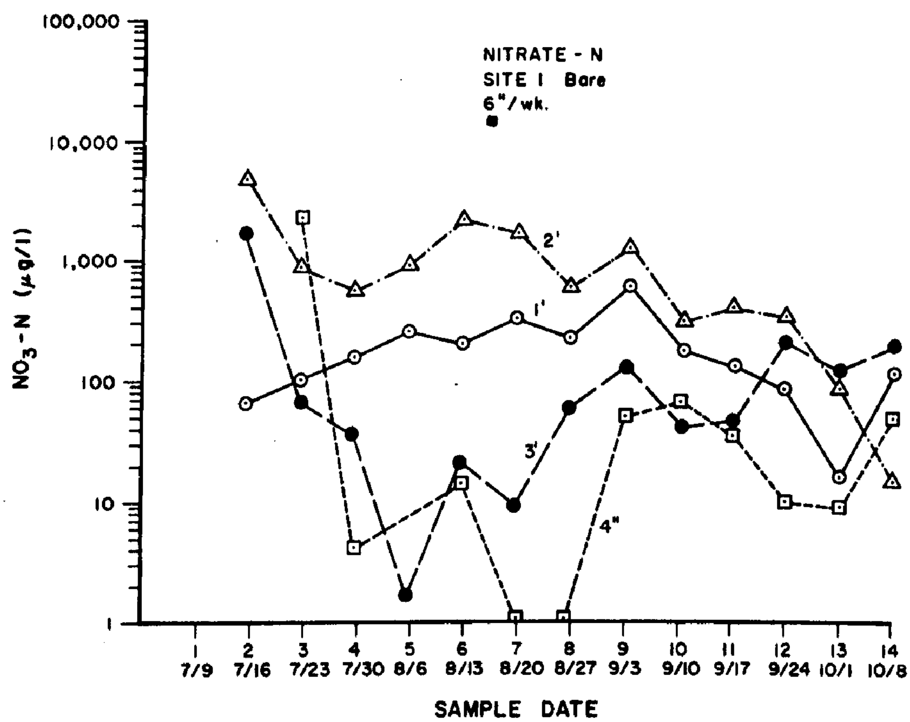


Figure B-21. Nitrate-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1976.

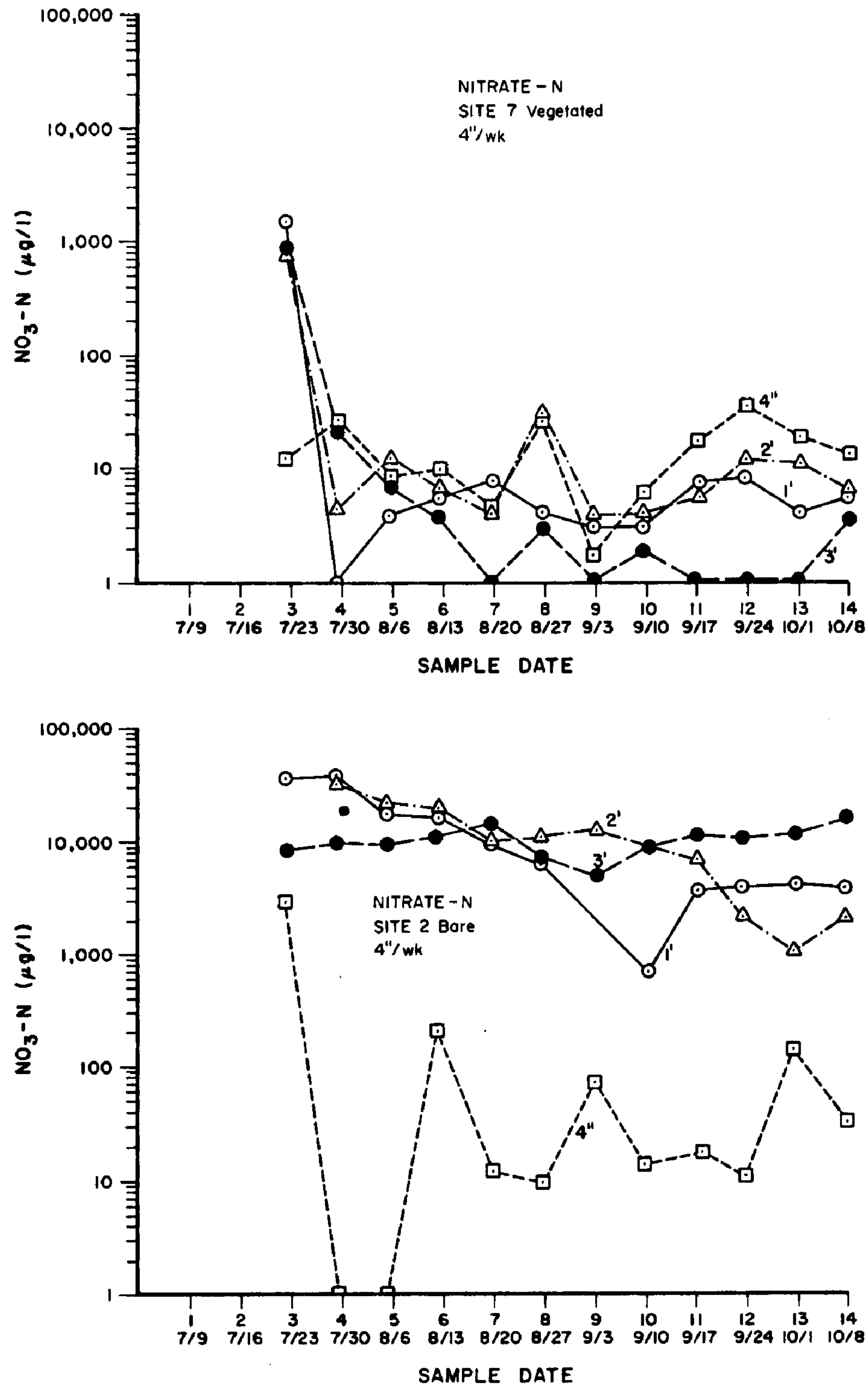
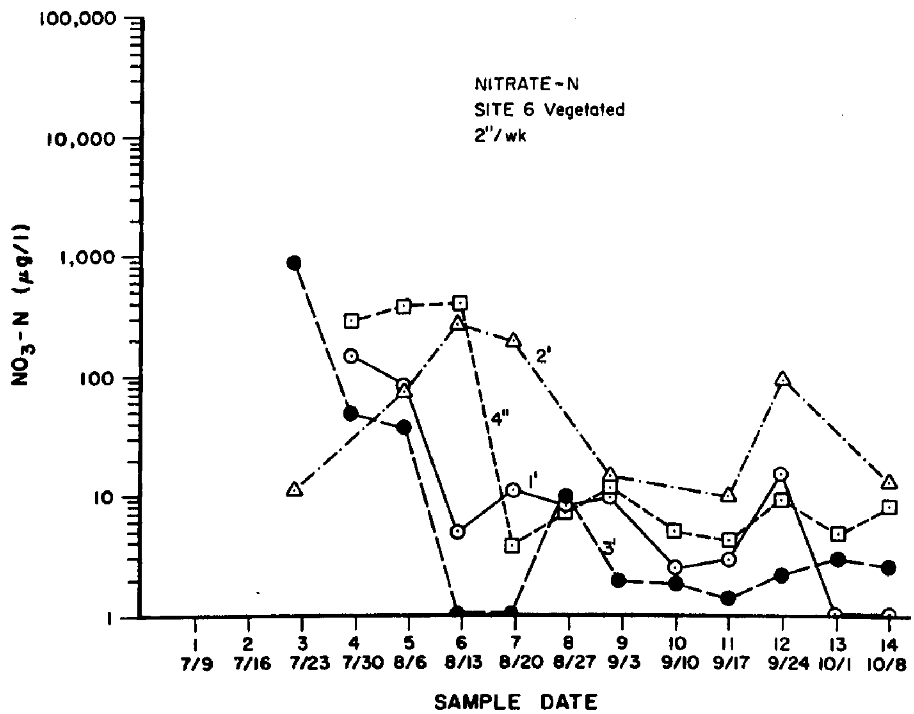


Figure B-22. Nitrate-N concentrations in the soil mantle treated stabilizaton pond effluent at 10.2 cm (4 in.), 30.5 cm -(1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.



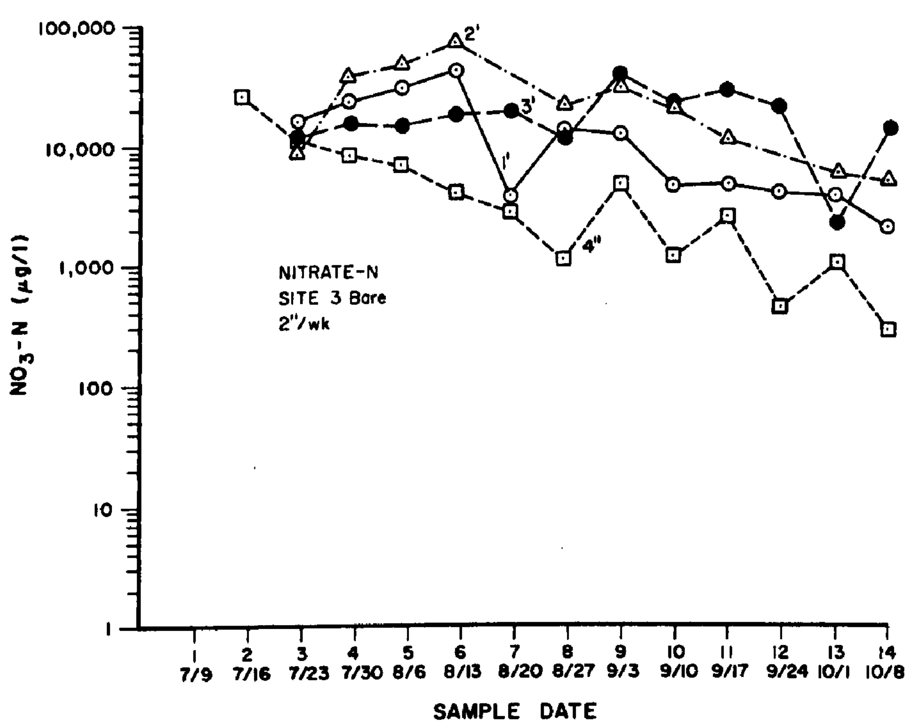
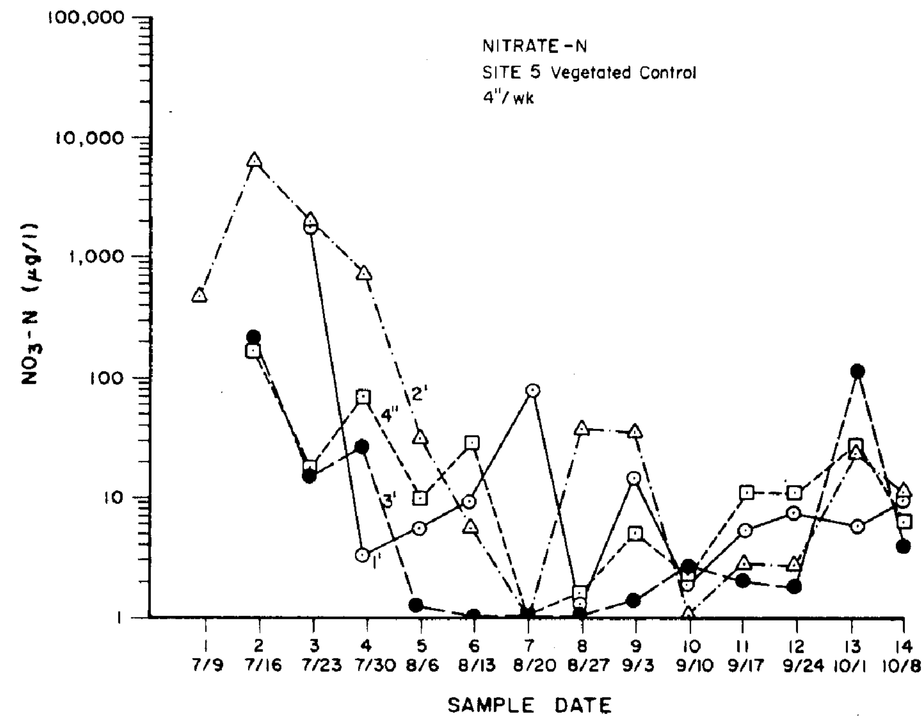


Figure B-23. Nitrate-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1976.



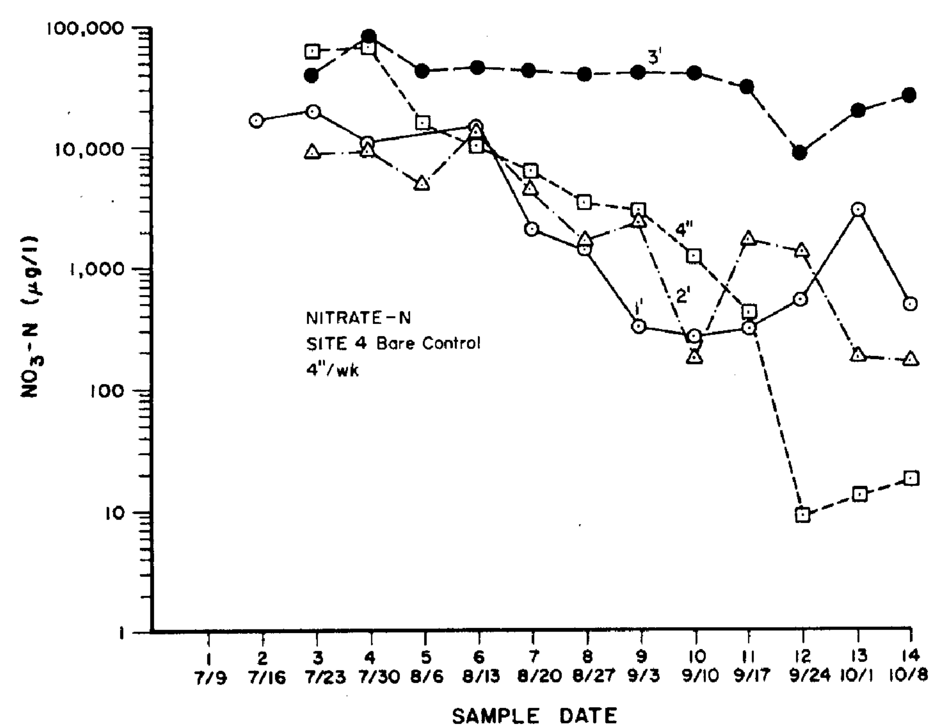
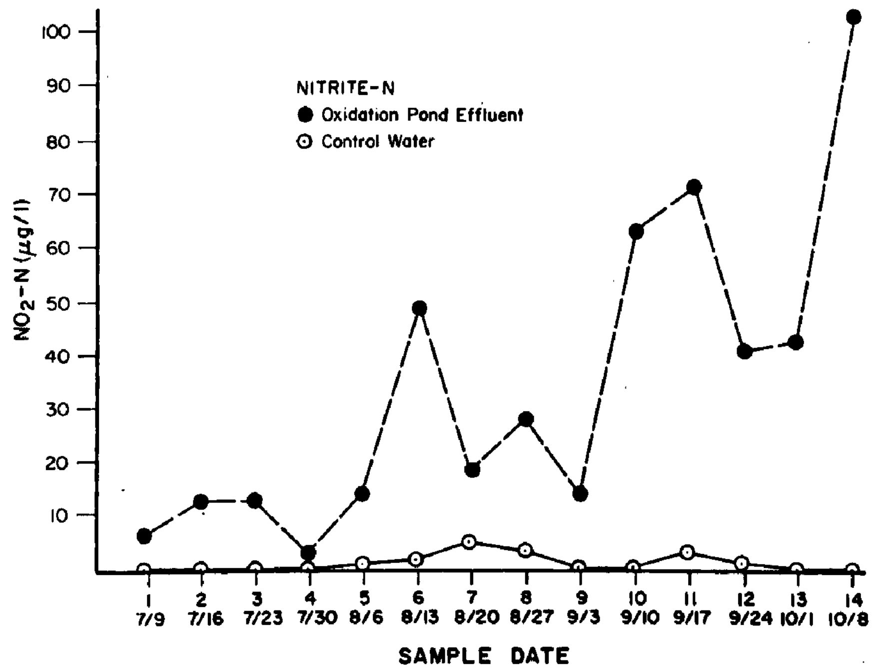


Figure B-24. Nitrate-N concentrations in the soil mantle treated control water at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.



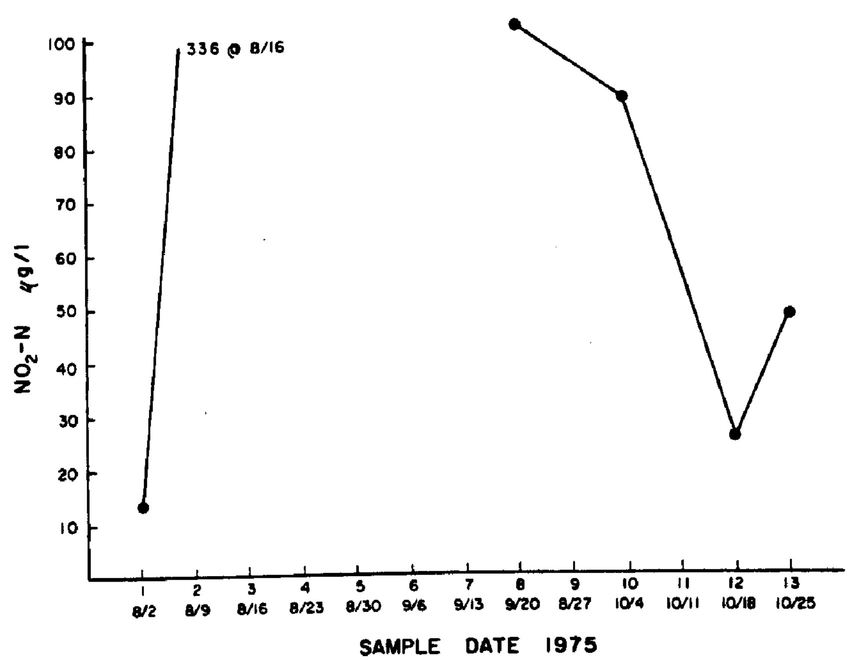
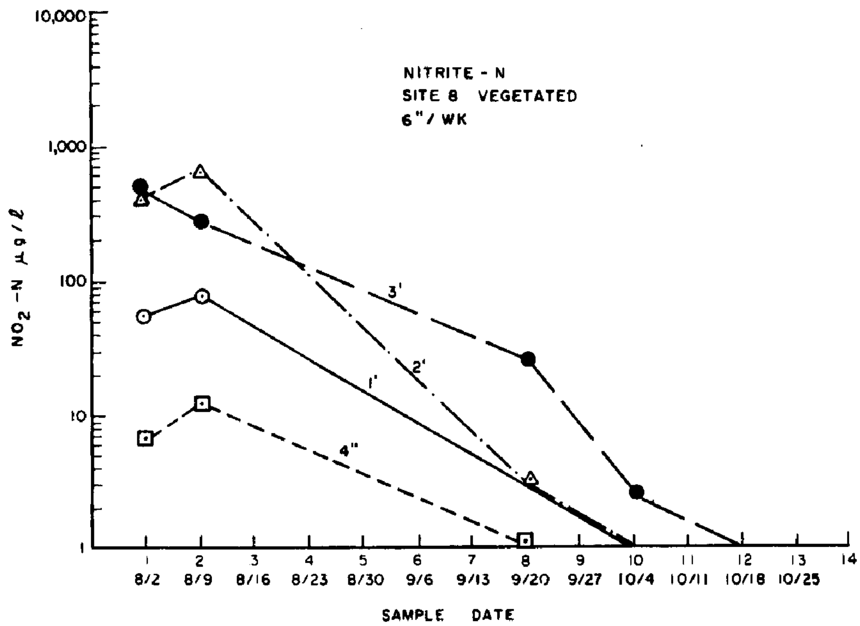


Figure B-25. Nitrite-N concentrations in the stabilization pond effluent and control water during 1976 (above) and nitrite-N concentrations in the stabilization pond effluent during 1976.



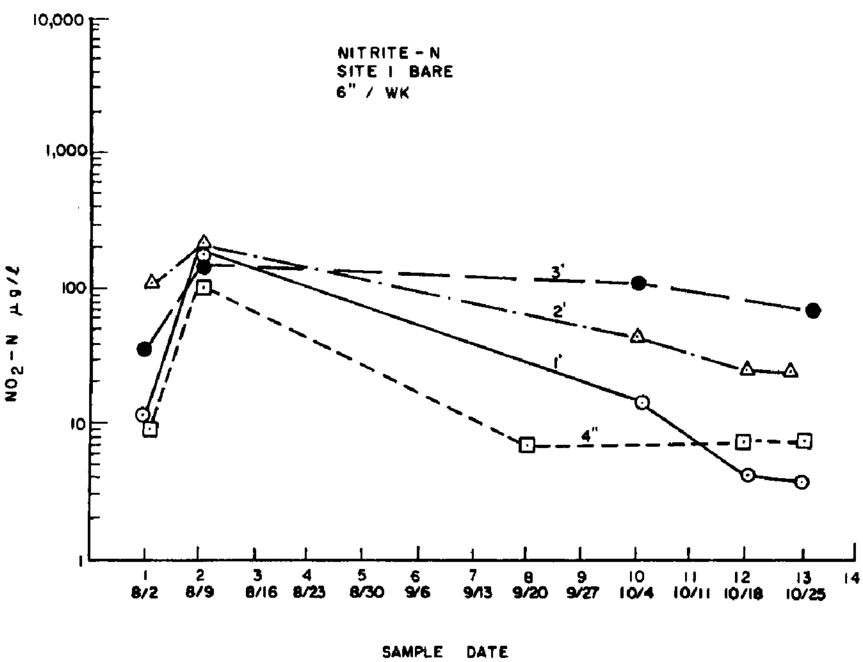


Figure B-26. Nitrite-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1975.

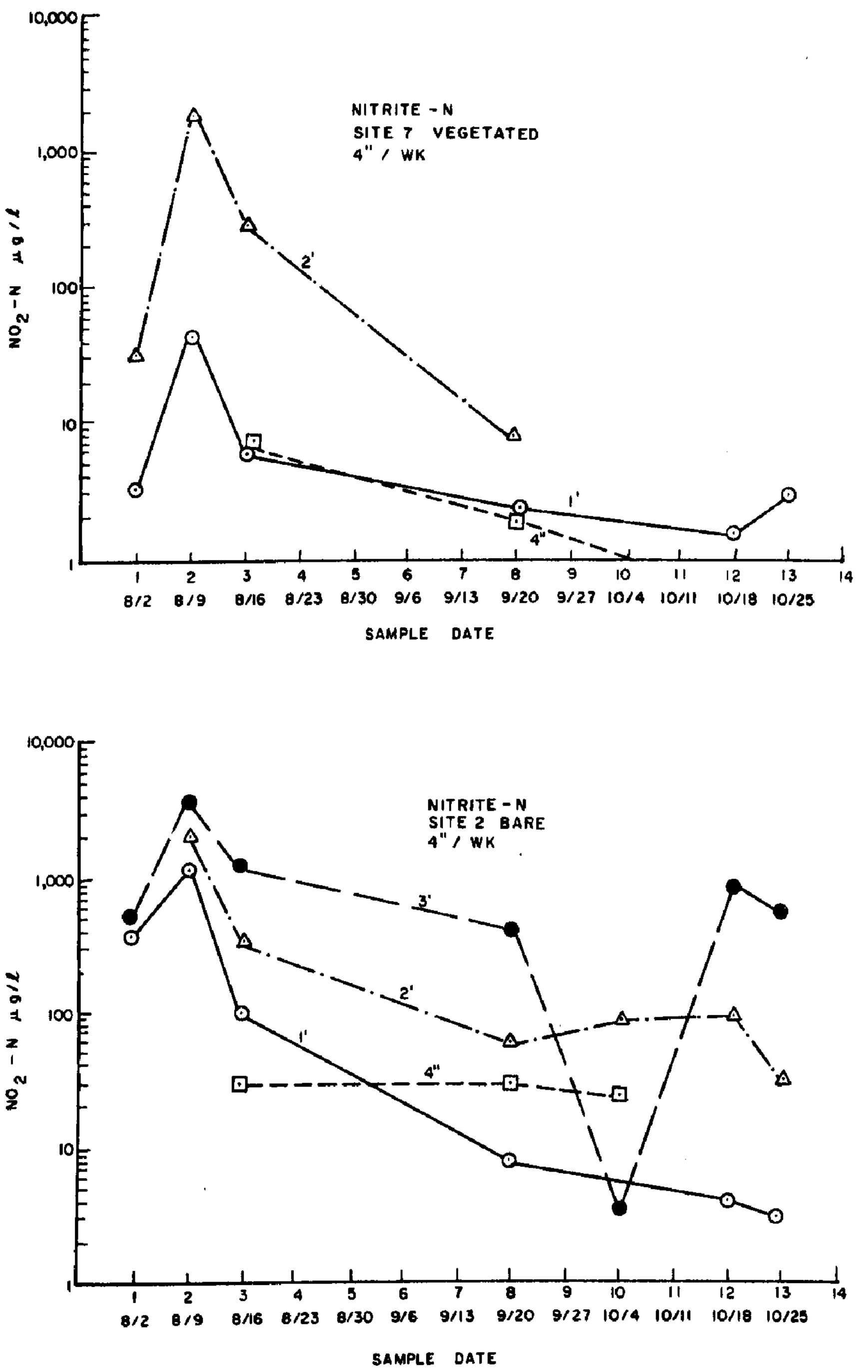


Figure B-27. Nitrite-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1975.

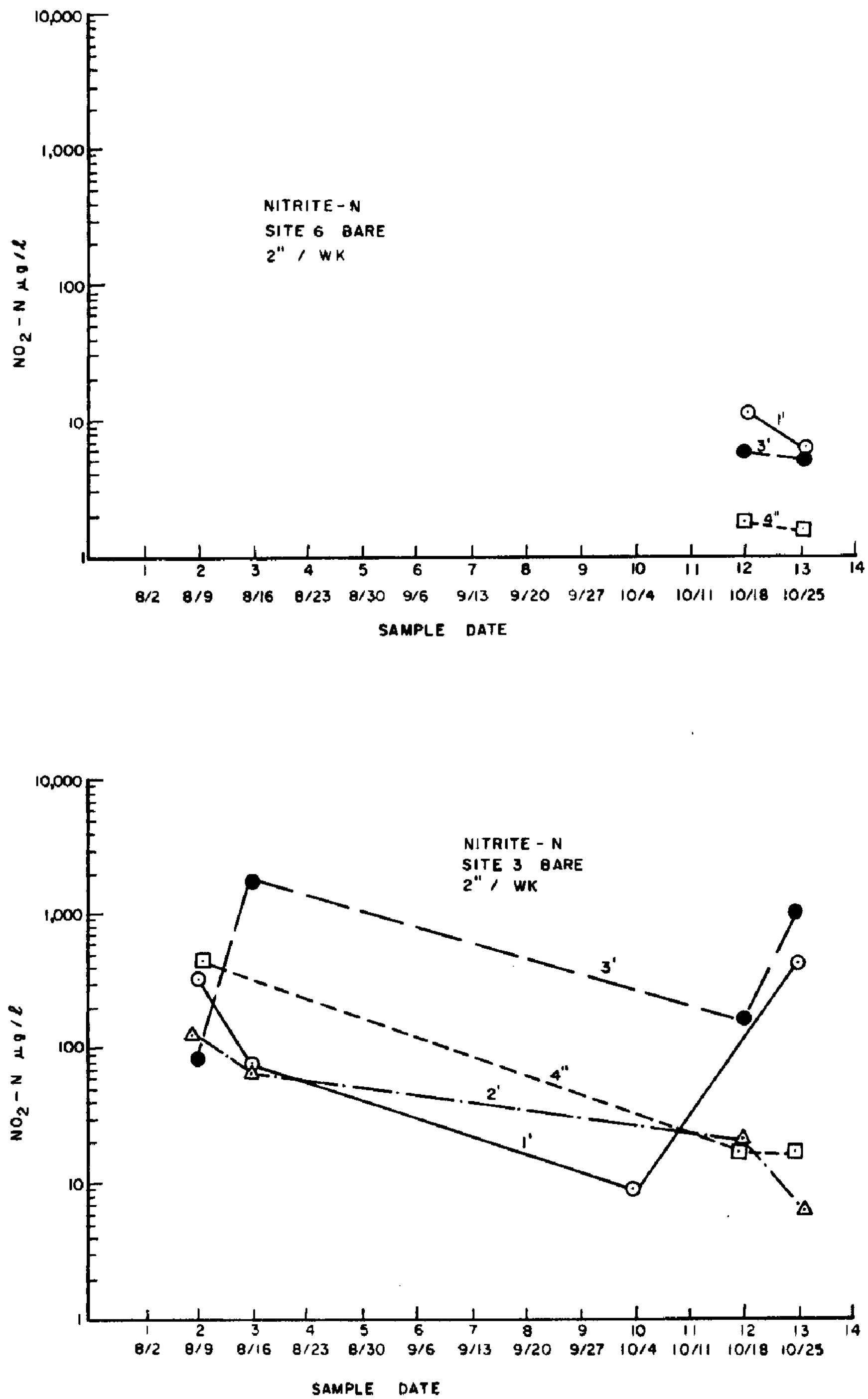
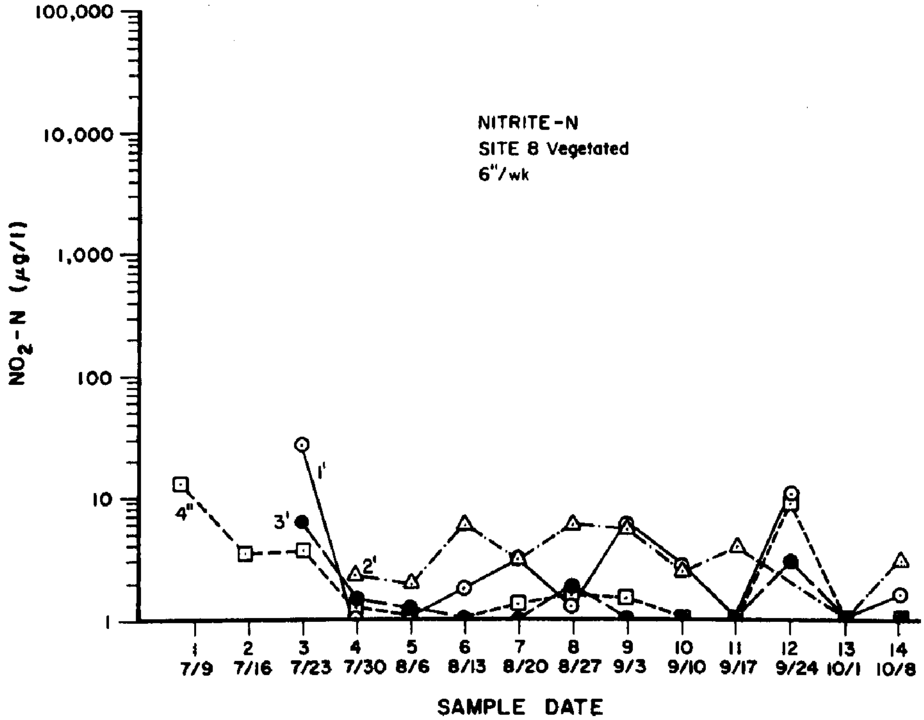


Figure B-28. Nitrite-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1975.



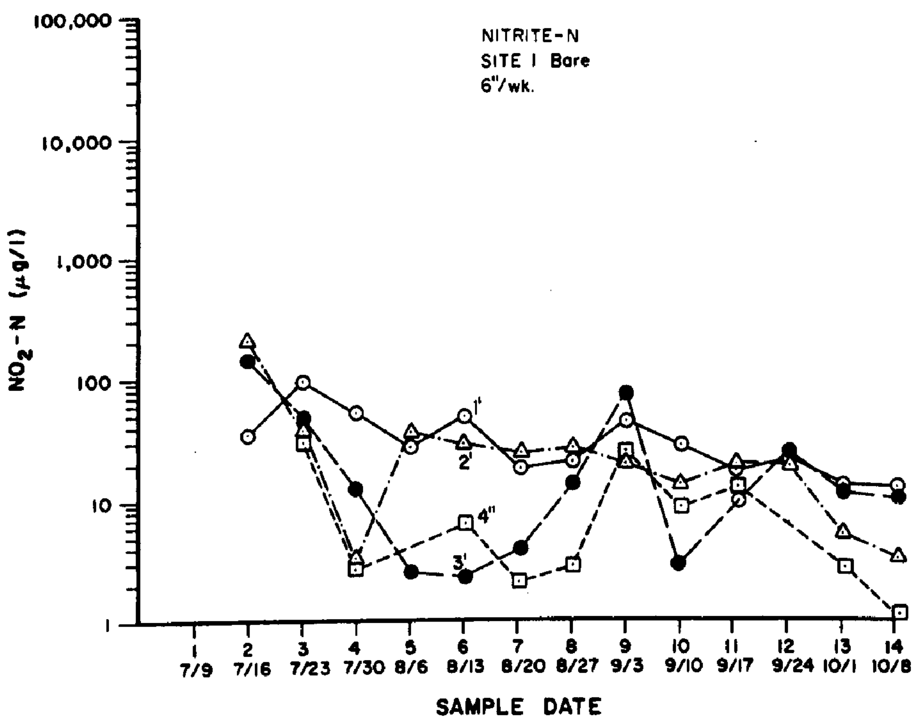


Figure B-29. Nitrite-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1976.

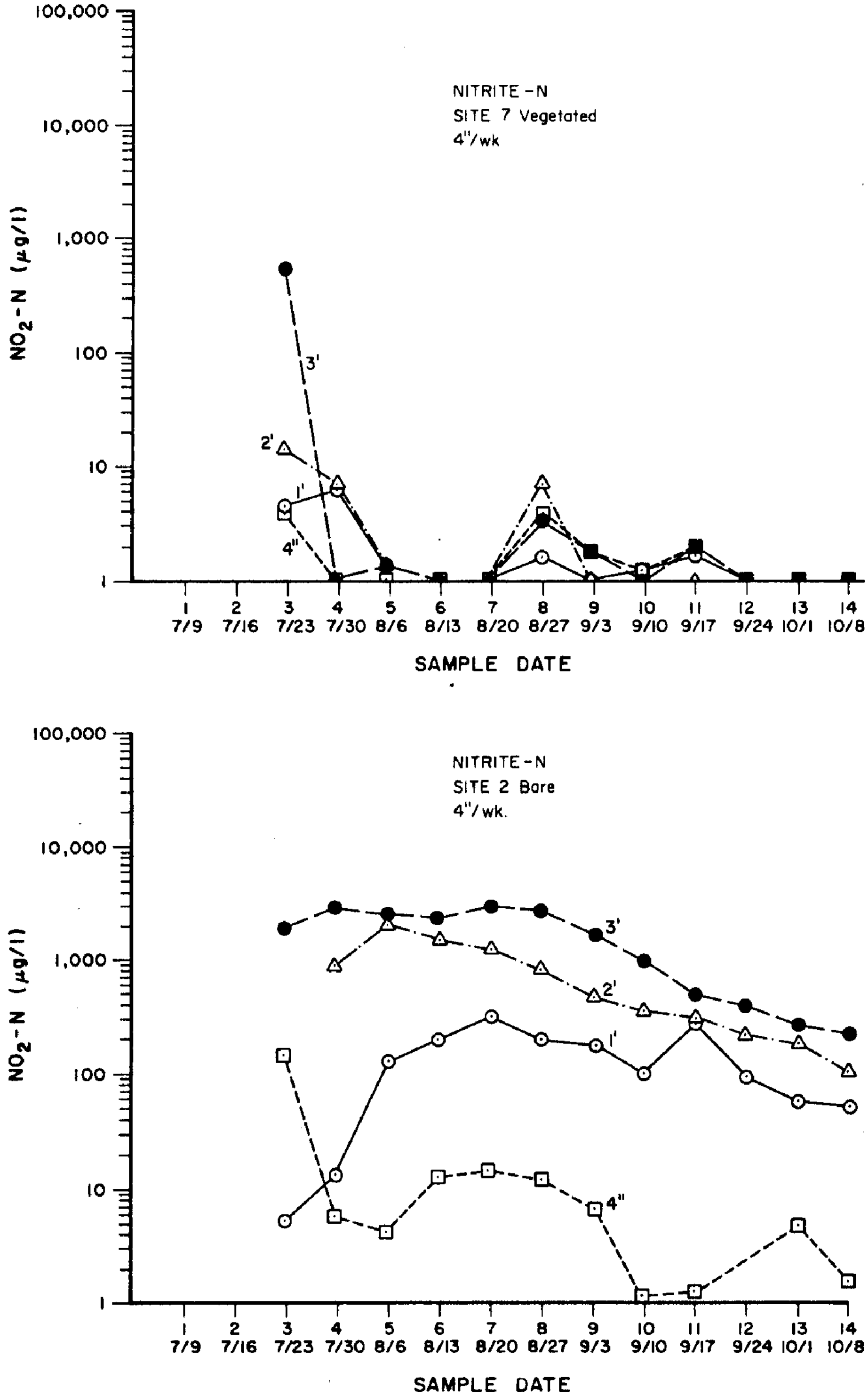
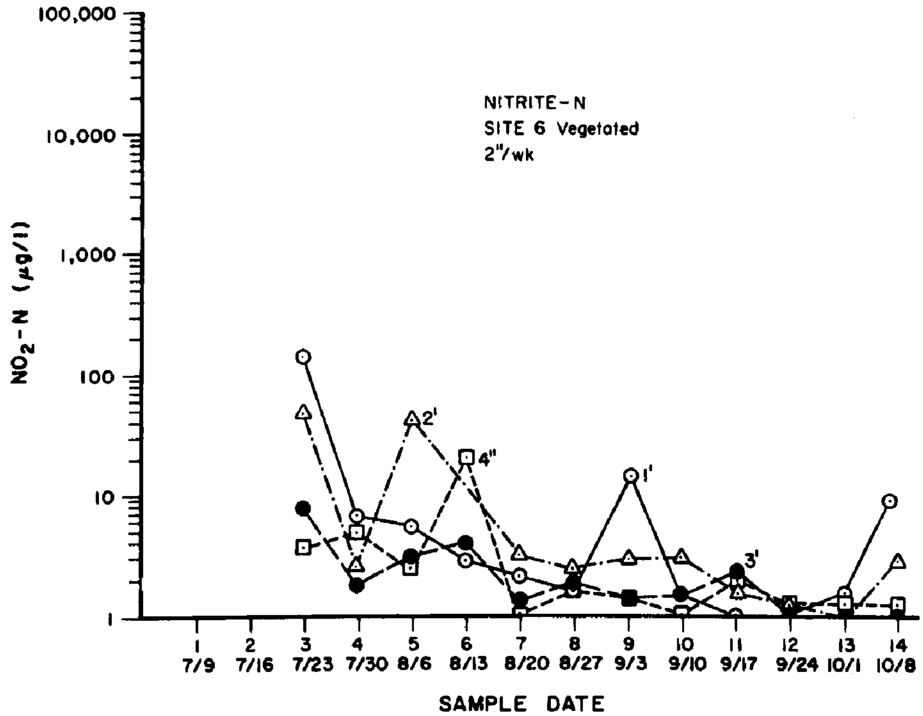


Figure B-30. Nitrite-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.



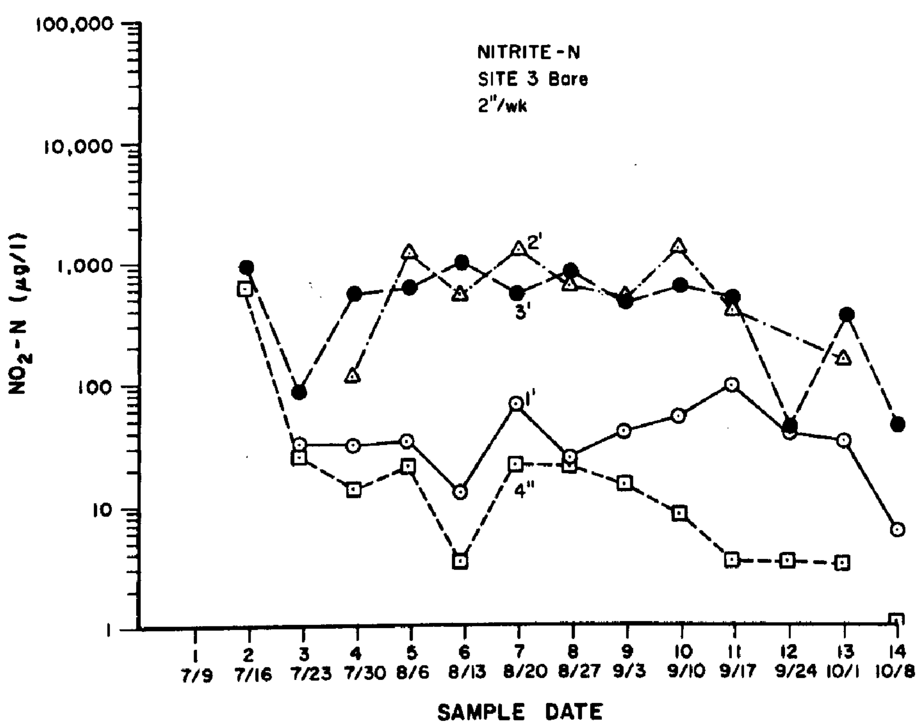
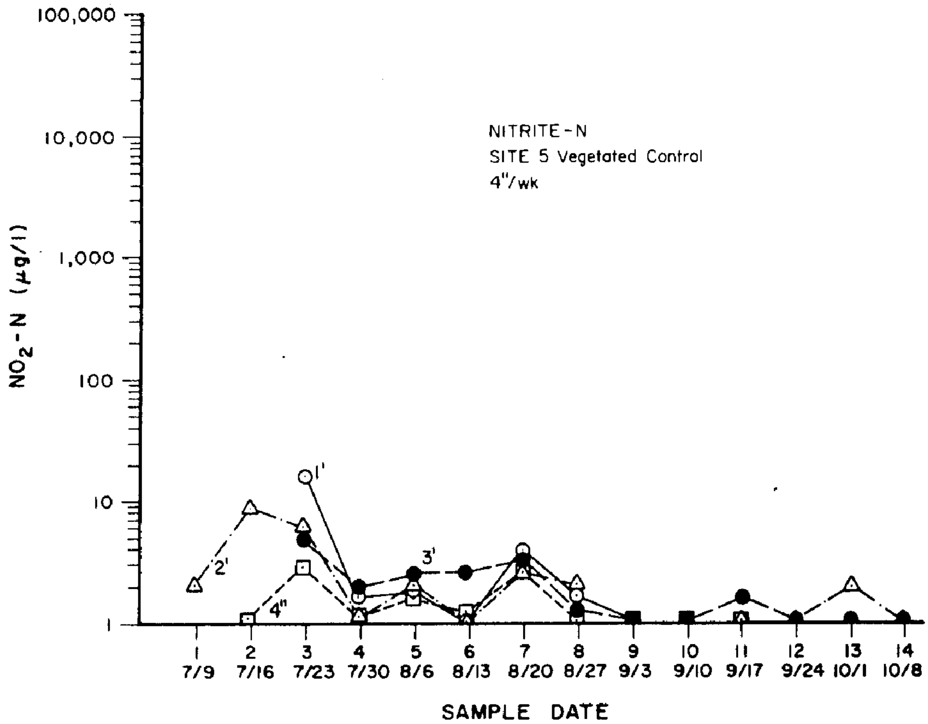


Figure B-31. Nitrite-N concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1976.



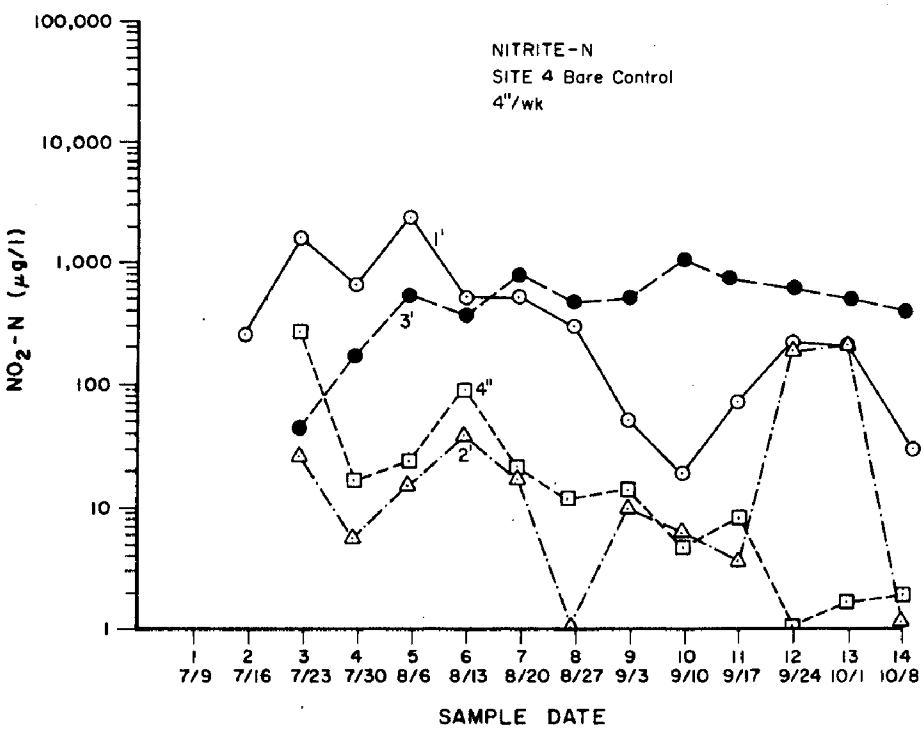
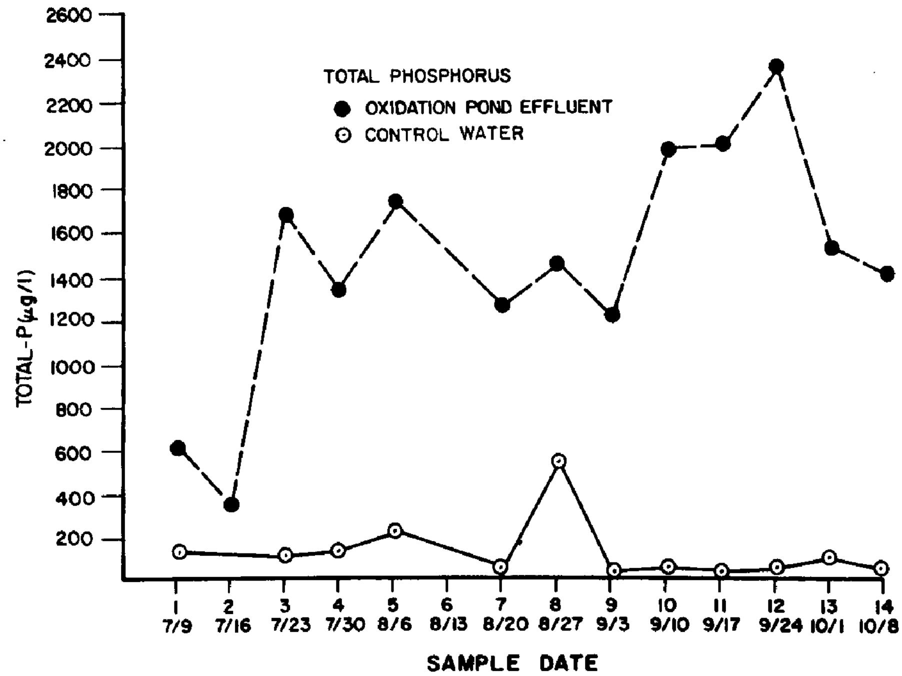


Figure B-32. Nitrite-N concentrations in the soil mantle treated control water at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.



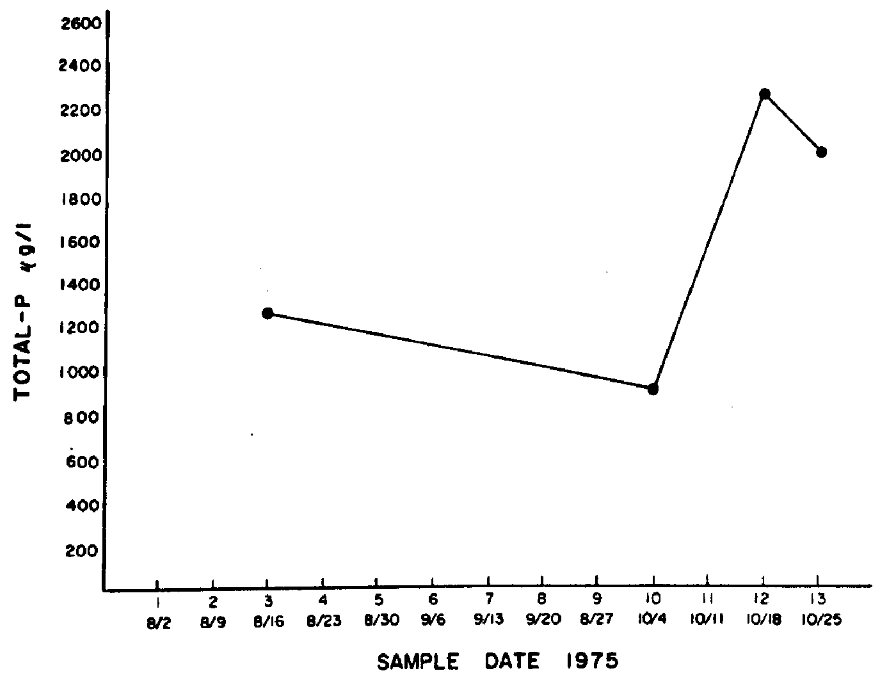
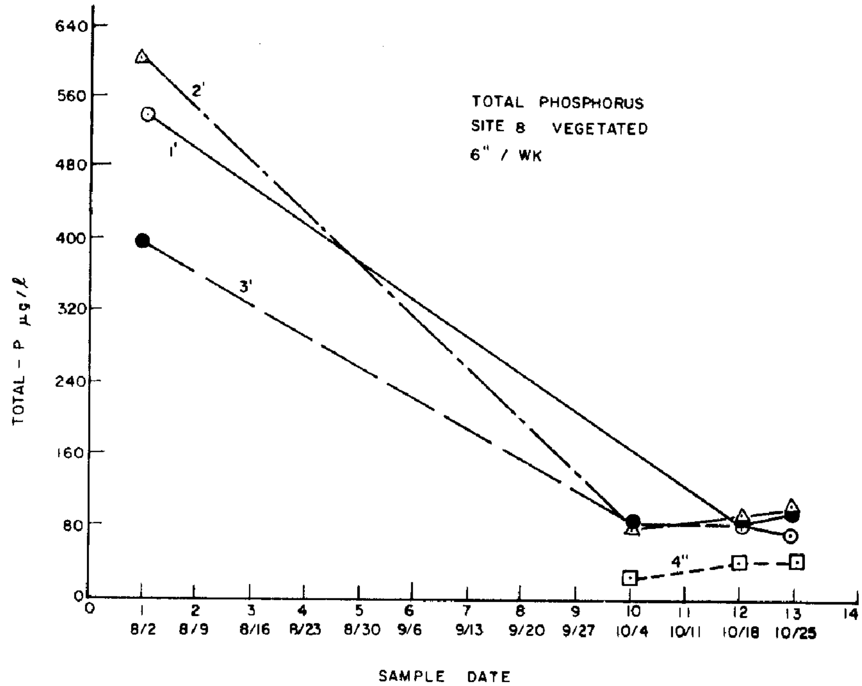


Figure B-33. Total phosphorus-P concentrations in the stabilization pond effluent and control water during 1976 (above) and total phosphorus-P concentrations in the stabilization pond effluent during 1975 (below).



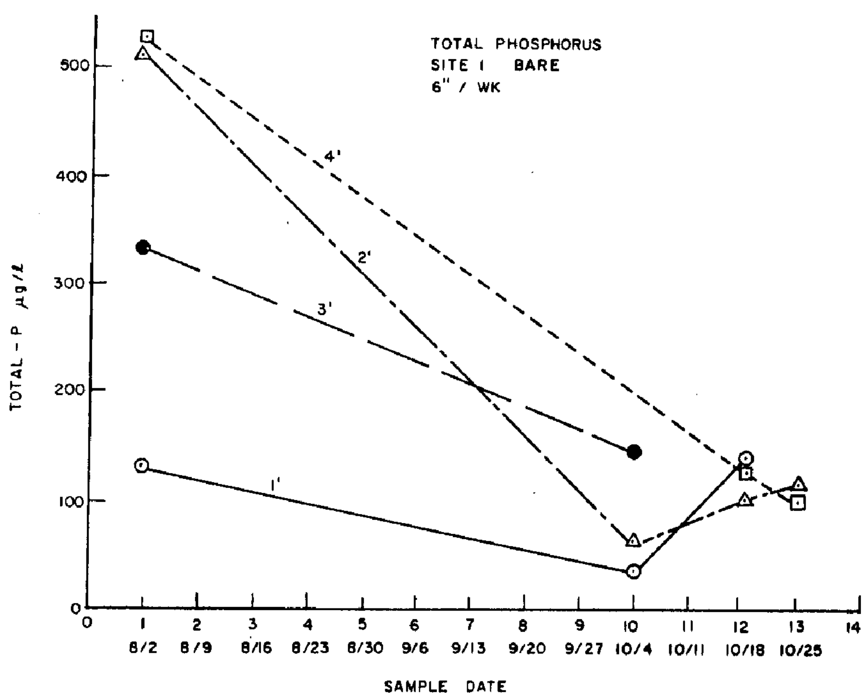


Figure B-34. Total phosphorus-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1975.

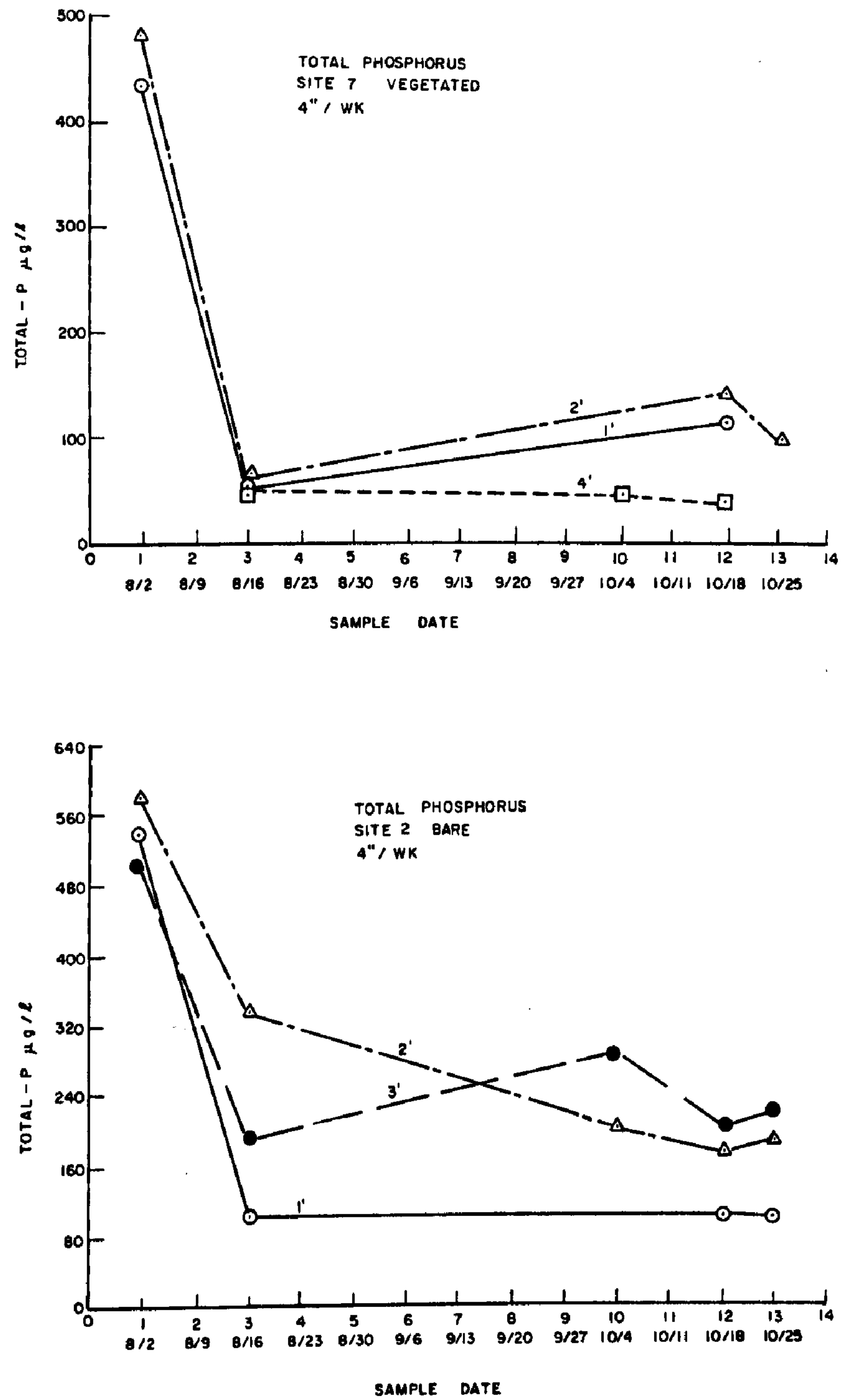
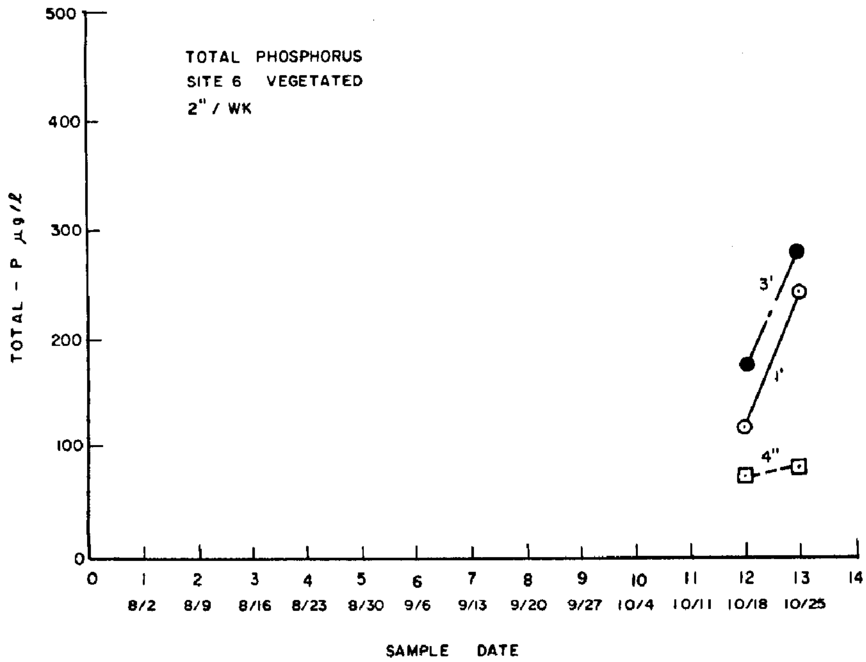


Figure B-35. Total phosphorus-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1975.



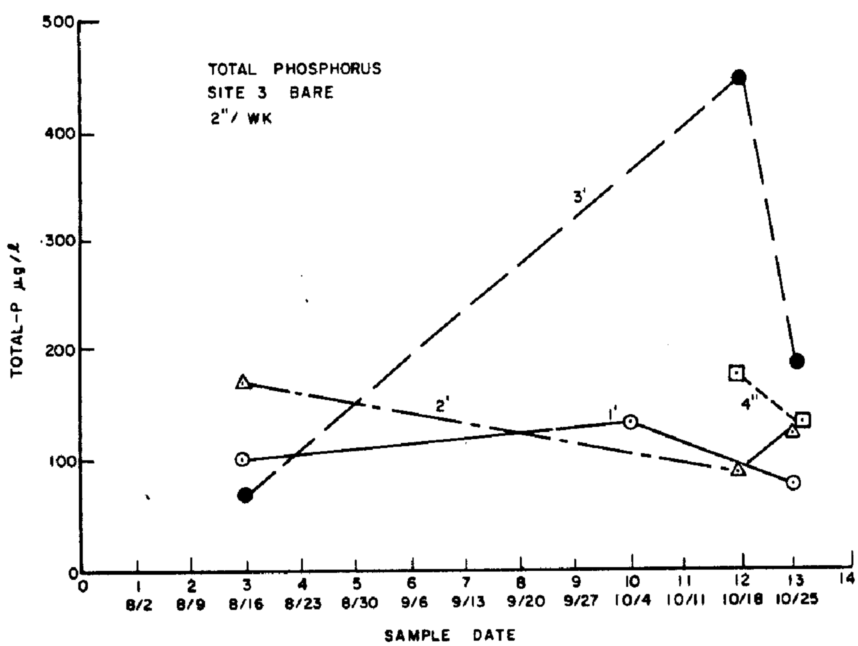
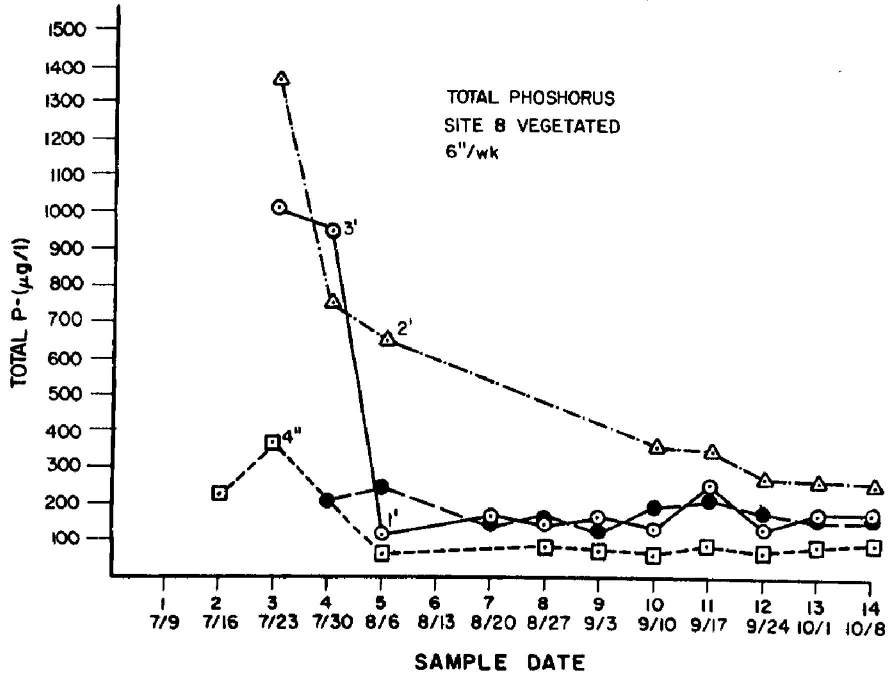


Figure B-36. Total phosphorus-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1975.



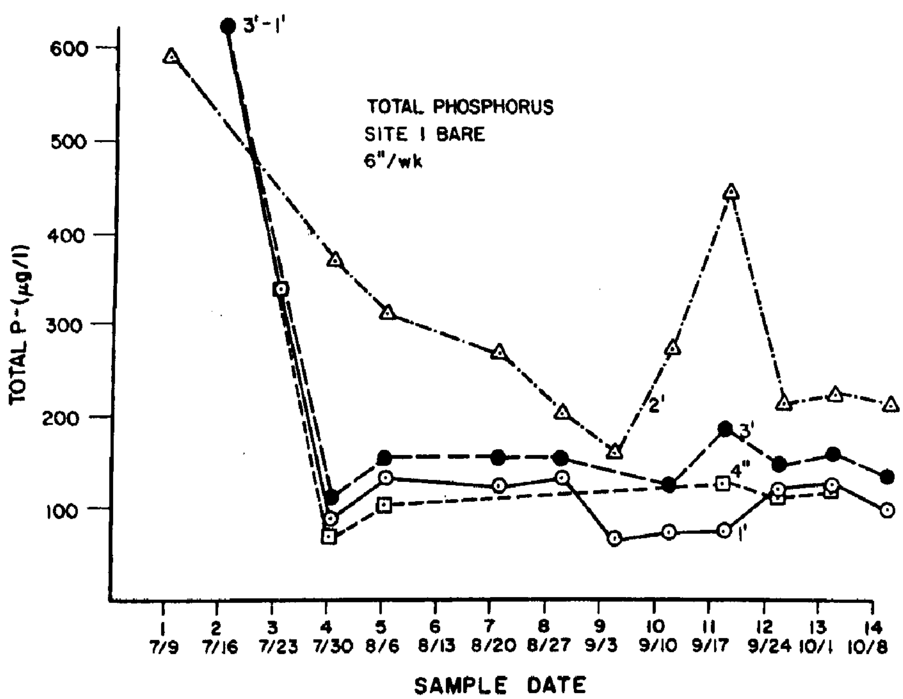
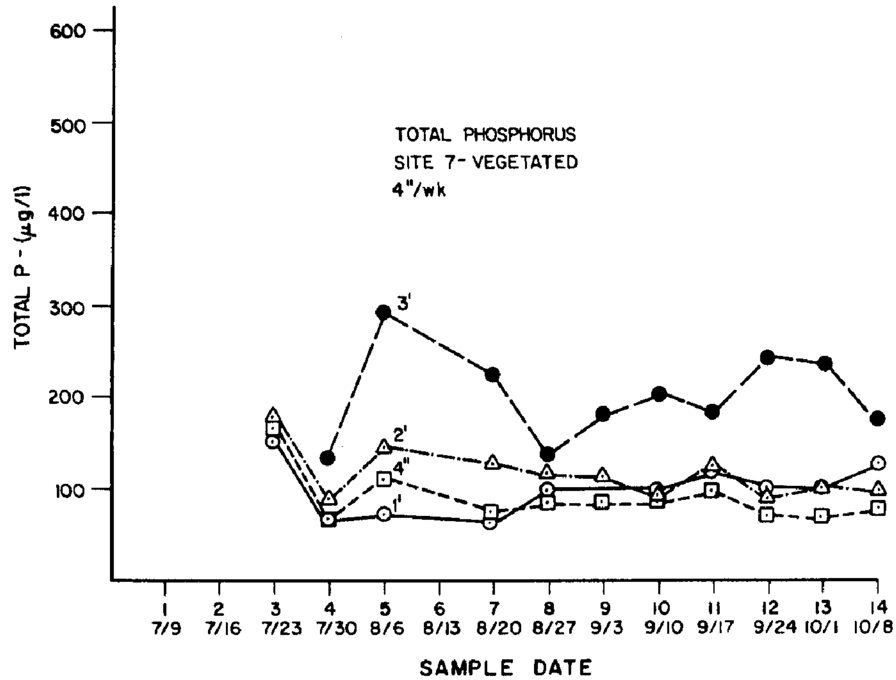


Figure B-37. Total phosphorus concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1976.



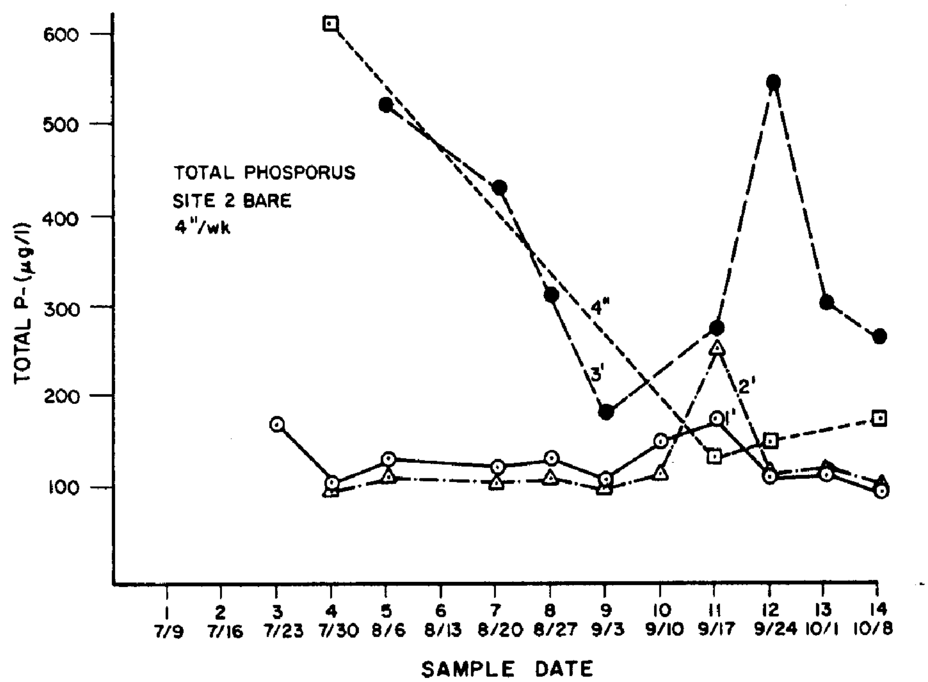


Figure B-38. Total phosphorus concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.

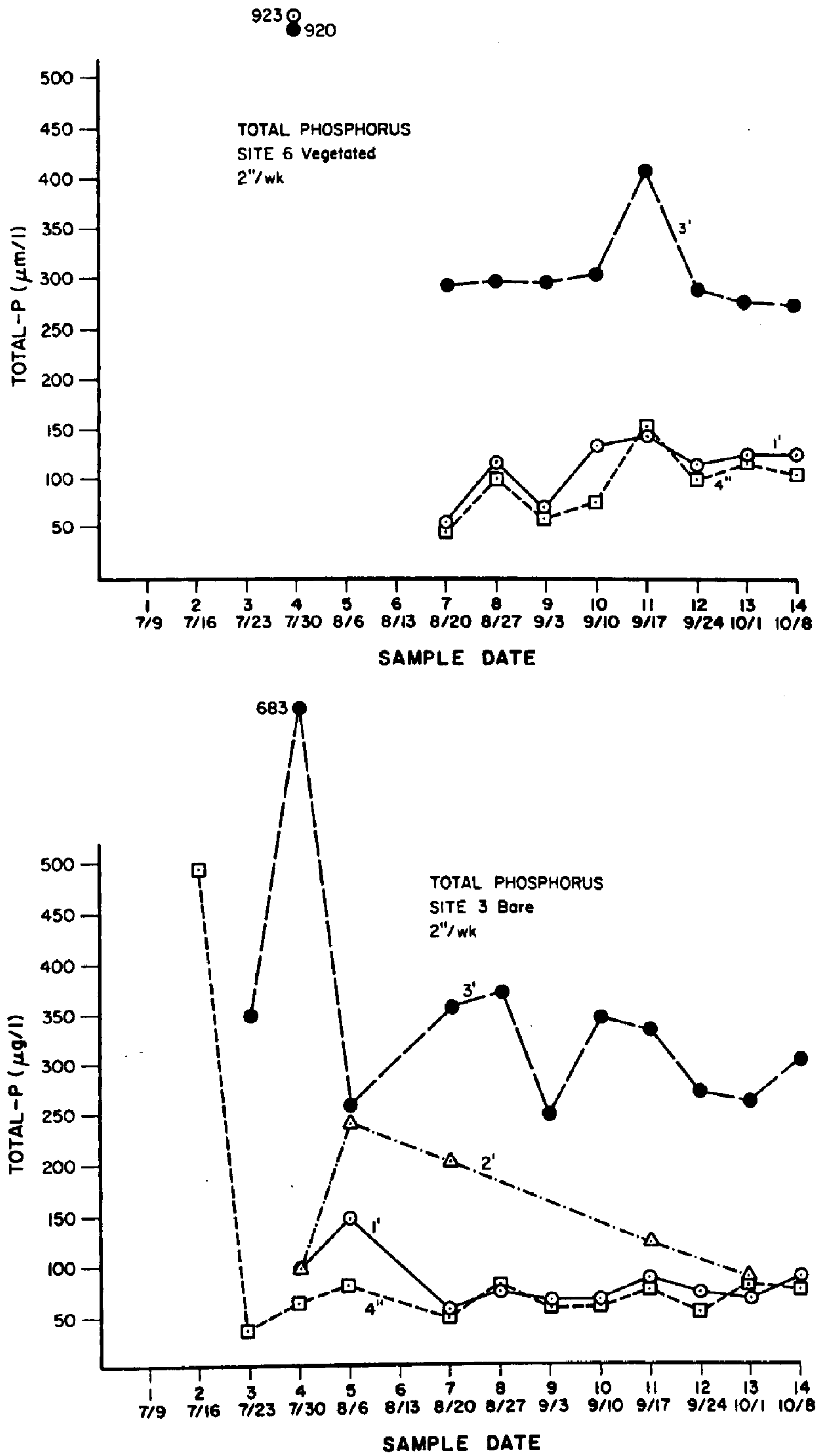


Figure B-39. Total phosphorus concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1976.

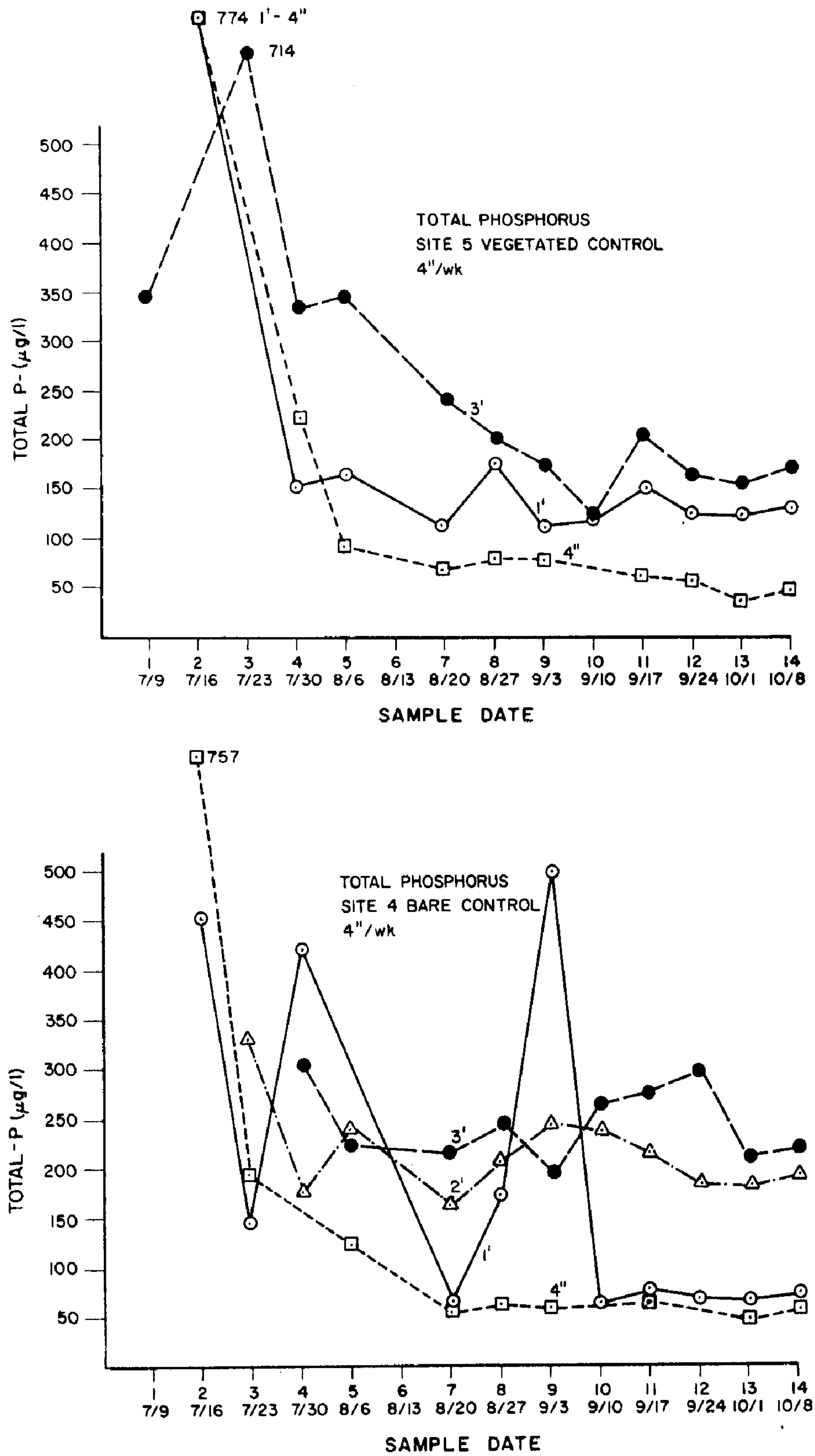
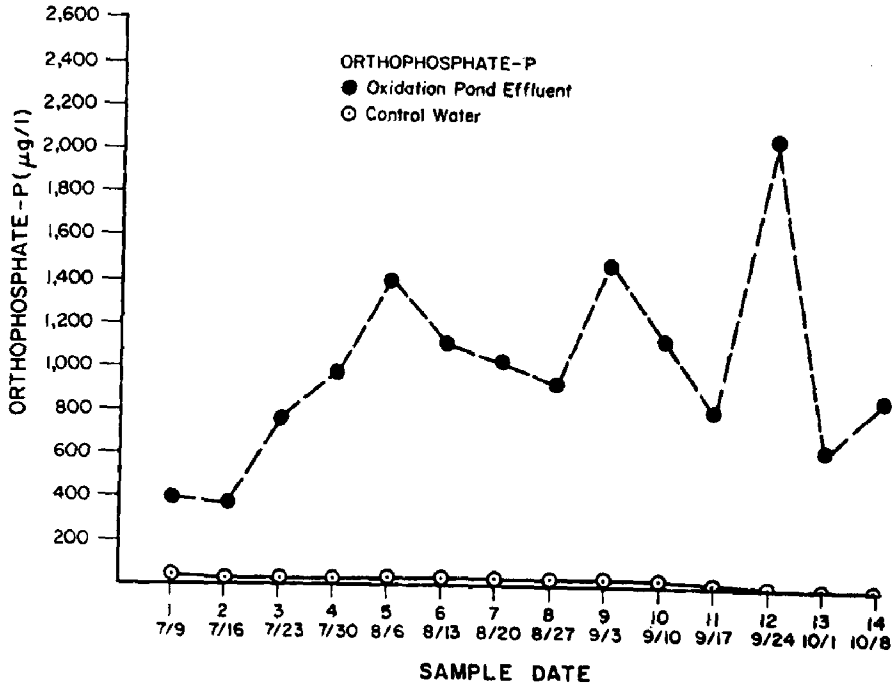


Figure B-40. Total phosphorus concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.



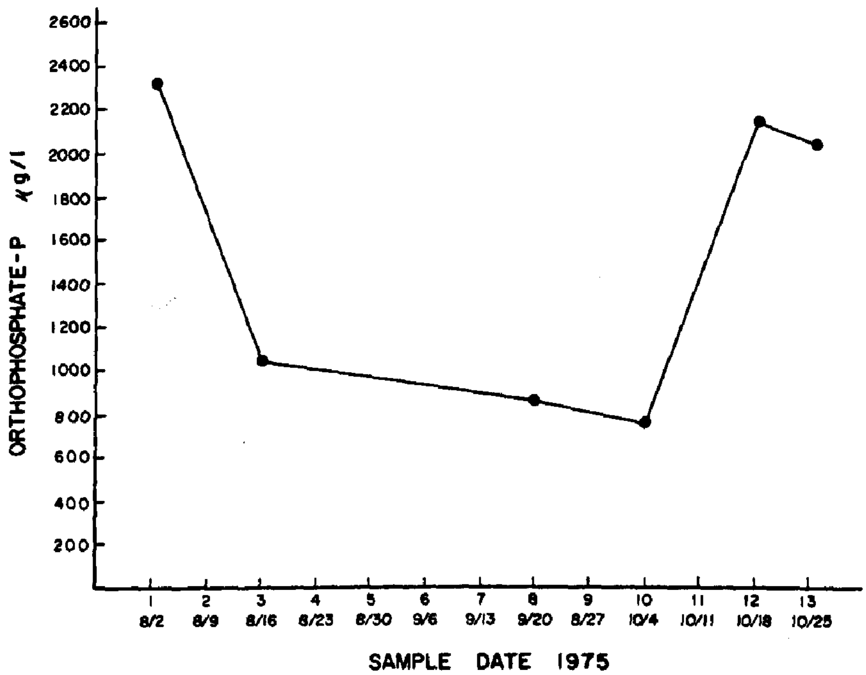
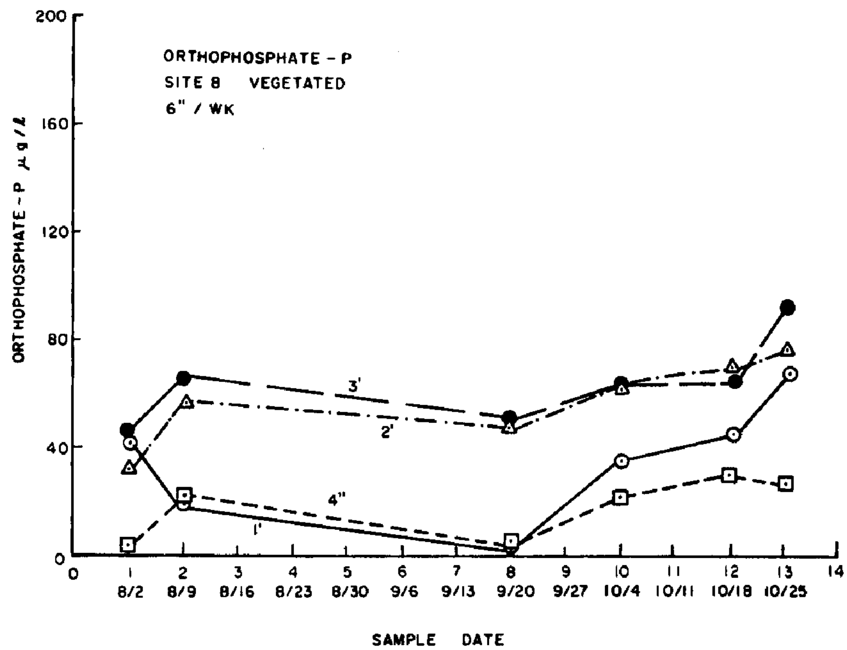


Figure B-41. Orthophosphate-P concentrations in the stabilization pond effluent and control water during 1976 (above) and orthophosphate-P concentrations in the stabilization pond effluent during 1975 (below).



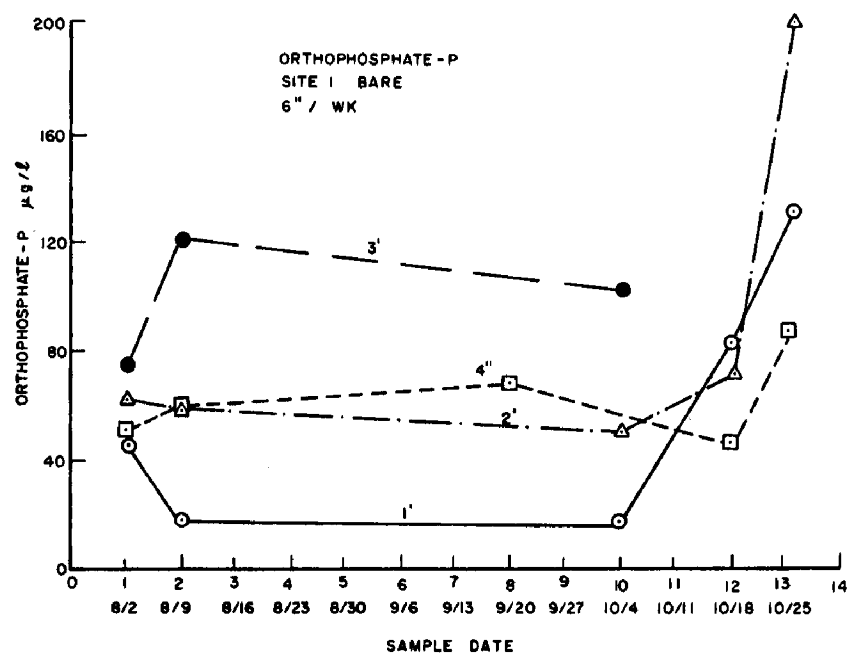


Figure B-42. Orthophosphate-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1975.

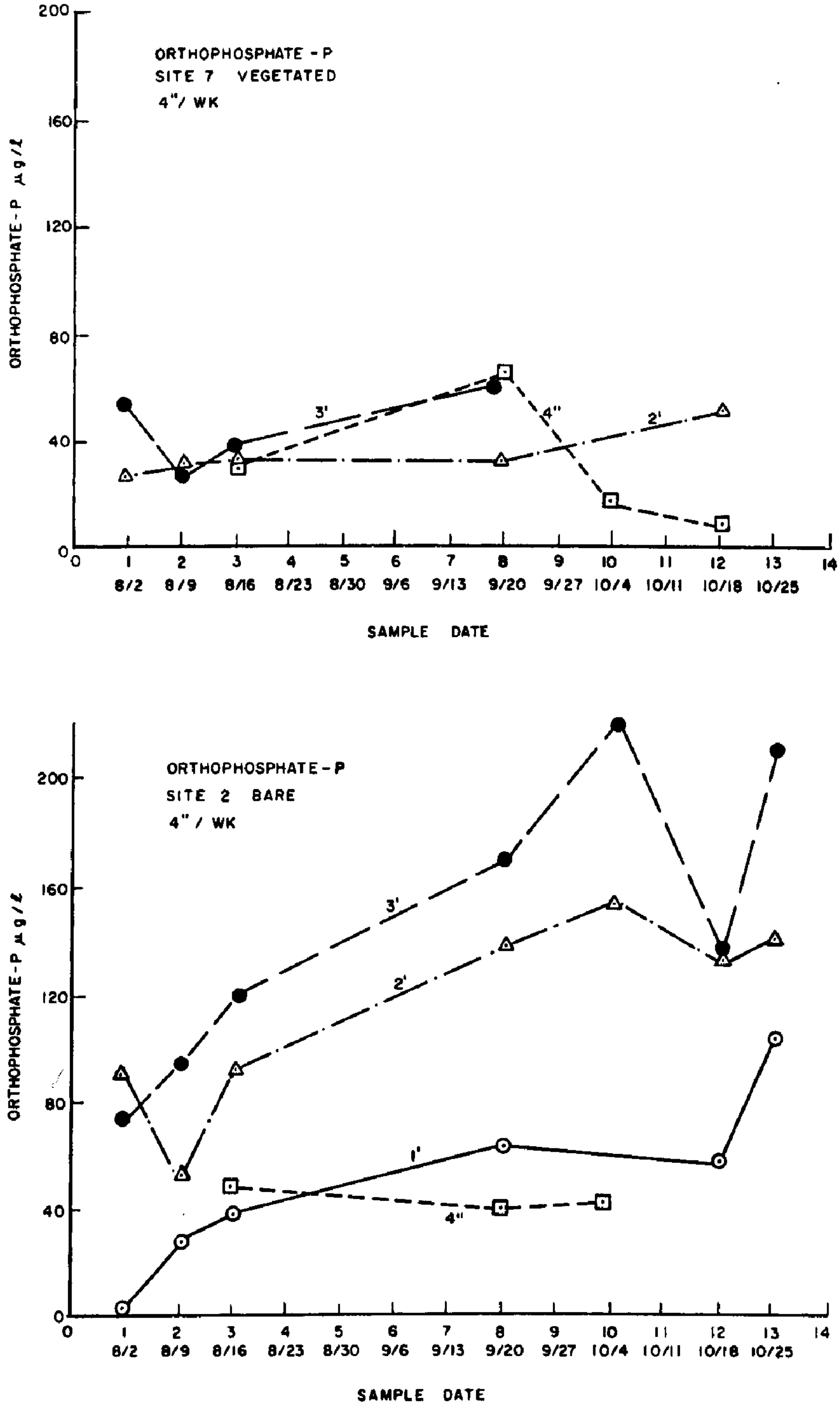


Figure B-43. Orthophosphate-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1975.

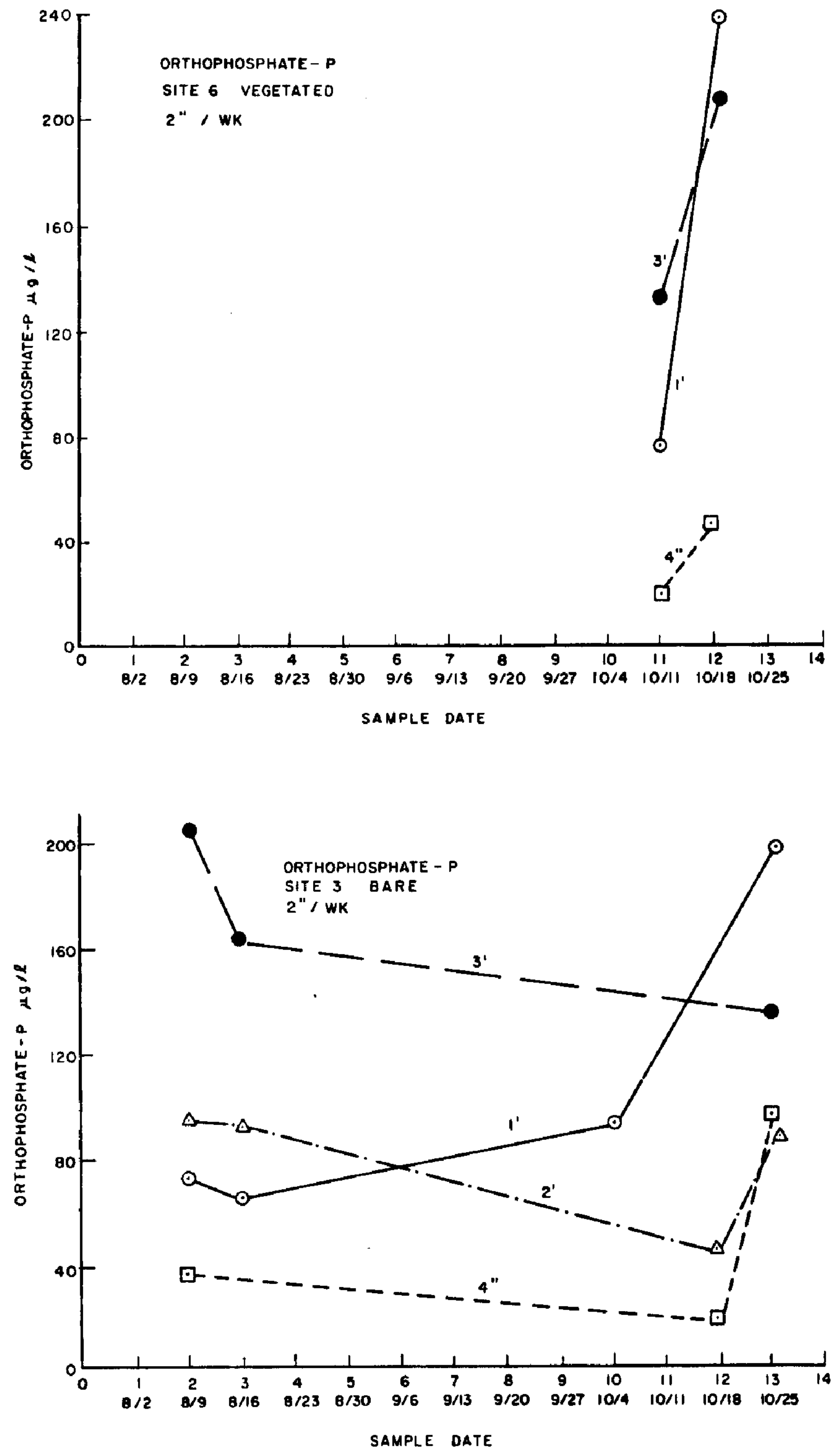
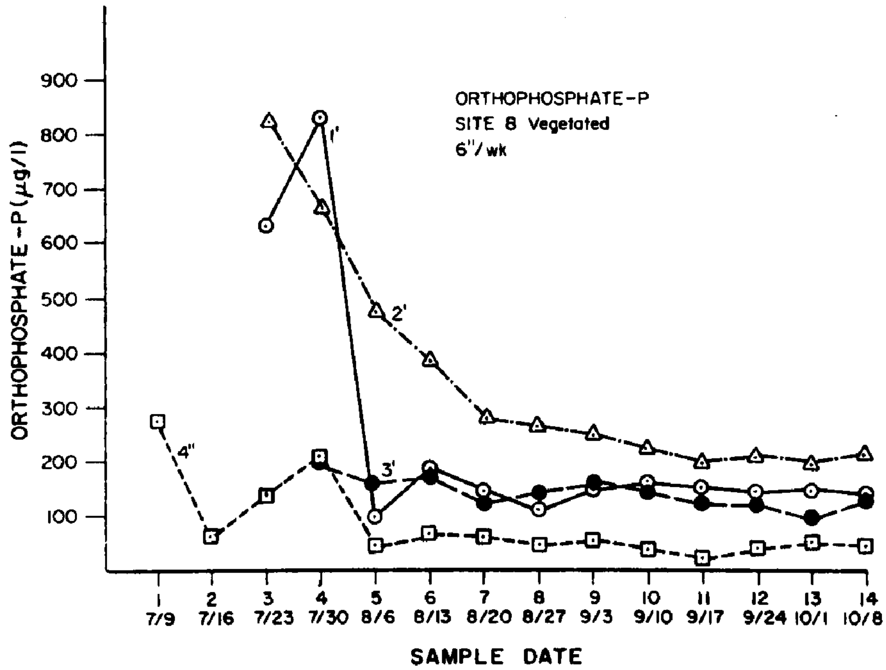


Figure B-44. Orthophosphate-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (2 in.) per week irrigation application rate during 1975.



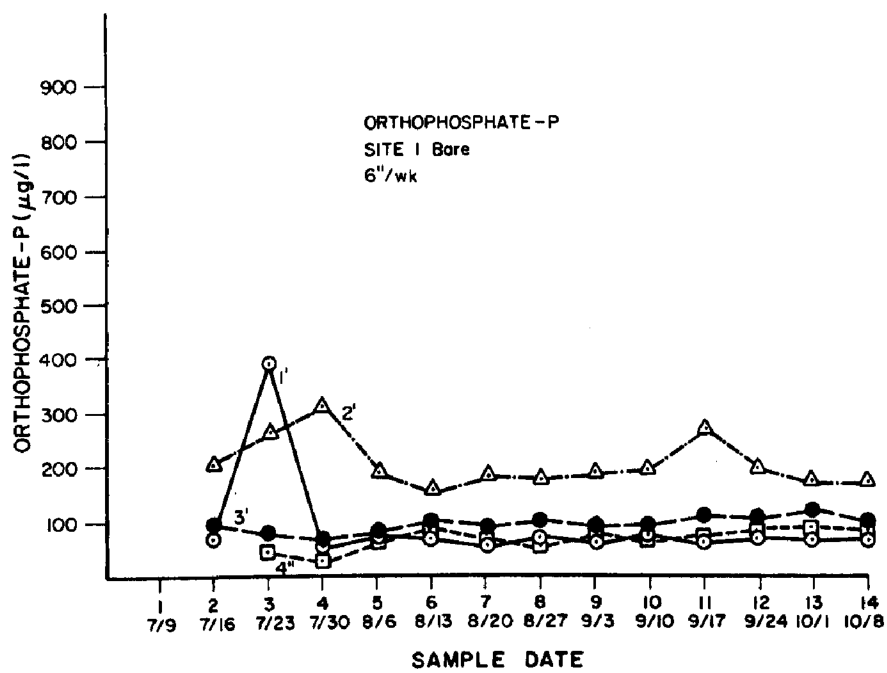
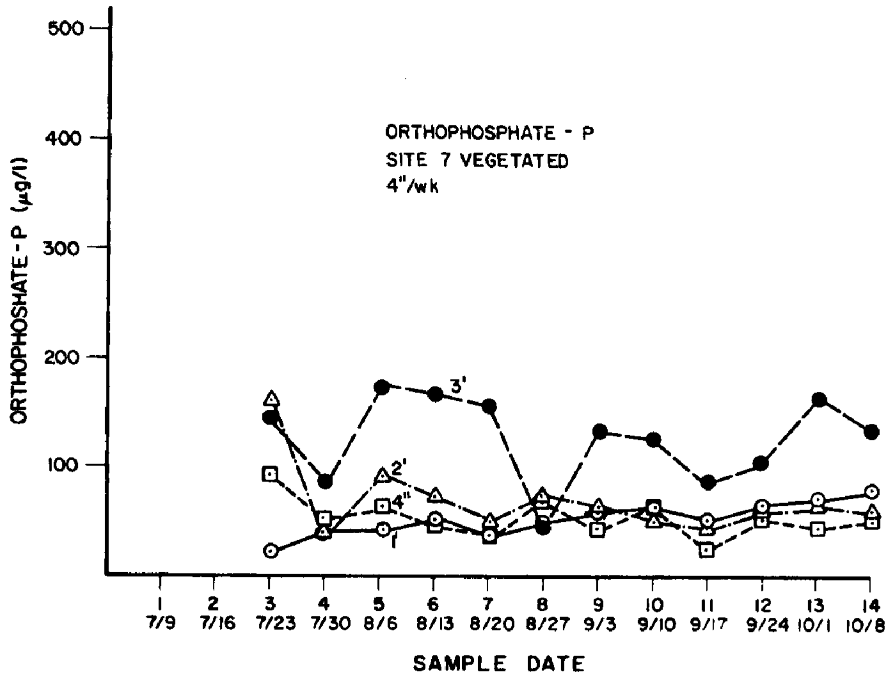


Figure B-45. Orthophosphate-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 15.2 cm (6 in.) per week irrigation application rate during 1976.



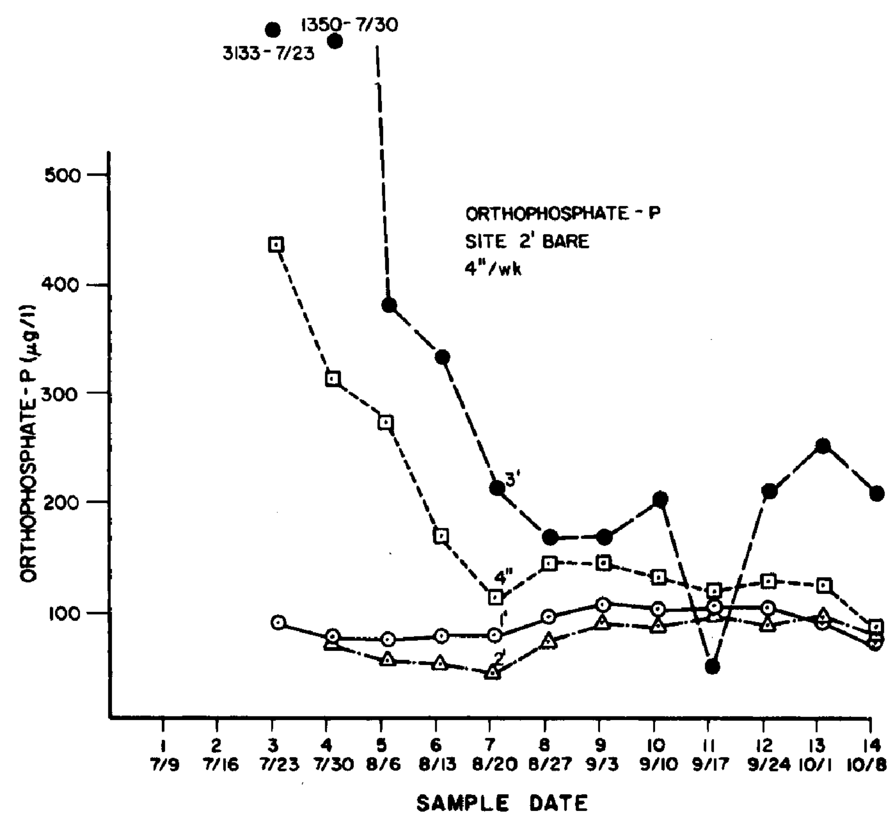
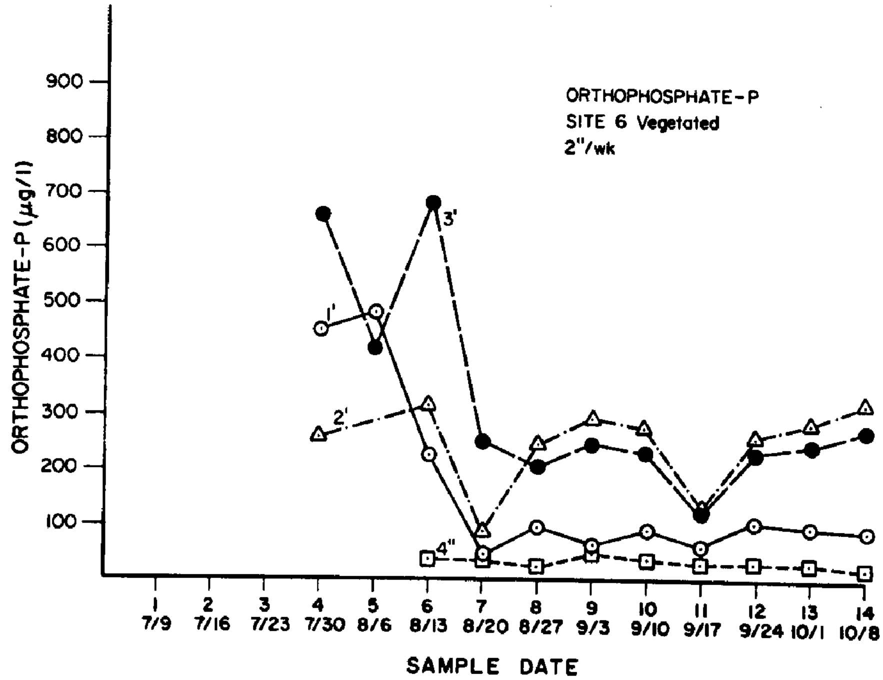


Figure B-46. Orthophosphate-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.



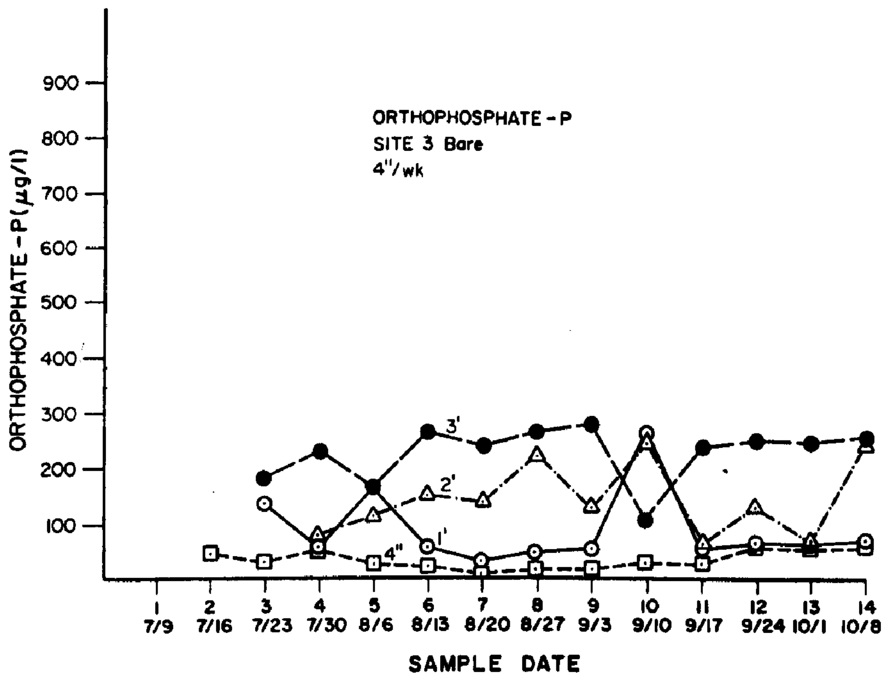
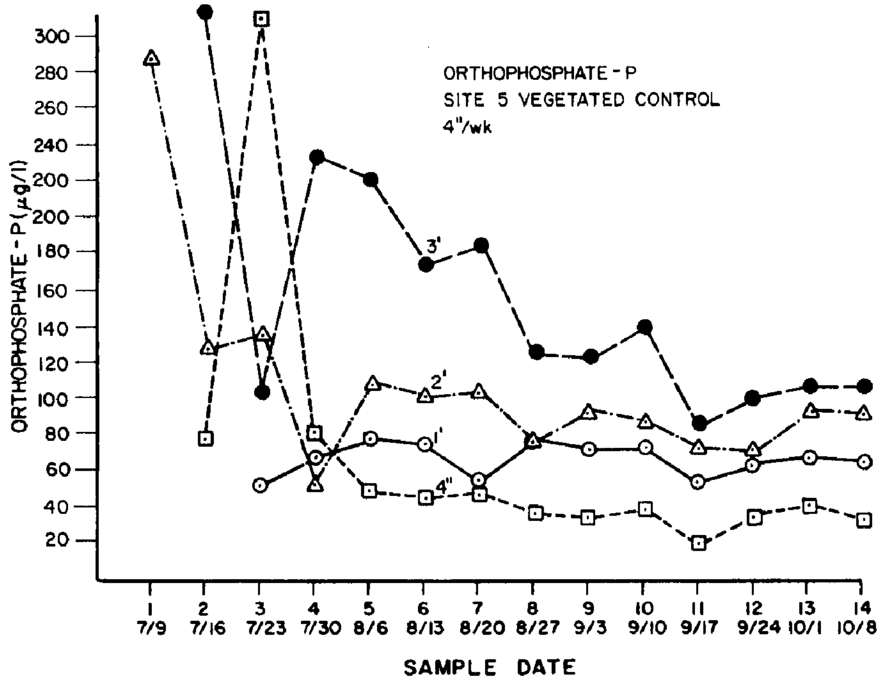


Figure B-47. Orthophosphate-P concentrations in the soil mantle treated stabilization pond effluent at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 5.08 cm (6 in.) per week irrigation application rate during 1976.



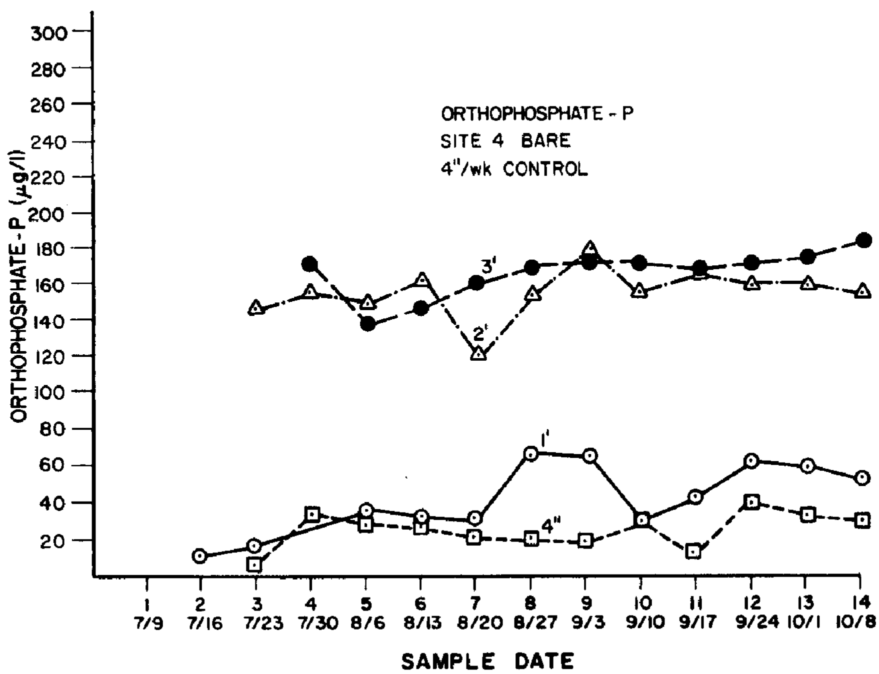


Figure B-48. Orthophosphate-P concentrations in the soil mantle treated control water at 10.2 cm (4 in.), 30.5 cm (1 ft.), 61.0 cm (2 ft.), and 91.4 cm (3 ft.) depths in the soil profile on vegetated and bare sites using a 10.2 cm (4 in.) per week irrigation application rate during 1976.

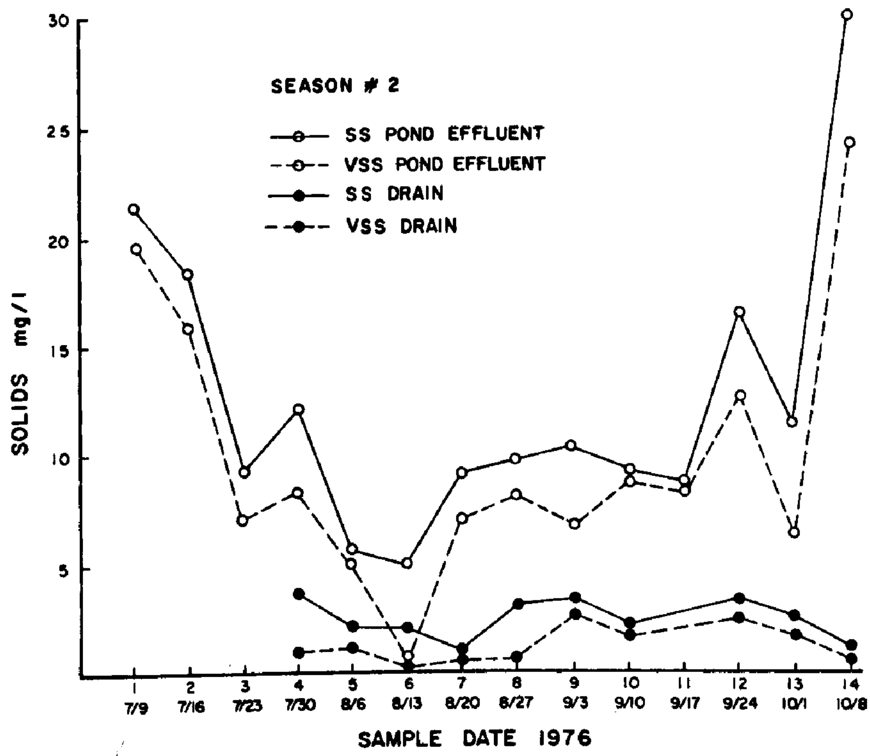


Figure B-49. Suspended and volatile suspended solids concentrations in the mole drain effluent from the eight experimental sites.

APPENDIX C

SPRAY IRRIGATION ECONOMIC ANALYSIS

The program for the economic analysis of spray irrigation will analyze solid set, on the ground, and center pivot systems. It is assumed that the system operates 24 hours a day as any waste disposal plant does. Output will plot cost in dollars vs. MGD treated and generates three curves per graph that correspond to three application rates (inches/acre/day) that was fed in with the data. Three graphs are generated for each data set: yearly operational costs, yearly ownership costs, and total yearly costs.

The computer plot routine dimensions the ordinate and abscissa based on the largest number generated. The graphs were designed to depict order of magnitude estimates of costs. The program also produces a table of values which can be used for more specific estimates of ownership costs, operation costs, and total costs.

PROGRAM GUIDE FOR ECONOMIC ANALYSIS OF SPRAY IRRIGATION SYSTEMS UTILIZED IN THE TREATMENT OF WASTEWATER STABILIZATION POND EFFLUENTS

<u>Program Variable Terminology</u>

Q MIN	Minimum flow (MGD)
Q MAX	Maximum flow (MGD)
AP	Application rate (inches/day) 3 rates for each data set
FC	Fuel cost ($/kw)
FCON	Fuel consumption (bhp-hrs/kw)
OC	Oil cost ($/gal)
OCON	Oil consumption (bhp-hrs/gal)
CPU	Cost of power unit maintenance ($/bhp-hr)
CIEQ	Cost of irrigation equipment ($/acre)
CRMAN	Cost of reservoir maintenance ($/hr)
EFFM	Labor requirement to run the system (hr/acre/day)
WAGE	Hourly wage of system labor ($/hr)
CHAR	Cost of harvesting ($/acre)
SFL	Standard friction loss (ft. of water)

HPY	Harvests per year
WCPA	Worth of crop per acre ($/acre)
ISW	Program indicator: (0 = solid set 1 = center pivot)
ISPF	Installation of sprinkler system per ft. ($/ft.)
IDPF	Installation of drainage system per ft. ($/ft.)
CW	Hazen-Williams coefficient
D	Diameter of the pipe (ft.)
RINT	Interest rate (in percent)
RLE	Reservoir life expectancy (yrs)
PMTLE	Pump, motor, transmission life expectancy (yrs)
PLE	Pipe life expectancy (yrs)
CPPA	Cost of pipe per acre ($/acre)
PTLE	Pipe trailer life expectancy (yrs)
CPT	Cost of pipe trailer ($)
SPLE	Sprinkler life expectancy (yrs)
CPASP	Cost per acre for sprinkler ($/acre)
DSLE	Drainage system life expectancy (yrs)
CPADS	Cost per acre of the drainage system ($/acre)
CISPDS	Cost of installation of sprinklers and drainage system per acre ($/acre)
PC	Cost of land out of production due to its use as treatment for lagoon effluent ($/acre)
LCPA	Cost to buy the land per acre ($/acre)
FLPA	Friction loss per acre--3 friction losses are read in--one for each application rate

Solid Set or on the Ground

When the program indicator (ISW) = 0 the following routine will be followed to calculate costs for a solid set system. Costs for an on the ground system is calculated by substracting the in the ground costs from the value obtained for the solid set system.

$$\text{ACR (acres)} = \frac{Q}{\text{AR (application rate) (0.0271583)}}$$

0.0271583 MG = 1 acre-inch of water

TFL (total friction loss) = (ACRES X FLPA) + SFL

FLPA = Friction loss per acre

SFL = Standard friction loss (discharge pressure, riser height, etc.)

$$P \text{ (horsepower)} = \frac{Q \times 694 \times TFL}{2660}$$

$$HP = \frac{Q \text{ (gpm) } H \text{ (ft.)}}{4000 \text{ (Drive eff.) (pump eff.)}} = \frac{Q \left(694 \frac{gpm}{mgd}\right) (TFL)}{2660}$$

Drive eff. = 0.7   Pump eff. = 0.95

CRM = Cost of repair and maintenance

CRM = 0

$$CRM = CRM + P \times 8760 \times \frac{FC}{FCON}$$

$$CRM = CRM + HP \times 8760 \frac{hrs}{yr} \times \frac{\$/kw}{\frac{bhp\text{-}hrs}{kw}}$$

$$CRM = CRM + P \times 8760 \times \frac{OC}{OCON}$$

$$CRM = CRM + HP \times 8760 \frac{hrs}{yr} \times \frac{\$/gal}{\frac{bhp\text{-}hrs}{gal}}$$

CRM = CRM + P x 8760 x CPU

$$CRM = CRM + HP \times 8760 \frac{hrs}{yr} \times \$/bhp\text{-}hr$$

CRM = CRM + 0.005 x CIEQ x ACRES

CRM = CRM + 0.005 x $/ACRE x ACRES

CIEQ = Capital cost of sprinklers, pipe, and drainage

CRM = CRM + 80 x CRMAN

CRM = CRM + 80 x $/hr

It is assumed only 80 hrs a year are required for maintenance.

CRM = CRM + EFFM x 365 x ACRES x WAGE

$$CRM = CRM + hr/acre/day \times \frac{365 \text{ days}}{yr} \times ACRES \times \$/hr$$

CRM = CRM + CHAR x ACRES x HPY

$$CRM = CRM + \$/ACRE \times ACRES \times \frac{harvest}{yr}$$

Plot CRM vs. Q (Annual operational costs)

T = 0

T = T + RIN (I,IFUN2(RLE)) x 4951. x (IQ)

T = T + INTEREST FACTOR x $4951/MGD x Q MGD

RIN(I,IFUN2(RLE)) - Selects the interest factor from the program. The table this information is derived from will be shown in the data section.

The capacity of the reservoir is assumed equal to one day's flow. The cost of a reservoir is $\$1.00/yd^3$ and 4951 yd^3 is equal to a million gallons.

T = T + RIN (I,IFUN2(PMTLE)) x 45 x P

T = T + INTEREST FACTOR x \$45/HP x HP

Pump, motor and transmission run approximately \$45/horsepower.

T = T + RIN(I,IFUN2(PLE)) x CPPA x ACRES

T = T + INTEREST FACTOR x \$/ACRE x ACRES

T = T + RIN(I,IFUN2(PTLE)) x CPT

T = T + INTEREST FACTOR x \$/TRAILER

T = T + RIN(I,IFUN2(SPLE)) x CPASP x ACRES

T = T + INTEREST FACTOR x \$/ACRE x ACRES

CPASP - Capital cost of piping and sprinkler/acre

T = T + RIN(I,IFUN2(DSLE)) CPADS x ACRES

T = T + INTEREST FACTOR x \$/ACRE x ACRES

CPADS - Capital cost of drainage system/acre

T = T x 1.01

1% of capital cost is considered the yearly cost of taxes and insurance.

T = T + CISPDS x ACRES ÷ 20

CISPDS = Installation cost of sprinklers, pipe and drainage per acre.

The cost is spread over 20 years which is the design life of the system.

T = T + PC x ACRES

PC is dollar value per acre of the crop that was grown on the land before the treatment scheme was installed.

T = T + LCPA x ACRES ÷ 20

LCPA = Cost of land acquisition per acre (Interest must be included)

20 years is the design life of the system.

Plot T vs. Q (yearly operational costs)

WORTH = WCPA x ACRES x HPY

WORTH = Total yearly dollar value of crop grown

WCPA = Worth of the crop per acre

HPY = Harvests per year

TOTAL COST = CRM + T - WORTH

Plot TOTAL COST vs. Q (total yearly costs)

Center Pivot System

When ISW = 1 this routine is followed:

DD4 = D ÷ 4

This estimates DD4 as the hydraulic radius of the pipe.

ACR(ACRES) = Q/(AR*0.0271583)

Q is MGD

AR is application rate in inches-acre-day

0.0271583 is 1 acre-inch in million gallons

(π) Pi = 3.1416

$$V = \frac{Q(0.1337)\ (12.37)}{\pi\left(\frac{d^2}{4}\right)}$$

$$S = \frac{V}{1.318 \times C_w \times (DD4)^{0.63}}$$

$$S = \text{POWER}\ (S,\ 1.85)$$

This is a form of the Hazen-Williams equation

$$V = 1.318\ C_{hw} R_h^{\ 0.63}\ S^{0.54}$$

Put V in fps from MGD $$V = \frac{Q\left(0.1337\ \frac{ft.^3}{gal}\right)\ 10^6\ \frac{gal}{day}}{\pi\left(\frac{d^2}{4}\right)\ 86400\ \frac{sec}{day}}$$

$$S^{0.54} = \frac{Q(MGD)(V)}{1.318\ C_{hw} R_h^{\ 0.63}} \qquad C = \frac{V}{1.318}$$

$$S = \left(\frac{Q(C)}{C_w\ (DD4)^{0.63}}\right)^{1.85}$$ S is system headloss in Ft/Ft

Since most of the discharge in a center pivot system occurs nearer the periphery, S will be assumed constant throughout the radius of the pivot.

R = SQRT(ACR(IA,IQ)*43500/3.1416)

R is the radius of the pivot in feet

AREA = ACRES x 43500 $ft.^2$/ACRE = πR^2

R^2 = ACRES x 43500/π

$$R = \sqrt{\frac{\text{ACRES} \times 43500}{\pi}}$$

TFL = (R * S) + SFL

Total Headloss = S(loss in $\frac{ft.}{ft.}$) x R (ft. in system)

+ standard loss (discharge pressure, height of sprinkler, etc.)

$$P \text{ (horsepower)} = \frac{Q \times 694 + TFL}{2660}$$

$$HP = \frac{Q\text{ (gpm) } H\text{ (ft.)}}{4000\text{ (Drive eff.) (pump eff.)}} = \frac{Q\left(694\ \frac{gpm}{mgd}\right) TFL}{2660}$$

Drive eff. = 0.7 Pump eff. = 0.95

CRM = Cost of repair and maintenance

CRM = 0

$$CRM = CRM + P\ (8760) \times \frac{FC}{FCON}$$

$$CRM = CRM + HP \times 8760\ \frac{hrs}{yr} \times \frac{\$/kw}{\frac{bhp\text{-}hrs}{kw}}$$

$$CRM = CRM + P\ (8760) \times \frac{OC}{OCON}$$

$$CRM = CRM + HP\ (8760\ \frac{hr}{yr}) \times \frac{\$/gal}{\frac{bhp\text{-}hrs}{gal}}$$

CRM = CRM + P (8760) x CPU

CRM = CRM + HP (8760 $\frac{hr}{yr}$) x \$/bhp-hr

CRM = CRM + 0.005 x CIEQ x R

R is the radius of the pivot system in ft.

CIEQ is in \$/ft of the pivot system

CRM = CRM + 80 x CRMAN

80 hrs is assumed the annual labor needed to maintain the reservoir

CRM = CRM + EFFM x 365 x ACRES x WAGE

EFFM = Efficiency of farm maintenance hr/acre/day

WAGE = \$/hr

Y = CRM + CHAR x ACR x HPY

CHAR - Cost of harvesting

HPY - Harvests per acre

Plot Y vs. X or \$ vs. Q in MGD (yearly operational costs)

T = 0

T = T + RIN(I,FUN2(RLE)) x 4951 x Q

RIN(I,FUN2(RLE))--Selects the interest factor from the program. The table that this information is derived from will be shown in the data section.

Reservoir capacity is assumed equal to one day's flow. The cost of a reservoir 1.00/yd^3 and 4951 yd^3 is equal to a million gallons.

T = T + RIN(I,FUN2(PLE)) x CPPA x R

T = T + INTEREST FACTOR x \$/ft x ft

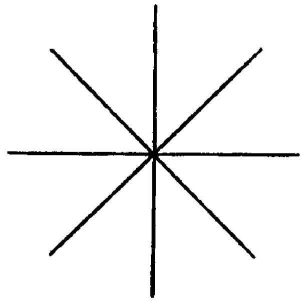
CPPA is expressed in $/ft. because this is more practical in the rotational system. This includes cost of pump-motor, etc.

T = T + RIN(I,IFUN2(PTLE))·CPT

T = T + INTEREST FACTOR x $/TRAILER

T = T + RIN(I,IFUN2(DSLE))·CPADS x 8 x R

T = T + INTEREST FACTOR · $/FT x 8 x FT



A circular drainage system is planned. Therefore, total footage will be 8 times that of the radius. CPADS is expressed in $/ft.

T = T 1.01

1% of total capital cost is assumed for yearly taxes and insurance.

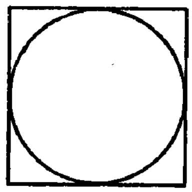
T = T + (R x ISPF + 8 x R x IDPF)/20

T = T + (FT x $/FT + 8 x FT x $/FT)/20

The cost of sprinkler installation and the cost of drainage installation are spread over 20 yrs.

AACRES = (2 x R xx 2)/43500

This calculation figures the number of acres actually needed for the system if you are forced by buy square sections of land.



The area of the circle is ACR-ACRES

The area of the square is AACRES

T = T + PC x AACRES

T = T + $/ACRE x AACRES

PC = Production worth of the land now used in the treatment scheme

T = T + LCPA x AACRES/20

This distributes the cost of the land of 20 yrs which is the design life of the system.

Plot T vs. Q (MGD) (annual ownership costs)

WORTH = WCPA x ACRES·HPY

$/YR = $/ACRE x ACRES x $^{x/}$yr

WORTH is the annual value of the crop under spray irrigation.

COST = T + Y - WORTH

COST is the sum of ownership and operation--the return of the worth of the crop.

Plot COST vs. Q (MGD) (annual total cost)

Basic Data Used in Economic Analysis

* Fuel Cost (FC) was assumed $0.05/kwh

This accounts for the power consumed as well as the necessary transformer costs to step the power to three phase from the Logan City power lines.

* Fuel Consumption (FCON) (This is from the University of Mo. Extension.)

TABLE 1
Fuel Consumption (bhp-hrs. per unit of fuel)[1]

Fuel	Average[2]	Standard[3]
Diesel	12.5 per gallon	14.6
Gasoline	10.0 per gallon	11.5
Propane	8.0 per gallon	9.2
Natural Gas	8.0 per 100 cu. ft.	8.9
Electric	1.03 per kw.-hr.	1.18[4]

[1]To estimate fuel used per hour, divide continuous brake horsepower by the bhp-hrs/unit of fuel. For example, 60 bhp/10 bhp-hrs/gal = 6 gallons/hour.

[2]Denotes the average of a large number of irrigation pumping units tested by the University of Nebraska. Use these figures for estimating pumping costs over the live of the system.

[3]Nebraska Irrigation Pumping Test Standard. Pumping units that are new or in excellent condition and adjustment should maintain this standard.

[4]1 hp = 746 watts, 1 kwh = 1.34 hp-hr, assuming the electric motor is 100% efficient. As 88% efficient is more realistic, 0.88 x 1.34 = 1.18.

* Oil Cost (OC) $2/gal--This assumes the use of rerefined oil.

* Oil Consumption (OCON) (University of Mo. Extension.)

Oil Consumption

Type Engine	bhp-hrs. per gallon of oil
Gasoline, tractor fuel, diesel	900
Propane, natural	1000
Electric	9000
Right angle gear drive	5000

* Cost Power Unit Maintenance (CPU)

Since motor costs are calculated on a basis of \$/hp, it is impossible to say how many motors would require \$10/yr.

Power Unit Repairs and Maintenance

Type Engine	Cost per bhp-hr
Gasoline, tractor fuel	\$.0016
Propane, natural gas	\$.0012
Diesel	\$.0019
Electric motor is assumed to be \$10.00 per year	

Therefore, $\$4.5 \times 10^{-5}$/bhp-hr is used, that is $\$10/8760 \frac{hr}{yr} \times 25$ hp.

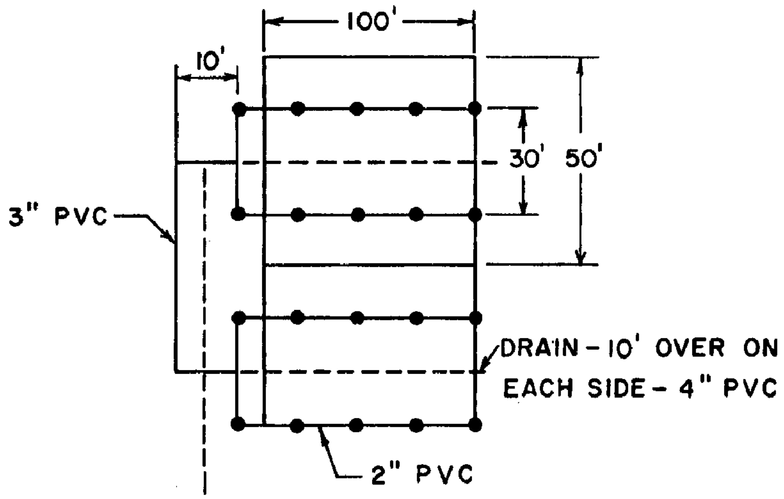
25 hp is the basis for our \$/hp figure which is shown later.

* Cost of Irrigation Equipment (CIEQ)

A percentage (1/2) of this cost is used to figure the repair and maintenance cost. Included is the cost of sprinklers, pipe and drainage but not their installation costs.

Solid set and on the ground

(This is figured in \$/acre.)



1 Pipe set sprays
5000 ft.^{2} in each set:
290' - 2" PVC
60' - 3" PVC
10 sprinklers on
6' risers
170' - 4" PVC

2" PVC at \$.32/ft. x 290 ft.	=	\$ 92.80
3" PVC at \$.65/ft. x 60 ft.	=	39.00
4" PVC at \$.60/ft. x 170 ft.	=	102.00
10 sprinklers at \$5.50 ea.	=	55.00
		\$288.80

$$\frac{43500 \text{ ft.}^2/\text{ acre}}{5000 \text{ ft.}^2/\text{pipe set}} = 8.7 \text{ pipe sets/acre}$$

8.7 x 288.80 = \$2572.56/acre CIEQ

Center Pivot

$28,000 for 1/4 mile of equipment--excluding motor

$21.21/ft. CIEQ

* Cost of Reservoir Maintenance (CRMAN)

$3/hr for all cases

* Labor Requirements to Run the System (EFFM)

(.05 hrs/acre/day was adopted for both the solid set and center pivot)

Labor Requirements

Equipment	Hours Labor Per Acre Per Application
Traveling gun sprinkler	.25[1]
Boom sprinkler	.78
Towline sprinkler	.54
Side-roll sprinkler	.55
Center pivot sprinkler	
135 acre size	.05[2]
35 acre size	.07[3]
Grated pipe	.60[4]
Handy carry portable sprinkler	.92
Solid set sprinkler	[5]

[1]This assumes four man-hours of labor plus one hour of supervision per day for a sprinkler covering 20 acres per day (2 sets). A system with buried pipe and a hose reel requires approximately one hour of labor per set plus one-half hour supervision per set.

[2]This requirement is without moving time. This is two hours per revolution for lubrication, adjustment, etc. plus two hours supervision per day. Moving requires eight man-hours.

[3]This requirement is without moving time. This is one hour per revolution for lubrication, adjustments, etc. plus one and one-half hours per day supervision. Moving requires six man-hours.

[4]This requirement is for systems requiring some pipe moving, and no tailwater pits. A system utilizing a tailwater return pump and no pipe moving should require approximately two-tenths hours/acre/application.

[5]These systems can be completely automated. One hour of supervision per day is generally sufficient.

* Hourly Wage of System Labor (WAGE)

$3/hr

* Cost of Harvesting (CHAR)

  $4/acre to cut grass
  $.56 to bale ea. bale → .25 x 25 → $14.00

  1.5 tons/acre at 60 lbs/bale → 25 bales

  $18.00/acre to harvest

* Standard Friction Loss (SFL)

  Assuming 6' risers for solid set
  Assuming 6' elevated pivot
  Discharge of 50 psi (115.5') for both
  SFL = 115.5 + 6 = 121.5'

* Harvests Per Year (HPY)

  3 mowings/year

* Worth of Crop Per Acre (WCPA)

  1.5 tons of grass/acre at $50/ton
  ∴ $75/acre

* I-Switch (ISW)

  0 - Solid Set 1 - Center Pivot

* Installation of Sprinkler Per Foot (ISPF)

  Solid Set - 0
  Center Pivot - $.65/ft.

* Installation of Drainage Per Foot (IDPF)

  Solid Set - 0
  Center Pivot - $2.00/ft. (includes gravel base)

* Hazen-Williams Coefficient (CW)

  Solid Set - 0
  Center Pivot - 120

* Diameter of Pipe (D) in feet

  0.833 ft.

* Interest Rate (RINT) in percent

  9

Life Expectancy and Interest Factors

Maximum Expected Life of Irrigation Equipment

Equipment	Years
Well	
Casing Gauge	
8	25+
10	25
12	15
Standard 3/16 in. wall thickness	25+

Equipment	Years
Pump	
Line Shaft Propellor	10
Turbine Pump	15
Centrifugal Pump	10-12
Power Unit	
Electric Motor	25
Diesel Engine	15
Natural gas, LPG, or propane	12
Tractor fuel, gasoline	10
Power Transmission Unit	
Gear Drive or Belt Head	12
Belts	6
Electric Switches, Natural Gas Lines, Fuel Tanks, and Land Plane	
Switch	20
Gas Line	
Iron	20
Plastic	18
Fuel Tank	
Propane	20
Diesel	18
Land Plane	15
Water Pipe and Pipe Trailer	
Underground Pipe	
Polyvinyl Chloride (PVC)	20
Steel	20
Asbestos Cement	25
Aboveground Pipe	
Rigid Plastic	15
Flexible Plastic (for Traveling Guns)	5
Steel	18
Aluminum	15
Pipe Trailer	10
Sprinkler System	
Solid Set	15
Hand Move	15
Side Roll	12
Skid Tow	10
Wheel Tow	10
Boom Type	10
Traveling-Big Gun	10-12
Center Pivot	10-15
Irrigation Reservoir	
Prairie Soils Under Cultivation, No Silting Basin	20
Prairie Soils Under Cultivation, With Silting Basin	30+

Annual Depreciation and Interest Cost Factors*							
Interest %	Cost Factors at Various Expected Years of Life						
	5	6	8	10	12	15	20
6	0.2300	0.1967	0.1550	0.1300	0.1133	0.0967	0.0800
6½	0.2325	0.1992	0.1575	0.1325	0.1158	0.0992	0.0825
7	0.2350	0.2017	0.1600	0.1350	0.1183	0.1017	0.0850
7½	0.2375	0.2042	0.1625	0.1375	0.1208	0.1042	0.0875
8	0.2400	0.2067	0.1650	0.1400	0.1233	0.1067	0.0900
8½	0.2425	0.2092	0.1675	0.1425	0.1258	0.1092	0.0925
9	0.2450	0.2117	0.1700	0.1450	0.1283	0.1117	0.0950
9½	0.2475	0.2142	0.1725	0.1475	0.1308	0.1142	0.0975
10	0.2500	0.2167	0.1750	0.1500	0.1333	0.1167	0.1000

*Cost factors are used to calculate total annual depreciation and interest, where depreciation = new cost divided by years of life, and interest = ½ new cost x current interest rate.

The program combines the interest rate and life expectancies to derive the interest factor from the above table which is stored in the program.

* Pump, Motor, Transmission Life Expectancy (PMTLE)

Since the above are purchased as a unit, they are considered to have the same life expectancy--15 yrs.

The cost of the above 3 items is figured at $45/HP and this figure is built into the program.

25 hp PMT costs $1125
∴ 1 hp = $45

PMTLE is 0 for center pivot.

* Pipe Life Expectancy (PLE)

20 yrs for solid set and center pivot

* Cost of Pipe Per Acre (CPPA)

Solid Set

2" - $.32/ft. x 290' = $92.80
3" - $.65/ft. x 60' = 39.00

$131.80 x 8.7 pipe sets = 1146.66/acre

Center pivot (this includes cost of motor, pump and piping to center)
28,000 for pipe + $8000/1/4 mile
$27.27/ft.

* Pipe Trailer Life Expectancy (PTLE)

10 yrs

* Cost of Pipe Trailer (CPT)

  $350.00

* Sprinkler Life Expectancy (SPLE)

  15 yrs

* Cost Per Acre for Sprinklers ($/acre) (CPASP)

  10 sprinklers/set x 8.7 sets/acre x 5.50 ea.
  $478.50/acre

  This is 0 for center pivot because the sprinklers are included with the pipe price.

* Drainage System Life Expectancy (DSLE)

  20 yrs

* Cost Per Acre of the Drainage System (CPADS)

  170'/set x $.60/ft. x 8.7 sets/acre = 887.40/acre

  Center Pivot - $.60/ft.

* Cost of Installation of Sprinklers and Drainage System (CISPDS)

  Solid Set
  SP (290' + 60') x $.65/ft. x 8.7 = $1979.25
  DR (170') x $2.00/ft. x 8.7 = $2958.00

  $4937.25/acre

  On the Ground
  SP (350') x $.05/ft. x 8.7 = $ 152.25
  DR (170') x 2.00/ft. x 8.7 $2958.00

  $3110.25/acre

  0 - Center Pivot
  Drainage installation includes gravel.

* Cost of Land Out of Production (PC)

  $0/acre--it is assumed the land is being reclaimed.

* Cost to Buy the Land for Use (LCPA)

  $600/acre

* Friction Loss Per Acre (FLPA)

  A head loss calculator is included

  Use Main line calculations for 3"
  Use Lateral calculations for 2"

  at 2"/ac/day
  2" pipe has .08' hl/100'
  or $\frac{.08}{100}$ x 230 x 8.7 = 1.6' hl/acre

  3" pipe has .036' hl/100'

or $\frac{.036}{100}$ x 60 x 8.7 = .187' hl/acre

allowing 2 psi/acre for elbows and miscellaneous losses
(2 psi = 4.61')

2"/ac/day has FLPA of 6.39'/acre

4"/ac/day has FLPA of 10.16'/acre

6"/ac/day has FLPA of 15.7'/acre

4" and 6" application rates' head loss are figured in the same manner.

Program Used to Calculate Economics

```
      REAL ISPF,IDPF
      REAL L(10)
      DIMENSION AP(3),ACR(3,21),P(3,21),X(23),Y(3,21)
      DIMENSION RIN(9,7),COST(3,21),OWN(3,21)
      DIMENSION F1(9),F2(9),F3(9),F4(9),F5(9),F6(9),F7(9)
      EQUIVALENCE (RIN(1),F1(1))
      EQUIVALENCE (RIN(10),F2(1))
      EQUIVALENCE (RIN(19),F3(1))
      EQUIVALENCE (RIN(28),F4(1))
      EQUIVALENCE (RIN(37),F5(1))
      EQUIVALENCE (RIN(46),F6(1))
      EQUIVALENCE (RIN(55),F7(1))
      DATA((F1(I),I=1,9)= .23,.2325,.235,.2375,.24,.2425,.245,.2475,.25)
      DATA((F2(I),I=1,9)=.1967,.1992,.2017,.2042,.2067,.2092,.2117,.2142
     C,.2167)
      DATA((F3(I),I=1,9)=.155,.1575,.16,.1625,.165,.1675,.17,.1725,.175
     C)
      DATA((F4(I),I=1,9)=.13,.1325,.135,.1375,.14,.1425,.145,.1475,.15)
      DATA((F5(I),I=1,9)=.1133,.1158,.1183,.1208,.1233,.1258,.1283,.1308
     C,.1333)
      DATA((F6(I),I=1,9)=.0967,.0992,.1017,.1042,.1067,.1092,.1117,.1142
     C,.1167)
      DATA((F7(I),I=1,9)=.08,.0825,.085,.0875,.09,.0925,.095,.0975,.1)
100   READ110,QMIN,QMAX,(AP(I),I=1,3)
110   FORMAT(5(F5.0))
      IF (QMIN.EQ.999)GO TO 999
      ISW=0
      READ(60,120)FC,FCON,OC,OCON,CPU,CIFQ,CRMAN,EFFM
      READ(60,125)WAGE,CHAR,SFL,HPY,WCPA,CW,D
      READ(60,130)ISW,ISPF,IDPF
120   FORMAT(8(F10.0))
125   FORMAT(7(F10.0))
130   FORMAT(I1,9X,2F10.0)
      NID=3
      NX=20
      QINC=(QMAX-QMIN)/NX
      NX=NX+1
      IF(ISW.EQ.1)GO TO 500
      DO 150 IA=1,3
      READ(60,135)FLPA
135   FORMAT(F5.0)
      AR=AP(IA)
      Q=QMIN
      DO 150 IQ=1,NX
```

```
      ACR(IA,IQ)=Q/(AR*0.0271583)
      TFL=(ACR(IA,IQ)*FLPA)+SFL
      P(IA,IQ)=Q*694.*TFL/2660.
      CRM=0.
      CRM=CRM+P(IA,IQ)*8760*FC/FCON
      CRM=CRM+P(IA,IQ)*8760*OC/OCON
      CRM=CRM+P(IA,IQ)*8760*CPU
      CRM=CRM+0.005*CIEQ*ACR(IA,IQ)
      CRM=CRM+80.*CRMAN
      CRM=CRM+EFFM*365*ACR(IA,IQ)*WAGE
      Y(IA,IQ)=CRM+CHAR*ACR(IA,IQ)*HPY
      X(IQ)=Q
      Q=Q+QINC
  150 CONTINUE
      GO TO 550
  500 CONTINUE
      DD4=D/4.
      DO 550 IA=1,3
      Q=QMIN
      AR=AP(IA)
      DO 550 IQ=1,NX
      ACR(IA,IQ)=Q/(AR*0.0271583)
      PIE=3.1416
      V=Q*.1337*12.73/(PIE*((D*D)/4.))
      S=V/(1.318*CW*POWER(DD4,.63))
      S=POWER(S,1.85)
      ACR(IA,IQ)=Q/(AR*.0271583)
      R= SQRT(ACR(IA,IQ)*43500./3.1416)
      TFL=(R*S)+SFL
      P(IA,IQ)=Q*694.*TFL/2660.
      CRM=0.
      CRM=CRM+P(IA,IQ)*8760.*FC/FCON
      CRM=CRM+P(IA,IQ)*8760.*OC/OCON
      CRM=CRM+P(IA,IQ)*8760.*CPU
      CRM=CRM+.005*CIEQ*R
      CRM=CRM+80.*CRMAN
      CRM=CRM+EFFM*365.*ACR(IA,IQ)*WAGE
      Y(IA,IQ)=CRM+CHAR*ACR(IA,IQ)*HPY
      X(IQ)=Q
      Q=Q+QINC
  550 CONTINUE
      READ(60,140)RINT
140   FORMAT(F5.0)
      READ(60,145)RLE,PMTLE,PLE,CPPA,PTLE,CPT,SPLE,CPASP,DSLE,
     $            CPADS,CISPDS,PC,LCPA
145   FORMAT(12F5.0,I5)
      IF(ISW. EQ.1) GO TO 200
      DO 250 IA=1,3
      DO 250 IQ=1,NX
      ACRES=ACR(IA,IQ)
      T=IFUNT(RINT)
      T=0.
```

```
      IFURLE=IFUN2(RLE)
      T=T+RIN(I,IFURLE)*4951.*X(IQ)
      IFUPMT=IFUN2(PMTLE)
      T=T+RIN(IFUPMT)*45.*P(IA,IQ)
      IFUPLE=IFUN2(PLE)
      T=T+RIN(I,IFUPLE)*CPPA*ACRES
      IFUPTL=IFUN2(PTLE)
      T=T+RIN(I,IFUPTL)*CPT
      IFUSPL=IFUN2(SPLE)
      T=T+RIN(I,IFUSPL)*CPASP*ACRES
      IFUDSL=IFUN2(DSLE)
      T=T+RIN(I,IFUDSL)*CPADS*ACRES
      T=T*1.01
      T=T+CISPDS*ACRES/20.
      T=T+PC*ACRES
      T=T+LCPA*ACRES/20.
      OWN(IA,IQ)=T
      WORTH=WCPA*ACRES*HPY
      COST(IA,IQ)=T+Y(IA,IQ)-WORTH
  250 CONTINUE
      GO TO 600
  200 CONTINUE
      DO 600 IA=1,NID
      DO 600 IQ=1,NX
      R= SQRT(ACR(IA,IQ)*43500/3.1416)
      AACRES=(4*R**2)/43500
      T=IFUN1(RINT)
      T=0.
      IFURLE=IFUN2(RLE)
      T=T+RIN(I,IFURLE)*4951.*X(IQ)
      IFUPLE=IFUN2(PLE)
      T=T+RIN(I,IFUPLE)*CPPA*R
      IFUPTL=IFUN2(PTLE)
      T=T+RIN(I,IFUPTL)*CPT
      IFUDSL=IFUN2(DSLE)
      T=T+RIN(I,IFUDSL)*CPADS*8.*R
      T=T*1.01
      T=T+(R*ISPF+8*R*IDPF)/20
      T=T+PC*AACRES
      T=T+LCPA*AACRES/20.
      OWN(IA,IQ)=T
      WORTH=WCPA*ACRES*HPY
      COST(IA,IQ)=T+Y(IA,IQ)-WORTH
  600 CONTINUE
      DO 275 I=1,NID
      IF(ISW.EQ.1) WRITE(61,375)
      IF(ISW.EQ.0)WRITE(61,376)
      WRITE(61,300)AP(I)
      DO 275 J=1,NX
  275 WRITE(61,350)ACR(I,J),Y(I,J),OWN(I,J),COST(I,J)
      CALL PLOTIT(Y,X,NID,NX,AP)
      CALL PLOTIT(OWN,X,NID,NX,AP)
```

```
      CALL PLOTIT(COST,X,NID,NX,AP)
      GO  TO  100
  300 FORMAT(     11X,≠APPLICATION RATE=≠,F7.2,3X,≠INCHES/ACRE≠,//,
     $           20X,≠AREA≠,
     $  11X,≠OPERATING COST≠,6X,≠OWNERSHIP COST≠,7X,≠TOTAL COST≠,/)
  350 FORMAT(17X,E10.4,10X,E10.4,10X,E10.4,10X,E10.4)
  375 FORMAT(1H1,10X,≠CENTER PIVOT SYSTEM≠)
  376 FORMAT(1H1,10X,≠SOLID SET SYSTEM≠)
  999 CONTINUE
      IF(OVERFLF(5).EQ.1) KLOPES=1
      WRITE(61,9999)
 9999 FORMAT(1H1)
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR SPRAY

RRORS

```
      SUBROUTINE PLOTIT(Y,X,LL,M,AP)
      INTEGER CODE(3)
      DIMENSION Y(3,21),X(21),T(23),L(13),AP(3)
      DATA ((CODE(I),I=1,3)=4HA      ,4HB      ,4HC
      NX=M
      CALL MINMAX(X,NX,XMIN,XMAX)
      DO  200 K=1,LL
      CALL TRANS(Y,T,NX,K)
      CALL MINMAX(T,NX,YMIN,YMAX)
      IF(K.GT.1)  GO  TO 175
      AMIN=YMIN
      AMAX=YMAX
      GO  TO  200
  175 CONTINUE
      IF(YMAX.GE.AMAX) AMAX=YMAX
      IF(YMIN.LT.AMIN) AMIN=YMIN
  200 CONTINUE
      IF( AMIN.GT.0 .AND. X(1).EQ.0 ) AMIN=0.
      K=1
      IPATH=2
      CALL DPLOT(X,T,NX,CODE(K),XMAX,XMIN,AMAX,AMIN,IPATH)
      IPATH=3
      DO  225  K=1,LL
      CALL TRANS(Y,T,NX,K)
  225 CALL DPLOT(X,T,NX,CODE(K),XMAX,XMIN,AMAX,AMIN,IPATH)
      K=K-1
      IPATH=4
      READ(60,10)(L(I),I=1,13)
      WRITE(61,20)(L(I),I=1,13)
      WRITE(61,21)(AP(I),I=1,3)
      CALL DPLOT(X,T,NX,CODE(K),XMAX,XMIN,AMAX,AMIN,IPATH)
      RETURN
 10   FORMAT(19A4)
 20   FORMAT(1H1,//,50X,19A4)
 21   FORMAT(40X,≠A=≠,F4.1,5X,≠B=≠,F4.1,5X,≠C=≠,F4.1,
     $     3X,≠INCHES/ACRE/DAY≠,/)
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR PLOTIT

RRORS

```
      FUNCTION POWER(X,Y)
      IF(X.EQ.0)   GO   TO  10
      POWER= EXP(Y*ALOG(X))
      RETURN
   10 POWER=0.
      RETURN
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR POWER

ORS

```
      FUNCTION IFUN1(A)
      J=(2.*(A-5.5))+.5
      IF(J.LE.0.OR.J.GT.9)J=5
      IFUN1=J
      RETURN
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR IFUN1

ORS

```
      FUNCTION IFUN2(A)
      I=A+.5
      IF(I.EQ.5) GO TO 1
      IF(I.EQ.6) GO TO 2
      IF(I.EQ.8) GO TO 3
      IF(I.EQ.10) GO TO 4
      IF(I.EQ.12) GO TO 5
      IF(I.EQ.15) GO TO 6
      IF(I.EQ.20) GO TO 7
      IF(I.GT.20) GO TO 7
      IF(I.GT.15) GO TO 6
      IF(I.GT.12) GO TO 5
      IF(I.GT.10) GO TO 4
      IF(I.GT.8) GO TO 3
      IF(I.GT.6) GO TO 2
    1 K=1
      GO TO 8
    2 K=2
      GO   TO   8
    3 K=3
      GO TO 8
    4 K=4
      GO TO 8
    5 K=5
      GO TO 8
    6 K=6
      GO TO 8
    7 K=7
    8 IFUN2=K
      RETURN
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR IFUN2

IORS

```
      SUBROUTINE TRANS(U,V,N,J)
      DIMENSION U(3,102),V(102)
      DO 100 I=1,N
```

```
  100 V(I)=U(J,I)
      RETURN
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR TRANS

RORS

```
      SUBROUTINE MINMAX(X,N,XMIN,XMAX)
C
C     SUBROUTINE TO SCALE MAXIMUM AND MINIMUM VALUES USED IN PLOT.
      DIMENSION X(23)
C
C         IF USING REAL*4 USE FUNCTION BELOW.
C     DABS(XXX) = ABS(XXX)
C
C         DETERMINE AMIN AND AMAX.
C
      AMIN = X(1)
      AMAX = X(1)
      DO 399 I = 2, N
      IF (X(I) - AMIN) 100,200,200
  100 AMIN = X(I)
      GO TO 399
  200 IF (X(I) - AMAX) 399,399,300
  300 AMAX = X(I)
  399 CONTINUE
      XMIN = AMIN
      XMAX = AMAX
C
C     SCALE XMIN AND XMAX.
C
      CALL SIGDIG(AMIN,2,KPOW)
      IF (XMIN .LT. AMIN) AMIN = AMIN - 10.0**KPOW
      CALL SIGDIG(AMAX,2,KPOW)
      IF (XMAX .GT. AMAX) AMAX = AMAX + 10.0**KPOW
      XDIF = AMAX - AMIN
      ADIF = XDIF
      CALL SIGDIG(ADIF,2,KPOW)
      IF (XDIF .LT. ADIF) ADIF = ADIF + 10.0**KPOW
      IF (DABS(AMIN) - DABS(AMAX)) 400,600,500
  400 AMIN = AMAX - ADIF
      GO TO 600
  500 AMAX = AMIN + ADIF
  600 XMIN = AMIN
      XMAX = AMAX
      RETURN
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR MINMAX

RORS

```
      SUBROUTINE SIGDIG(VAL,NDIGTS,KPOW)
C.........ROUTINE WILL REDUCE A NUMBER DOWN TO A SPECIFIED NUMBER OF
C         SIGNIFICANT DIGITS.
C
C
C         IF USING REAL*4 USE FUNCTION BELOW.
C     DABS(XXX) = ABS(XXX)
C
      KPOW = 0
```

```
      CON1 = 10.0 ** NDIGTS
      CON2 = CON1 / 10.0
C
      IF (VAL .EQ. 0.0) GO TO 199
C
  100 IF (DABS(VAL) .LT. CON1) GO TO 150
      KPOW = KPOW + 1
      VAL = VAL / 10.0
      GO TO 100
  150 IF (DABS(VAL) .GE. CON2) GO TO 199
      KPOW = KPOW - 1
      VAL = VAL * 10.0
      GO TO 100
  199 IVAL = VAL + 0.001
      VAL = IVAL
      IF (KPOW) 200,400,300
  200 IPOW = - KPOW
      DO 250 I = 1, IPOW
  250 VAL=VAL/10.0000
      GO TO 400
  300 DO 350 I = 1, KPOW
  350 VAL=VAL*10.0000
  400 RETURN
      END
```

FORTRAN DIAGNOSTIC RESULTS FOR SIGDIG

RORS

```
      SUBROUTINE DPLOT(X,Y,N,CODE,XMAX,XMIN,YMAX,YMIN,IPATH)
C     X    ARRAY OF X-ORDINATES.
C     Y    ARRAY OF Y-ORDINATES.
C     N    NUMBER OF POINTS.
C     CODE CHARACTER THAT WILL REPRESENT PLOTTED POINT.
C     XMAX THE LARGEST X VALUE THAT IS TO BE PLOTTED.
C     YMAX THE LARGEST Y VALUE THAT IS TO BE PLOTTED.
C     XMIN THE SMALLEST X VALUE THAT IS TO BE PLOTTED.
C     YMIN THE SMALLEST Y VALUE THAT IS TO BE PLOTTED.
C
C     THERE CAN BE N PLOTES ON ONE PRINT OUT.
C     THERE IS ONE SET OF SCALLING FACTORS FOR EACH PRINTED PLOT
C     CONTAINING ONE OR MORE SETS OF POINTS.
C     IF ONE POINT FROM ONE SET OF POINTS OVERLAPS ANOTHER POINT FROM
C     ANOTHER SET OF POINTS AN EXE WILL REPRESENT THE OVERLAP.
C
      INTEGER FRMT1(20),FRMT2(20),INUM(9),IPATH,N
      INTEGER LINE(101,101),CODE,SPACE,PLUS,MINUS,XXXX
      DIMENSION X(23),Y(23),XX(6)
      DATA(SPACE=4H    ),(PLUS=4H+   ),(MINUS=4H-   ),(XXXX=4HX   )
C
      DATA((FRMT1(I),I=1,20)=4H(    ,4H1   ,4HH   ,4H    ,
     C4HF   ,4H1   ,4H0   ,4H.   ,4H0   ,4H,   ,4H5   ,
     C4HX   ,4H,   ,4H1   ,4H0   ,4H1   ,4HA   ,4H1   ,
     C4H)   ,4H    )
      DATA((FRMT2(I),I=1,20)=4H(    ,4H1   ,4HH   ,4H    ,
     C4H6   ,4H(   ,4H1   ,4H1   ,4HX   ,4H,   ,4HF   ,
     C4H0   ,4H9   ,4H.   ,4H0   ,4H)   ,4H)   ,4H    ,
     C4H    ,4H    )
      DATA((INUM(I),I=1,9)=4H0   ,4H0   ,4H0   ,4H1   ,4H2   ,
     C4H3   ,4H4   ,4H5   ,4H6   )
C
      GO TO (50,100,160,350),IPATH
```

```
   50 ISW=1
      GO TO 105
C
C     ROUTINE FOR INITIALIZATION.
C
  100 ISW=0
  105 IXCT=100
      IXCTP1 = IXCT + 1
      IYCT = 50
      IYCTP1 = IYCT + 1
      DO 110 I = 2, IXCT
      DO 110 J = 2, IYCT
  110 LINE(I,J) = SPACE
C
      DO 120 I = 2, IXCT
      IYCTP2=IYCTP1+10
      DO 120 J = 1, IYCTP2,10
  120 LINE(I,J) = MINUS
```

```
C
      DO 130 I = 1, IXCTP1,10
      DO 130 J = 1, IYCTP1
  130 LINE(I,J) = PLUS
      DO 135 J=1, IYCTP1
  135 LINE(101,J)=PLUS
C
      DELX = (XMAX - XMIN) / IXCT
      DELY = (YMAX - YMIN) / IYCT
C
      DO 140 I = 1, 9
      IF (DABS(XMAX) .LT. 10.0**(8-I) .AND. DABS(XMIN) .LT. 10.0**(8-I))
     1                  GO TO 140
      FRMT2(15) = INUM(I)
      GO TO 145
  140 CONTINUE
      FRMT2(15) = INUM(9)
  145 DO 150 I = 1, 9
      IF (DABS(YMAX) .LT. 10.0**(8-I) .AND. DABS(YMIN) .LT. 10.0**(8-I))
     1                  GO TO 150
      FRMT1(09) = INUM(I)
      GO TO 155
  150 CONTINUE
      FRMT1(09) = INUM(9)
C
C     ******************************************************************
C
  155 IF (ISW .EQ. 1) GO TO 200
      GO TO 999
C
  160 CONTINUE
      ISW = 0
C
C     ******************************************************************
C
C     THIS ROUTINE DOES THE PLOTTING.
C
  200 DO 300 I = 1, N
      IX = (X(I) - XMIN) / DELX + 1.5
      IF (IX .LT. 1 .OR. IX .GT. IXCTP1) GO TO 300
      IY = IYCTP1 + 1 - ((Y(I) - YMIN) / DELY + 0.5)
      IF (IY .LT. 1 .OR. IY .GT. IYCTP1) GO TO 300
      IF (LINE(IX,IY) .EQ. SPACE .OR. LINE(IX,IY) .EQ. PLUS .OR.
     1    LINE(IX,IY) .EQ. MINUS .OR. LINE(IX,IY) .EQ. CODE) GO TO 290
      LINE(IX,IY) = XXXX
      GO TO 300
  290 LINE(IX,IY) = CODE
  300 CONTINUE
C
C     ******************************************************************
C
      IF (ISW .EQ. 1) GO TO 400
```

```
      GO TO 999
C
  350 CONTINUE
C
C     ****************************************************************
C
C     ROUTINE PRINTS OUT PLOT.
C
  400 JJ = 1
      YY = YMAX
      DO 430 J = 1, IYCTP1
      IF (JJ .NE. J) GO TO 420
      WRITE(61,FRMT1)YY,(LINE(I,J),I=1,IXCTP1)
      JJ = JJ + 10
      YY = YY - 10.0*DELY
      GO TO 430
420   WRITE(61,9010)(LINE(I,J),I=1,IXCTP1)
  430 CONTINUE
C
      J = 1
      XX(1) = XMIN
      DO 440 I = 20, IXCTP1, 20
      J = J + 1
  440 XX(J) = XX(J-1) + 20.0 * DELX
      WRITE(61,FRMT2)(XX(I),I=1,J)
C
      WRITE(61,9030)DELX,DELY
C
C     ****************************************************************
C
  999 RETURN
C
 9010 FORMAT (1H ,15X,101A1)
 9030 FORMAT (1H0,15X,13HX-INTERVAL = ,E10.4 /
     1         1H ,15X,13HY-INTERVAL = ,E10.4)
      END

              FORTRAN DIAGNOSTIC RESULTS  FOR    DPLOT

RORS

      FUNCTION DABS(A)
      A=ABS(A)
      DABS=A
      RETURN
      END

              FORTRAN DIAGNOSTIC RESULTS  FOR    DABS

RORS
NO 0011  ERROR IN  BCDINP    CALLED FROM 76640 (ILLEGAL CODE ON INPUT)
PUT RECORD FOLLOWS ARROW  *  COST OF OPERATION
 FLAGS ERR OR FIELD-END      +
NO 0011  ERROR IN  BCDINP    CALLED FROM 77201 (ILLEGAL CODE ON INPUT)
PUT RECORD FOLLOWS ARROW  *  COST OF OWNERSHIP
 FLAGS ERR OR FIELD-END      +
NO 0011  ERROR IN  BCDINP    CALLED FROM 77207 (ILLEGAL CODE ON INPUT)
NO 0011  ERROR IN  BCDINP    CALLED FROM 77211 (ILLEGAL CODE ON INPUT)
NO 0011  ERROR IN  BCDINP    CALLED FROM 77213 (ILLEGAL CODE ON INPUT)
NO 0011  ERROR IN  BCDINP    CALLED FROM 77215 (ILLEGAL CODE ON INPUT)
```

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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16. ABSTRACT

Lysimeter studies and a two-year field study were conducted to evaluate the efficiency of sprinkler irrigation wastewater treatment as a means of polishing wastewater stabilization lagoon effluent. In the lysimeter study four typical Utah soils were evaluated for their effectiveness in removing total and fecal coliform and fecal streptococcal organisms as well as nitrogen, phosphorus and carbon compounds. The field experiments evaluated the removal efficiencies for carbon, nitrogen and phosphorus compounds.

All four soils used in the lysimeters were effective in removing the three indicator organisms, organic carbon, and suspended and volatile suspended solids. In the field experiments leaching of salts from soils on the drainage farm occurred. The quality of the effluent from the soil wastewater treatment system appeared to be controlled by the characteristics of the drainage farm system. Once equilibrium is established a far superior quality effluent is expected. Phosphorus removal in the field experiments exceeded 80%. The rate of application of irrigation water made no significant difference in the phosphorus removal rate. Evidence of nitrate leaching from the soil was also observed. Ammonia stripping removed approximately 35% of the ammonia when the lagoon effluent was sprayed on the land. Suspended solids removal by soil mantle treatment system was excellent and the suspended solids concentrations in the drainage water from a 1.2 m (4 ft.) deep mole drain contained an average suspended solids concentration of 2 mg/ℓ.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sprinkler irrigation Wastewater Lagoon (ponds) Effluents Algae Separation		13B

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