CLEAN WATER

WATER POLLUTION CONTROL RESEARCH SERIES ● 13030ELY5/71-6
REC-R2-71-6
DWR NO. 174-9

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE

SAN JOAQUIN VALLEY, CALIFORNIA

REMOVAL OF NITROGEN FROM TILE DRAINAGE

A SUMMARY REPORT

MAY 1971

ENVIRONMENTAL PROTECTION AGENCY●RESEARCH AND MONITORING

CALIFORNIA DEPARTMENT OF WATER RESOURCES

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE SAN JOAQUIN VALLEY, CALIFORNIA

The Bio-Engineering Aspects of Agricultural Drainage reports describe the results of a unique interagency study of the occurrence of nitrogen and nitrogen removal treatment of subsurface agricultural wastewaters of the San Joaquin Valley, California.

The three principal agencies involved in the study are the Water Quality Office of the Environmental Protection Agency, the United States Bureau of Reclamation, and the California Department of Water Resources.

Inquiries pertaining to the Bio-Engineering Aspects of Agricultural Drainage reports should be directed to the author agency, but may be directed to any one of the three principal agencies.

THE REPORTS

It is planned that a series of twelve reports will be issued describing the results of the interagency study.

There will be a summary report covering all phases of the study.

A group of four reports will be prepared on the phase of the study related to predictions of subsurface agricultural wastewater quality -- one report by each of the three agencies, and a summary of the three reports.

Another group of four reports will be prepared on the treatment methods studied and on the biostimulatory testing of the treatment plant effluent. There will be three basic reports and a summary of the three reports.

This report, "TECHNIQUES TO REMOVE NITROGEN IN DRAINAGE EFFLUENT DURING TRANSPORT", is one of a group of three reports which also include (2) possibility of reducing nitrogen in drainage water by on farm practices, and (3) desalination of subsurface agricultural wastewaters.

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE
SAN JOAQUIN VALLEY, CALIFORNIA

REMOVAL OF NITROGEN FROM TILE DRAINAGE A SUMMARY REPORT

Based on Reports
Prepared by the

California Department of Water Resources
William R. Gianelli, Director

– – –

Environmental Protection Agency
Robert S. Kerr Water Research Center
William C. Galegar, Director

– – –

Environmental Protection Agency
Region IX
Paul De Falco, Director

The agricultural drainage study was conducted under the direction of:

Robert J. Pafford, Jr., Regional Director, Region 2
UNITED STATES BUREAU OF RECLAMATION
2800 Cottage Way, Sacramento, California 95825

Paul De Falco, Jr., Regional Director, Region IX
WATER QUALITY OFFICE, ENVIRONMENTAL PROTECTION AGENCY
760 Market Street, San Francisco, California 94102

John R. Teerink, Deputy Director
CALIFORNIA DEPARTMENT OF WATER RESOURCES
1416 Ninth Street, Sacramento, California 95814

DWR–WQO Grant #13030 ELY
DWR-USBR Contract #14-06-200-3389A
May 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 50 cents

REVIEW NOTICE

This summary report has been reviewed by the California Department of Water Resources, the Water Quality Office, Environmental Protection Agency, and the U. S. Bureau of Reclamation, and has been approved for publication.

The mention of trade names or commercial products does not constitute endorsement or recommendation for use by either of the two federal agencies or the Department of Water Resources.

ABSTRACT

Studies conducted by members of an interagency group have shown that it is technically feasible to remove nitrate from subsurface agricultural tile drainage by either of two biological processes, algae stripping or bacterial denitrification. Laboratory studies using process effluents and untreated drainage demonstrated that nitrogen removal effectively reduced the algae growth potential of the drainage when mixed with waters from the Sacramento-San Joaquin Delta, a possible discharge location for subsurface tile drainage from California's San Joaquin Valley.

Algae stripping is an assimilatory nitrogen removal process in which growth of algae in shallow outdoor ponds was encouraged by the addition of iron, phosphorus, and carbon dioxide.

The detention times required to meet the nitrogen removal objective of the project, that is, to reduce an influent of 20 mg N/l (milligrams nitrogen per liter) to 2 mg N/l, range from about 5 days in the summer to 16 days in the winter. The algal suspension from the growth unit was then harvested by coagulation-sedimentation, dewatered to about 20 percent solids by vacuum filtration, and air dried to about 90 percent solids. Possible markets for the algal product include feeding as a protein supplement and use as a soil conditioner.

Bacterial denitrification, mainly a dissimilatory process in which most of the nitrate is reduced to nitrogen gas, requires anaerobic conditions and an organic carbon source such as methanol. The denitrification process was studied by means of deep ponds and upflow filters. Results of the deep pond studies indicate that ponds had to be covered to ensure anaerobic conditions. When water temperatures were above 14°C, detention times extending from 8 to 20 days were needed to reduce nitrogen to the 2 mg N/l level. Below 14°C, the effluent total N was about 3-4 mg/l at detention times as long as 50 days. The anaerobic filters produced an effluent that contained 2 mg/l or less total nitrogen, when operated above 14°C with 1- to 2-hour detention time and using 1-inch rounded aggregate. Below 14°C, a detention time of 2 hours was required. Long-term operation of the filters indicated that periodic flushing may be required to control bacterial biomass within the filter.

Preliminary estimates for the two processes indicated that treatment cost about $90 per million gallons (about $30 per acre-foot) for the anaerobic systems and $135 per million gallons ($45 per acre-foot) for algae stripping. These figures will be refined using data from the 1970 operational studies.

Two desalination processes, reverse osmosis and electrodialysis, were also studied. The reverse osmosis unit produced high quality effluent but relatively low product flow. The membrane stacks also deteriorated. The electrodialysis unit reduced total dissolved solids by about 25 percent after one pass and a product flow of about 75 percent of the influent.

BACKGROUND

This report is one of a series which presents the findings of intensive interagency investigations of practical means to control the nitrate concentration in subsurface agricultural wastewater prior to its discharge into other water. The primary participants in the program are the Water Quality Office of the Environmental Protection Agency, the U. S. Bureau of Reclamation, and the California Department of Water Resources, but several other agencies also are cooperating in the program. These three agencies initiated the program because they are responsible for providing a system for disposing of subsurface agricultural wastewater from the San Joaquin Valley of California and protecting water quality in California's water bodies. Other agencies cooperated in the program by providing particular knowledge pertaining to specific parts of the overall task.

The ultimate need to provide subsurface drainage for large areas of agricultural land in the western and southern San Joaquin Valley has been recognized for some time. In 1954, the Bureau of Reclamation included a drain in its feasibility report of the San Luis Unit. In 1957, the California Department of Water Resources initiated an investigation to assess the extent of salinity and high ground water problems and to develop plans for drainage and export facilities. The Burns-Porter Act, in 1960, authorized San Joaquin Valley drainage facilities as part of the State Water Facilities.

The authorizing legislation for the San Luis Unit of the Bureau of Reclamation's Central Valley Project, Public Law 86-488, passed in June 1960, included drainage facilities to serve project lands. This Act required that the Secretary of the Interior either provide for constructing the San Luis Drain to the Delta or receive satisfactory assurance that the State of California would provide a master drain for the San Joaquin Valley that would adequately serve the San Luis Unit.

Investigations by the Bureau of Reclamation and the Department of Water Resources revealed that serious drainage problems already exist and that areas requiring subsurface drainage would probably exceed 1,000,000 acres by the year 2020. Disposal of the drainage into the Sacramento-San Joaquin Delta near Antioch, California, was found to be the least costly alternative plan.

Preliminary data indicated the drainage water would be relatively high in nitrogen. The then Federal Water Quality Administration conducted a study to determine the effect of discharging such drainage water on the quality of water in the San Francisco Bay and Delta. Upon completion of this study in 1967, the Administration's report concluded that the nitrogen content of untreated drainage waters could have significant adverse effects upon the fish and recreation values of the receiving waters. The report recommended a three-year research program to establish the economic feasibility of nitrate-nitrogen removal.

As a consequence, the three agencies formed the Interagency Agricultural Wastewater Study Group and developed a three-year cooperative research program which assigned specific areas of responsibility to each of the agencies. The scope of the investigation included an inventory of nitrogen conditions in the potential drainage areas, possible control of nitrates at the source, prediction of drainage quality, changes in nitrogen in transit, and methods of nitrogen removal from drain waters including biological-chemical processes and desalination.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

CONCLUSIONS

1. Algal growth and harvesting (algae stripping) and bacterial denitrification are technically feasible methods of removing nitrate-nitrogen from subsurface agricultural tile drainage in the San Joaquin Valley. With an influent concentration of 20 mg/l total nitrogen, the algae stripping process will produce an effluent containing from 3-5 mg/l total nitrogen (depending on season) and bacterial denitrification an effluent of 2 mg N/l or less.

2. Laboratory algal growth assays comparing treated (either process) and untreated tile drainage mixed with potential receiving waters showed that nitrogen removal effectively reduced the biostimulatory nature of the waste.

3. Preliminary cost estimates for the system described in this report range from $90 per million gallons (about $30 per acre-foot) for bacterial denitrification to $135 per million gallons ($45 per acre-foot) for algae stripping. These figures are based on the results of technical feasibility studies and may be revised after 1970 operational studies.

4. Desalination of tile drainage by reverse osmosis or electrodialysis was found to be technically feasible although cost analysis indicated that the direct reuse of agricultural drainage after desalination was not economically feasible.

CHAPTER II

INTRODUCTION

This report summarizes the results of an investigation of the technical feasibility of removing dissolved nitrogen (95 percent in the nitrate form) from subsurface agricultural tile drainage in the San Joaquin Valley of California. The investigation was conducted from 1967 through 1969 at the Interagency Agricultural Wastewater Treatment Center (IAWTC), located about 45 miles from Fresno, California, near the town of Firebaugh (see Figure 1). The overall investigation at the Center was divided into the general areas of nitrogen removal by biological systems (algae stripping and bacterial denitrification), effect of nitrogen removal on the biostimulatory nature of the drainage water, and the use of desalination (reverse osmosis and electrodialysis) to remove minerals dissolved in the drainage with special interest in nitrate and boron removal. The data and conclusions of the individual technical feasibility studies have been published (Brown, 1971; Sword, 1971a; Tunzi, 1971; and Sword, 1971b) are available to readers interested in more detail than found in this summary report. The results of 1970 algae stripping and bacterial denitrification operational studies will be published in the fall of 1971.

The Background section of this report provides the chronological order of events leading to the development of the extensive study of subsurface agricultural drainage in the San Joaquin Valley. After publication of the results of the study by the Federal Water Pollution Control Administration, now the Environmental Protection Agency (EPA), entitled "Effect of the San Joaquin Master Drain on the water quality of the San Francisco Bay and Delta" (Federal Water Pollution Control Administration 1967), representatives of several agencies, including DWR, USBR, and EPA, met in Los Banos, California, to develop a coordinated program for studying the entire drainage problem in the San Joaquin Valley. At this meeting, the Interagency Nitrogen Removal Group (USBR, EPA, and DWR) was organized and two areas of investigation were assigned to the IAWTC -- nitrogen removal by biological systems (algal growth and harvesting and bacterial denitrification) and total dissolved solids and boron removal (desalination).

Although the actual Center was not developed until 1967, nutrient removal studies had been planned by DWR as early as 1964. In 1963, DWR retained Dr. William J. Oswald (Sanitary Engineer, University of California, Berkeley), Dr. Clarence G. Golueke (Microbiologist, University of California, Berkeley), and Dr. Donald G. Crosby (Toxicologist,

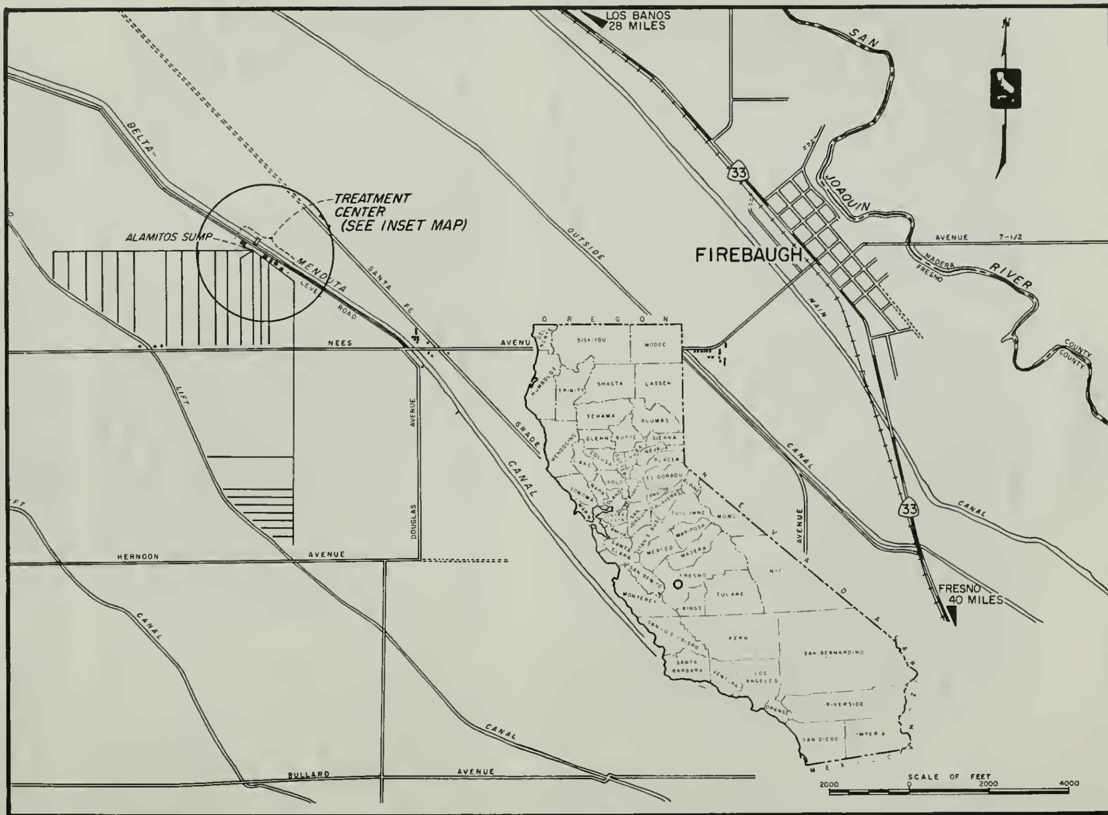

FIGURE I. LOCATION OF INTERAGENCY AGRICULTURAL WASTEWATER TREATMENT CENTER

University of California, Davis) to evaluate the feasibility of algal growth and harvesting (popularly known as "algae stripping") as a treatment method nitrogen removal for San Joaquin Valley agricultural wastewaters. Their report stated that algae stripping was probably economically feasible and recommended that pilot-scale studies using subsurface agricultural wastewaters be undertaken in the San Joaquin Valley. The Department reviewed the feasibility report and accepted the recommendation that prepilot studies be initiated at a site on the west side of the San Joaquin Valley. Land for the site was acquired from the Bureau of Reclamation in 1966. Construction of the algae stripping plant began in 1967 and was completed in early 1968.

The Department of Water Resources also retained Dr. Perry L. McCarty (Sanitary Engineer, Stanford University, Palo Alto) early in 1966 to evaluate the effectiveness of anaerobic denitrification as a treatment method. Dr. McCarty's report indicated that anaerobic denitrification in deep ponds would work and was economically competitive with algae stripping. He recommended that large-scale studies be undertaken in the San Joaquin Valley. Preliminary studies of this process were started during the summer of 1967. In addition to the work at Firebaugh, the EPA, in cooperation with the Los Angeles County Sanitation District, was using sewage as a substrate to study bacterial denitrification. These studies were begun in 1966.

The remaining process investigated at the Center, desalination, was begun in 1967 under the sponsorship of the Office of Saline Water with the EPA as the responsible agency. The purpose of this research was to define the problems involved in removing dissolved minerals from agricultural tile drainage.

Figure 2 contains an aerial photograph of the IAWTC after all of the facilities had been fully developed. The research at the Center was conducted by an interagency group of engineers, biologists, chemists, and technicians under the general guidance of the Board of Directors consisting of: the Director, Region 2, USBR; the Director, Pacific Southwest Region, EPA; and the Director, California Department of Water Resources. A Technical Coordinating Committee consisting of project directors from each of the responsible agencies provided direct technical direction. A Treatment Consulting Board made up by Drs. Oswald, Golueke, and McCarty, reviewed the overall work of the project and provided operating guidelines for specific areas of study. The organization of the Center is illustrated in Figure 3.

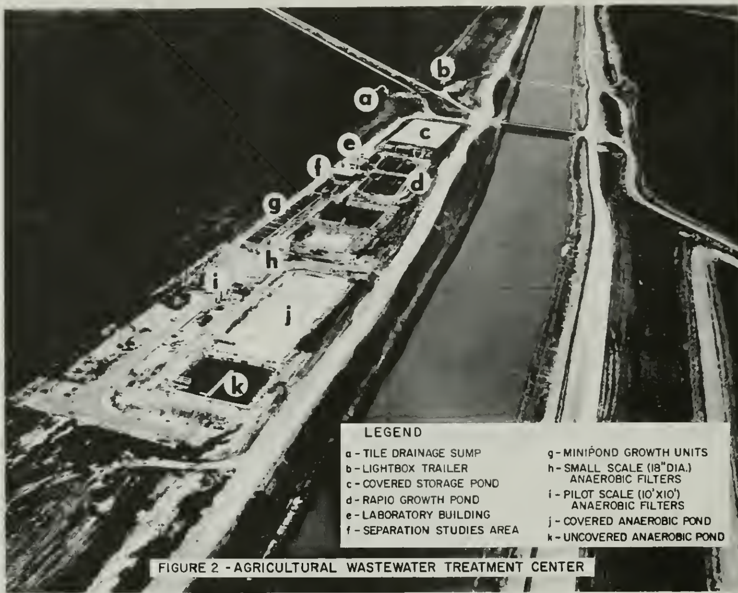

FIGURE 2 - AGRICULTURAL WASTEWATER TREATMENT CENTER

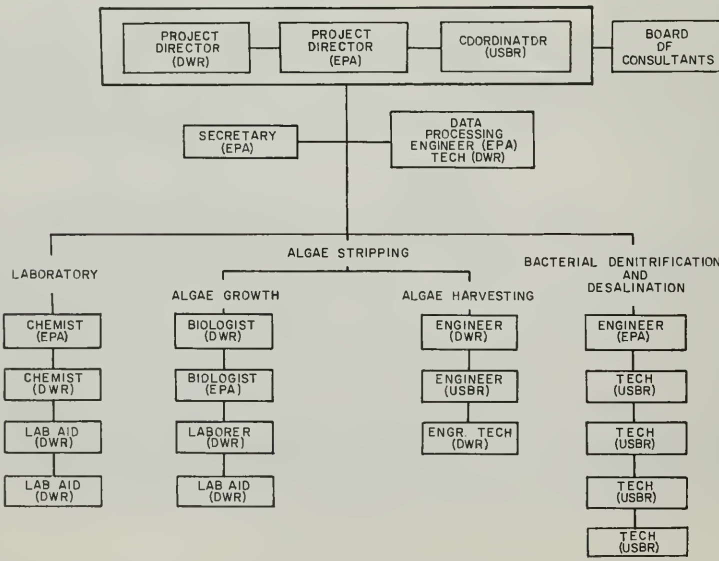

FIGURE 3-ORGANIZATION CHART-INTERAGENCY AGRICULTURAL WASTEWATER TREATMENT CENTER

CHAPTER III

PROCESSES STUDIED

This section provides general description of the algae stripping, bacterial denitrification, and desalination processes studied at the IAWTC. The methods used in the studies on the biostimulatory effect of the treated and untreated drainage waters on algae growth in Sacramento-San Joaquin Delta will be described in the Results section. More detailed descriptions of the systems can be found in the individual reports cited previously.

As much as possible, the tile drainage water was used without any alteration; however, annual fluctuations in water quality and quantity caused by irrigation practices in the overlying fields often made this impossible. As shown in Figure 4, total dissolved solids (TDS) and nitrate in the tile system varied considerably from year to year.

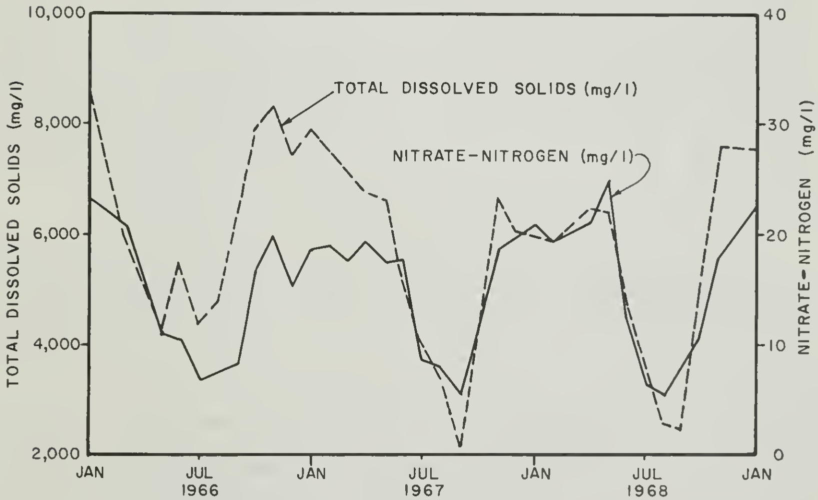

FIGURE 4 - SEASONAL VARIATION IN TOTAL DISSOLVED SOLIDS AND NITRATE-NITROGEN IN AGRICULTURAL DRAINAGE WATER AVAILABLE AT THE WASTEWATER TREATMENT CENTER

These changes caused some operational problems. During the periods of low TDS concentrations and accompanying low nitrogen levels, nitrogen was added as sodium nitrate to make a final concentration of about 20 mgN/l (milligrams nitrogen per liter). During periods of low winter flow, the drainage from the sump was mixed with water from the Delta-Mendota Canal (DMC). The mixture was used in the bacterial denitrification studies only after experimentation had shown that results with the mixed waters were comparable to those in which pure drainage was used, providing nitrogen levels were similar. In the latter part of the desalination work, drainage was blended with DMC water to provide a constant TDS of about 3,000 mg/l, thus eliminating salinity as a variable.

Nitrogen Removal Systems

Algae Stripping

Algae stripping is an assimilative nutrient removal process involving three phases. In the first, algae growth (with incorporation of the nutrient into cellular material) is encouraged by creating the most favorable environmental conditions. Shallow outdoor ponds were provided with some means of mechanically mixing the culture. Any nutrients other than those to be removed may be added to the growth medium and only the undesirable nutrients will limit growth. The second phase involves the removal of the algal biomass from suspension by some harvesting process, e.g., sedimentation, and then the biomass is dried to the desired moisture content. In the third phase the dried algal product must then be disposed of, preferably by utilization in a way which reduces the cost of the treatment system. Possible means of disposal include incineration, landfill, fertilizer, high-protein food supplement, or as a soil conditioner.

In the growth phase, algae, predominantly of the genus *Scenedesmus*, were grown in three levels of culture -- laboratory, small outdoor ponds (miniponds), and a larger 1/4-acre growth pond. The effect of various factors was first screened in the laboratory and small ponds, and then the optimum levels of the various factors were combined in operation of the larger pond. Algal harvesting studies were divided into laboratory and field (pilot-scale) unit evaluation, with the laboratory studies used to determine the most effective coagulant dosage for the sedimentation-flocculation unit. Also evaluated were methods of dewatering a 3- to 5-percent (by weight) algal slurry to about 20 percent solids and drying the resultant material to about 90 percent solids. The study of disposal was limited to a literature search and to supplying the dried algal product to interested companies.

The specific objective of the algal growth and harvesting investigation at the IAWTC was to produce an effluent containing 2 mg/l or less of total nitrogen, a limit recommended by the 1967 EPA report. This effluent nitrogen was composed of dissolved (both organic and inorganic) and particulate (incorporated in cellular tissue) forms of the element; thus, total nitrogen removal relied on growth and assimilation of the dissolved nitrate and harvesting of the algal cells from the liquid phase. For example, to remove 90 percent of the nitrogen from an influent containing 20 mg/l nitrogen by the algal process would require 95 percent assimilation by the algae and subsequent removal of 95 percent of the algal biomass. To achieve this objective, growth studies were designed to determine optimum conditions for nitrogen assimilation and separation studies were designed to remove algal biomass while maintaining costs at an economical level.

Bacterial Denitrification

In contrast to algae stripping, bacterial denitrification is a dissimilatory nitrogen removal process in which most of the incoming nitrate is converted to nitrogen gas; however, a small fraction of the nitrate does enter into the production of bacterial protein. The bacterial denitrification process requires anaerobic, or nearly anaerobic, conditions and the presence of an organic carbon energy source, such as methanol. Under these conditions, the bacteria can use nitrates and nitrites as terminal electron acceptors in the oxidation of the organic material. The overall reaction shows nitrate being reduced to nitrite and then to nitrogen gas; however, identification of the bacterial group or groups responsible for specific steps in the pathway was not attempted in the current study.

Dr. McCarty's original feasibility study investigated the use of several organic carbon sources for the denitrification process and found that both acetic acid and methanol were satisfactory compounds. Because it is available in large quantities, synthetically produced methyl alcohol, or methanol, was used in all denitrification studies at the IAWTC.

Two process configurations of the anaerobic denitrification system were evaluated at the Center -- deep ponds and filters. In deep ponds, methanol was mixed with the influent tile drainage, and the developing bacterial culture was either free-floating or attached to the sides of the container. The pond process was first tested at the Center using 3-foot diameter simulated deep ponds with water depths ranging from 6 to 11 feet. After these data had shown that the process was feasible, two larger earth-lined ponds having surface areas of 10,000 and 2,500 square feet and water depths of

14 feet were constructed at the site. Both ponds had provisions for recycling bacterial biomass from the bottom of the pond to the influent. The larger of the two units was completely covered with styrofoam planking to minimize reoxygenation of the water by algae and by wind mixing. The other pilot-scale pond remained uncovered.

In the filter configuration of the anaerobic process, methanol mixed with tile drainage flowed upward through an enclosure filled with an inert medium, small gravel, for example. The purpose of this medium was to provide a substrate to which the bacteria could attach and thus lengthen the solids retention time of the system (length of time a particle remained in the container). Four sizes of containers were used in the evaluation of the anaerobic filter process at Firebaugh -- 4-inch diameter PVC pipes, 18-inch diameter concrete pipes, 3-foot diameter concrete pipes, and a 10-foot wide by 10-foot long pilot-scale filter. Media depth in all units was 6 feet.

The objective of the denitrification study was also to achieve an effluent containing less than 2 mgN/l; although in this process, contrasted to algae stripping, the effluent contained only small amounts of particulate organic nitrogen.

Desalination

Two desalination methods were tested during this study -- reverse osmosis and electrodialysis. Package plants were supplied by OSW -- an Aerojet General reverse osmosis unit and an Ionics, Inc., electrodialysis unit. Representatives of the manufacturers provided assistance in the installation and initial operation of the units. The principles involved in the operation of these units will be explained as they pertain to the results obtained in the studies.

The primary objective of desalination was to obtain some operational data on the use of existing equipment to demineralize agricultural tile drainage. Reduction of dissolved nitrogen was a secondary objective. This part of the investigation was also designed to provide some preliminary cost data and an estimate of removal rates of boron and nitrate.

CHAPTER IV

RESULTS

This section discusses algae stripping, bacterial denitrification, soil ponds (so-called "symbiotic" ponds), effect of treatment on algal growth potential, botulism studies, and desalination. Results are based on data collection prior to January 1, 1970, although some algal harvesting results obtained after this date are included to complete missing areas of data.

Algae Stripping

Growth, harvesting, and disposal of the algae were studied under the general topic of algae stripping. In general, the studies at the IAWTC have shown that algal growth and harvesting is a technically feasible means of removing nitrate-nitrogen from subsurface tile drainage in the San Joaquin Valley. The results from specific areas of the algae stripping studies are summarized in the following paragraphs.

Growth

Tile drainage will support extensive algal growth, providing environmental conditions are made optimum for such growth. The effect of several chemical and physical factors on algal growth was studied using laboratory and outdoor cultures. The following discussion of these factors includes the best estimates for their optimum levels in outdoor cultures.

Nutrient Additions. Three nutrients -- phosphorus, iron, and carbon dioxide -- appeared necessary to support the required growth of Scenedesmus in agricultural tile drainage. The phosphorus requirement was about 2 mg/l and was necessary during all seasons of the year. During the spring, summer, and early fall, the addition of 5 percent CO_2 enhanced algal growth and nitrogen assimilation over non-CO_2 ponds. The influent-dissolved inorganic carbon appeared to be an adequate carbon source during the winter months. Iron also seemed to be a seasonal requirement. Routine addition of 2 to 3 mg/l of this substance may be desirable because of the beneficial effect iron has on algal harvesting.

Mixing. Mixing results obtained before carbon dioxide additions were tested showed that four days of daylight mixing at velocities from 0.25 to 0.50 foot per second were required for maximum nitrogen assimilation. Further studies of various combinations of carbon dioxide and mixing indicated that mixing alone had little effect on nitrogen assimilation, and that maximum nitrogen assimilation could be obtained by injection of a mixture of CO_2 and compressed air into an otherwise unmixed pond. Because mixing is a major cost component of algal treatment, 1970 operational studies will emphasize this facet of the treatment process.

Detention Time. Provided that inorganic phosphorus was supplied to the algal cultures, detention time was normally the most important variable studied in an individual minipond run. After January of 1969, detention times ranging from 3 to 16 days were used in outdoor studies. Three different detention times were used in each run of 4 to 6 weeks' duration. The detention times, based on previous data, were selected to include flow-through rates which bracketed the predicted optimum detention time. Theoretical detention times required for maximum nitrogen assimilation varied from 5 to 16 days and appeared to be directly related to pond temperature between 12 and 25°C and independent of temperature between 25 and 33°C. Culture depth and biomass control also significantly affected detention time.

Culture Depth. Culture depths of 8, 12, and 16 inches were studied, and maximum nitrogen assimilation occurred at the 8-inch culture depth. Assimilation rates in cultures with 12-inch depths comparable to those of 8 inches required a three- to four-day longer detention time. Comparison of the difference between nitrogen assimilation in the two extreme depths studied, 8 and 16 inches, showed that the effect of depth was more pronounced during the winter months, and was directly correlated with available light.

Biomass Control. Biomass control, or regulation of in-pond algal biomass, was studied when algal cells appeared to accumulate in the growth units. A sedimentation tank was attached to one of the miniponds to remove the older, heavier algal cells and suspended soil and chemical precipitates. These studies showed that the summer detention times necessary for attaining the desired level of nitrogen removal (less than 2 mg/l total effluent nitrogen) would be about five days, or about three days less than in comparable ponds without biomass control. Some control mechanism will be needed in an operational algal treatment plant, perhaps settling areas in the ponds themselves.

Laboratory Growth Studies. Laboratory growth studies were used to gain valuable information concerning such factors as nutrient additions, desirable algal species, and comparisons of growth rates in water from different tile drainage systems. Some discretion was required in the interpretation of results from these studies because environmental conditions in the laboratory were usually more conducive to algal growth than such conditions in outdoor cultures. Thus, in the laboratory some compounds caused a dramatic effect on algal growth, but in outdoor units their effect was masked because culture growth was limited by light, temperature, etc. The difference is demonstrated by the result of adding iron to the Scenedesmus cultures. Iron was necessary for maximum nitrogen assimilation in practically every light study but was only seasonally required in outdoor cultures.

Two series of laboratory studies were used to compare rates of nitrogen removal in water from various tile systems in the Valley. The results of these studies showed that water from the Alamitos sump (the tile drainage system providing water used at the IAWTC) exhibited algal growth similar to that shown by the other tile effluents and that phosphorus was necessary to all of the waters. There were more seasonal variations in the water quality from Alamitos sump (because of summer rice culture) than in most tile systems in the Valley, and there were indications that the algal growth potential of the Alamitos water decreased during the summer. This fluctuation in water quality may have led to conservative estimates of the potential of algae stripping as a mechanism for removing nitrate from drainage water.

Algal Harvesting

Harvesting of algal biomass is divided into three phases -- concentration, dewatering, and drying, all of which differ in the amount of moisture remaining in the algal product. Studies demonstrated that algae can readily be separated from agricultural tile drainage and concentrated to 1 to 2 percent solids (by weight) by either coagulation-flocculation and sedimentation with any of several chemical coagulants or by use of a special configuration rapid sand filter (Sanborn filter) with backwashing. The slurry resulting from this concentrating process can then be dewatered to about 10 to 20 percent solids by vacuum filtration or by self-cleaning centrifugation. Other concentrating and dewatering processes, microscreen and upflow clarifier, were tested with indefinite results, either because of operational problems or because of incorrect design for the type of material to be separated.

Laboratory Tests. Laboratory jar tests were conducted to determine the effectiveness of various mineral coagulants (lime, alum, and ferric sulfate) and polyelectrolytes in achieving coagulation of the alga Scenedesmus from growth pond samples. These studies showed the additions of lime, alum, or ferric sulfate could effect 90 to 95 percent removal of the suspended solids from samples containing from

100 to 800 mg/l total suspended solids. This level of removal was attainable during all seasons of the year; however, the required concentration of mineral coagulant varied with changes in operation of the growth unit. When iron ($FeCl_3$) was added to the rapid growth pond as an algal nutrient, the concentrations of chemical required for removal of approximately 95 percent of the influent suspended solids ranged from 5 mg/l for ferric sulfate, to 20 mg/l for alum, and 40 mg/l for lime. These concentrations are compared to 80 mg/l, 100 to 140 mg/l, and 180 to 200 mg/l additions for the same compounds when iron was not being added to the growth pond.

Approximately 60 anionic, cationic, and nonionic polyelectrolytes were tested alone and with the mineral coagulants to evaluate their effectiveness in the coagulation-flocculation step of algal harvesting. Seventeen compounds were found to aid coagulation at costs comparable to those found for the mineral coagulants. The effectiveness of the polyelectrolytes was also influenced by operation of the growth units. One compound, Cat-Floc, was completely ineffective when the growth units did not receive daily additions of iron; but, after iron was added, more than 95 percent of the suspended solids could be removed by the addition of less than 0.5 mg/l of the polyelectrolyte.

Concentration. A shallow sedimentation unit with inclined tubes in the sedimentation chamber (a Water Boy unit manufactured by Neptune Microfloc of Corvallis, Oregon) was tested using chemical coagulant dosages determined by laboratory tests. Up to 97 percent of the total suspended solids were removed in the sedimentation area of this unit, with another 2 to 3 percent removed by a mixed-media upflow filter which followed sedimentation. After the filter had been taken out of the unit, 95 to 97 percent of the suspended solids were consistently removed. The algal slurry from this unit contained 1 to 2 percent suspended solids. A second concentrating device, a Sanborn rapid sand filter assembled by Bohna Engineering of San Francisco, also removed about 95 percent of the suspended solids and produced an algal slurry containing 1 to 3 percent solids. Other units (microscreen, upflow clarifier, and centrifuges) were tested as concentration devices but were not found to be as effective or reliable as the sedimentation and rapid sand filter systems.

Dewatering. An Eimco vacuum filter produced an algal cake containing about 20 percent solids from an influent with about 0.3 to 3 percent solids. This level of removal was obtained using a multifilament nylon belt, a vacuum of 20 to 25 inches of mercury and a solids loading on the belt of up to 17,000 milligrams per square foot per minute. A self-cleaning De Laval centrifuge produced an algal product which contained about 10 to 12 percent solids and removed up to 95 percent of the influent algae (influent concentrations ranging from 500 to 30,000 mg/l). This centrifuge was found to be more effective than either a solid-bowl or nozzle-type unit.

Drying. The algae were normally dried in the open for three to four days on cloth toweling supported by wire frames. A layer of algal slurry 1/2-inch to 3/4-inch thick had dried to about 85 to 95 percent solids at the end of this time. This moisture content allowed safe storage of the material. Studies also showed that the algae could be dried in about two days by spreading the slurry in a 1/2-inch thick layer on asphalt pavement. Pavement drying is easily adaptable for mechanical spreading and collection of the product. One algal sample containing about 15 percent solids was spray-dried by the De Laval Company at the company's test facilities. The operators of the test equipment experienced no problems in attaining the desired level of moisture in the product.

Disposal. Based on a literature review of the possible uses for an algal product and predictions of commercial demands, a market can probably be developed for an algal product which will retail for about $80 to $100 per ton. The question of marketability can be answered more completely when the companies receiving samples of the product algae report their findings. The high ash content (30 to 50 percent) of product algae from these studies may preclude its use as livestock food but it may be acceptable as a protein supplement for fowl or as a soil conditioner. Modification of the harvesting process to include an in-pond settling process to remove soil particles and chemical precipitates may result in two by-products, one containing 10 percent ash and the other about 50 percent ash.

Bacterial Denitrification

The field feasibility studies of anaerobic denitrification of agricultural tile drainage, completed in December 1969, were designed to investigate nitrogen removal by anaerobic filters and covered and uncovered anaerobic deep ponds. The experimental work demonstrated that removal of nitrogen from agricultural tile drainage is technically feasible by means of bacterial denitrification in anaerobic filters and covered anaerobic ponds.

Anaerobic Filters

The anaerobic filter was tested to determine the effect of media, temperature, and long-term operation on filter performance. The following results were obtained primarily from the 18-inch diameter filters; the pilot-scale filter had not been operated extensively enough for adequate evaluation.

Media. Of the several media tested, including sand, activated charcoal, volcanic cinders, and various sizes of aggregate, it was concluded that one-inch diameter rounded aggregate was the most suitable for denitrification of tile drainage in upflow anaerobic filters. The use of smaller diameter aggregate, as well as sand and activated charcoal, eventually led to retention of large bacterial masses in the filters. This bacterial buildup caused high influent pressures and resulted in short-circuiting of water through the filter. Conversely, the larger medium was not effective because the filter did not retain the bacterial cells and these units required longer hydraulic detention times for nitrogen removal. An artificial plastic medium (Dow Surfpac) was tested with unfavorable results in that sufficient bacterial biomass was not retained for efficient filter operation.

Temperature. The effects of various temperatures on performance of the anaerobic filters were determined by observation of filter units under actual operating temperatures, and construction of a small filter in a temperature-controlled environment. In the small filter (4-inch diameter, 6-foot length), when the temperature was lowered from 20°C to 10°C, the denitrification efficiency (percent nitrogen removed) dropped from above 95 percent to about 60 percent. Hydraulic detention times of one and two hours in the 18-inch diameter filters (6-foot bed depth) produced effluents containing 2 mg/l or less total nitrogen until water temperatures fell below 14°C. Below this temperature, only the two-hour detention time filters met the proposed effluent criteria. Samples taken at various media depths in the units showed that as the temperature dropped, more of the filter area was required to achieve the same degree of nitrogen removal; for example, at temperatures above 16°C the two-hour detention time filter was able to achieve 90 percent nitrate reduction (20 mg/l influent) in one-fourth of the filter, but at temperatures of about 12 to 14°C, three-fourths of the bed was required for the same level of removal.

Long-term Operation. Long-term experimentation with anaerobic filters has shown that in time excessive bacterial growth within the filters will cause definite operational problems. Such growth increases effluent ammonia and organic nitrogen, presumably from decomposition of the bacteria, although the decomposition was only a problem in the warmer summer months. The main detrimental effects of the excess biomass are hydraulic changes within the filter such as short-circuiting and excessive head loss. Further experimentation has been conducted in 1970 to determine the most effective and economical method of controlling and/or removing excess bacterial growth from the filters. The 18-inch diameter filters have been effectively flushed by a mixture of air and water forced through the units. This process removes the biomass but also disrupts the filter's performance for several days thereafter.

Methanol Requirement. The amount of methanol required to reduce 20 mg/l of NO_3-N is calculated to be about 56 mg/l. (This assumes that the dissolved oxygen concentration is 8 mg/l and that the amount of methanol based on stoichiometric reactions will have to be increased by about 30 percent to allow for bacterial growth.) In actual operation, the practical lower limit was found to be closer to 65 mg/l. This concentration was necessary for both filter and pond operation.

Special Studies. Results of studies on algal-laden water used as an influent to an anaerobic filter have shown that the algae do not interfere with nitrate-nitrite reduction, but the accumulation of algal cells within the filter and the decomposition thereof, along with suspended algae passing through the filter, eventually produced effluent concentrations of organic and ammonia nitrogen in the range 2 to 5 mg/l.

Anaerobic Deep Ponds.

The large uncovered anaerobic pond never produced an effluent containing less than 2 mg/l total nitrogen, although during the summer months concentrations from 3 to 6 mgN/l were obtained at 10 days' detention time. The relatively low nitrogen removal efficiency undoubtedly resulted from reaeration of the water by wind mixing and photosynthetic oxygen production.

The pilot-scale covered pond reduced an influent nitrate-nitrogen concentration of 20 mg/l to 2 mg/l or less of total nitrogen at temperatures as low as 14°C at a 15-day theoretical hydraulic detention time. It produced 2 mg/l or less total nitrogen effluent concentration at an actual hydraulic detention of 8.2 days at temperatures between 20 and 22°C; however, an actual detention time of five days at this temperature range resulted in an average effluent nitrogen concentration of approximately 4 mg/l. In the experiments that have been completed thus far, successful operation at temperatures below 14°C has not been achieved, but continuing experimentation is expected to show that the 2 mg/l total nitrogen criterion can be met during the colder months of the year.

Effect of Treatment on Removal of Algal Growth Potential

Laboratory experiments were conducted to determine the effect of nitrogen removal on the biostimulatory nature of the subsurface agricultural tile drainage. In these experiments, algal growth was measured in various proportions of treated and untreated tile drainage mixed with water from the Sacramento-San Joaquin Delta near Antioch, a proposed discharge location of an agricultural drain from the San Joaquin Valley. The additions were 1, 10, and 20 percent drainage by volume and were designed to simulate expected ranges of concentration near the outfall. Growth responses of the indigenous Delta algae in the culture flasks were then measured by changes in chlorophyll fluorescence and cell counts.

In each of the mixtures of tile drainage and Delta water tested, the bioassay responses of the treated water mixtures were significantly lower than those of mixtures of untreated tile drainage and Delta water. Spiking the treated water back to the original nitrogen concentration resulted in bioassay responses statistically equal to those caused by the untreated water. Comparison of effluents from algae stripping (growth and harvesting) and bacterial denitrification indicated that, if the inorganic nitrogen concentrations were similar, the algae growth responses of the cultures were in the same range.

The results of this study demonstrated that, in laboratory cultures, nitrogen removal by the biological processes studied at the IAWTC effectively reduced the biostimulatory nature of the waste to Delta waters. The addition of 10 and 20 percent of effluents containing 2 mgN/l or less Delta water yielded growth responses comparable to control cultures containing Antioch water only.

Soil Ponds

The one removal process in which relatively little definitive work was accomplished during this investigation was that of soil-lined ponds. This type of process undoubtedly involves a combination of algal and bacterial metabolic pathways. What probably happened in these unmixed ponds was that algal growth partially removed the dissolved nitrogen; then the algae settled and the anaerobic decomposition of the algal biomass reduced the remaining nitrate to nitrogen gas. Data from the two units operated at the IAWTC showed that for 1969, the average nitrate removal in the soil ponds was about 85 percent of that obtained in the best conventional miniponds (mixing, iron and CO_2 additions, etc.), and that the average total effluent nitrogen was usually less than 3 mg/l. The soil ponds may be comparable to a system from another nitrogen removal process that involved passing the nitrogen-enriched water over a field of water grass. A Bureau of Reclamation study of this latter process indicated that substantial amounts of nitrogen were removed by the grass plots, but the exact mechanisms were not identified. The algal counts in the flooded field were uniformly low and the water remained aerobic at all times (at least as measured by the methods used). The results of the Bureau of Reclamation's study will be published by the Interagency Nitrogen Removal Group as part of the series on nitrogen removal (Williford and Cardon, 1971).

During the 1970 calendar year, studies began at the IAWTC to determine the types of biological systems involved in the soil pond system and to evaluate the process in larger units.

Botulism Studies

The California Department of Fish and Game conducted studies at the IAWTC to determine the potential for botulism outbreaks in the types of units tested at the Center. The studies concluded that the algal ponds and uncovered anaerobic ponds could develop botulism problems, especially if large invertebrate populations were to develop. Based on these and related Department of Fish and Game studies, specific recommendations were proposed to eliminate the potential problem.

All open ponds should have steep sides, a minimum of shoreline, and as great a depth as possible. Before flooding, all vegetation should be burned, and after flooding vegetation on the levees should be controlled. Fluctuation of water level should be minimized and the ponds not allowed to become stagnant for any length of time. All these management practices are designed to eliminate large invertebrate mortalities which can serve as food sources in an environment conducive to the development of *Clostridium botulinum*.

Desalination

Reverse Osmosis

One reverse osmosis unit was evaluated at the Center; however, two membrane stacks (each stack consisted of several membranes) were tested for removal of total dissolved solids and in particular, their ability to remove boron and nitrate. The membranes used in this type of desalination were designed to be permeable to water but not to most ions. In operation, pressure applied to the highly saline water on one side of the membrane forced fresh water across the membrane, leaving most of the salts behind. The first type of membrane tested at Firebaugh was designed to allow little penetration of salts through the membrane and required a high pressure, 750 pounds per square inch (psi), to obtain the desired demineralization. The first membrane also had a low product flow per unit of membrane area (flux). When operating at peak performance, the unit containing this membrane stack removed over 90 percent of the influent TDS (influent range of 3,000 to 7,000 mg/l TDS); however, boron and nitrate were reduced only about 27 percent. About 37 percent of the influent flow was recovered as low salinity product. Operation of the reverse osmosis unit required prefiltration of the influent, pH adjustment to prevent precipitation of calcium carbonate, and treatment to prevent precipitation of calcium sulfate. The efficiency of the first stack began to decrease after about five months, apparently because of biological fouling and subsequent membrane deterioration.

The second stack was designed to have a higher product flux with lower salt rejection characteristics and a lower operating pressures (about 350 psi). This stack was operated on a constant salinity water supply (3,000 mg/l TDS) prepared by blending irrigation canal water with the tile drainage. Initial evaluation of this stack showed that the unit reduced the TDS by about 85 percent but that nitrate and borate ions were not being removed to any measurable extent. Product recovery averaged about 40 percent with this stack, an unexpectedly low recovery rate that was probably caused by faulty assembly of the stack components.

Electrodialysis

The electrodialysis unit was operated as received during the entire project, although the stack was dismantled and cleaned at regular intervals to remove accumulated slime from the membranes which lowered the removal efficiency. The unit had some of the same operational procedures as the reverse osmosis process. The influent was filtered and the pH adjusted to prevent calcium carbonate precipitation. Precipitation of calcium sulfate in the brine stream was prevented by adding dilution water, thus maintaining the compound within its range of solubility. The blended 3,000 mg/l TDS influent used for the second membrane stack was also used to evaluate the electrodialysis unit. The TDS in this water was reduced by about 23 percent in one pass through the stack, with a maximum reduction of about 36 percent. Product recovery was about 75 percent of the influent flow. The unit did not remove the borate ion at any time but did remove nitrate at an average rate about twice that calculated for TDS.

This chapter will present an overall evaluation of the two biological nitrogen removal systems to include removal levels, design configuration, and preliminary cost estimates. Data from the desalination studies will not be included because neither unit removed nitrogen to the desired level.

Nitrogen Removal

Table 1 summarizes the effluent concentrations that might be expected from the biological processes studied at the Treatment Center. The figures for algae stripping include nitrogen assimilation by the growing algae with subsequent removal of 95 percent of the cells by a harvesting process.

Table 1

APPROXIMATE EFFLUENT NITROGEN CONCENTRATIONS EXPECTED FROM THE VARIOUS PROCESSES STUDIED AT THE IAWTC

Treatment Process	Approximate Effluent Nitrogen Concentration in mgN/l*			
	Summer		Winter	
	NO_3-N	Total N	NO_3-N	Total N
Algae Stripping	1.5	3.0	3.5	4.8
Anaerobic Filters	0.5	1.5	0.7	2.0
Covered Anaerobic Ponds		2.0		
Uncovered Anaerobic Ponds	3.6	4.7	6.0	7.5

*20 mg/l influent

These data indicate that the anaerobic filter was the only process studied which provided an effluent of the desired quality (less than 2 mg/l total nitrogen). Based on these data the uncovered anaerobic pond was eliminated from consideration in the 1970 operational studies.

Process Configuration

Figure 5 shows a schematic diagram of a proposed algae stripping system. Algal growth is encouraged by the addition of phosphorus, iron, and carbon dioxide. The growth pond effluent goes through a sedimentation unit, where algae is coagulated by the addition of ferric sulfate. The slurry from the sedimentation tank is then dewatered to about 20 percent solids by vacuum filtration. The sludge is then air or flash dried to about 90 percent solids.

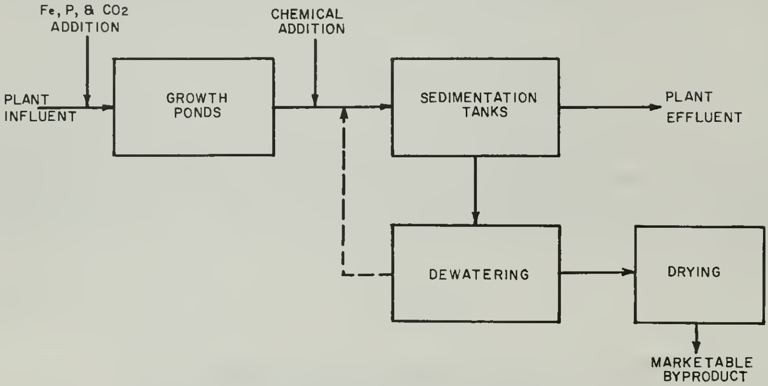

FIGURE 5 - FLOW DIAGRAM OF ALGAL STRIPPING PLANT

Figure 6 shows the proposed configuration for the two anaerobic processes studied at Firebaugh. The algal separation facilities, methanol addition, and reaeration are common to both designs. The sedimentation tank (algal separation) will probably be necessary to remove suspended materials coming in from the drainage canal. The decomposition of this material could cause increases in ammonia and organic nitrogen in the product effluent. Also the suspended material may clog the anaerobic filters. Reaeration of the effluent will be required to increase the dissolved oxygen concentration from zero to about 5 mg/l.

The anaerobic filters will include some type of biomass control system - probably air and water flushing. The material flushed out will go to a washwater lagoon and then will be recycled to the head of the plant.

Cost Estimates

The preliminary cost estimates shown in Table 2 were developed for the two biological nitrogen removal processes studied at the Treatment Center. The estimates are for a plant designed to treat an annual flow of 5×10^{10} million gallons (approximately 1.4×10^5 acre-feet). April climatic conditions in the San Joaquin Valley were used to

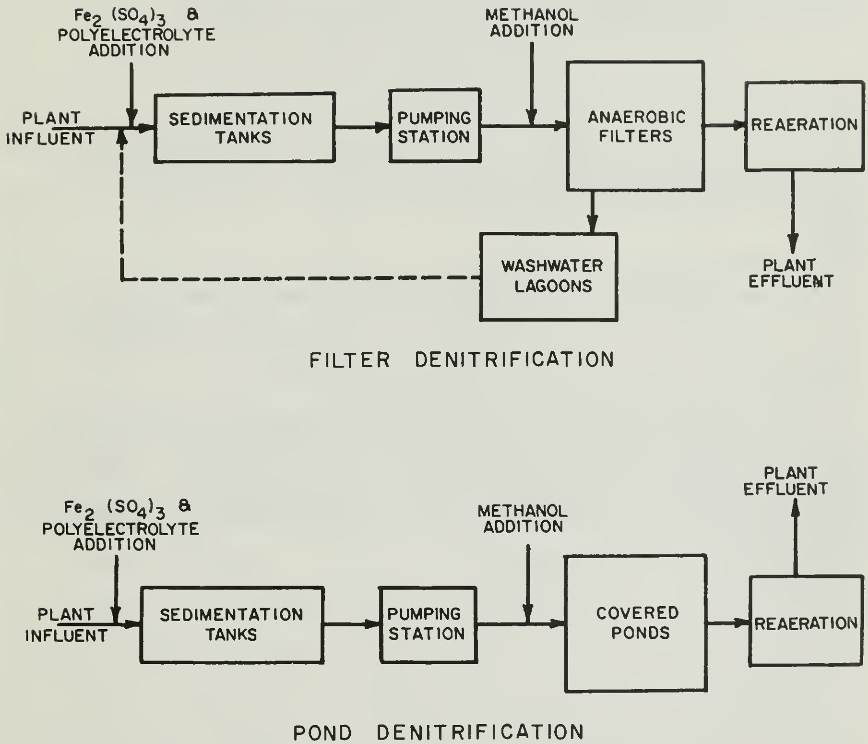

FIGURE 6-FLOW DIAGRAMS OF BACTERIAL DENITRIFICATION PLANT-POND AND FILTER CONFIGURATIONS

predict such important design criteria as depth of pond and detention time. April was selected as the critical month because flow and nitrogen levels in a combined tile drainage collection system are near their predicted yearly maxima, while light and temperature remain at relatively low levels.

Table 2

ESTIMATED TREATMENT COSTS FOR REMOVAL
OF NITROGEN FROM SAN JOAQUIN VALLEY TILE DRAINAGE
(Dollars/million gallons)

Item	Algae Stripping	Anaerobic Denitrification	
		Pond	Filter
Capital Cost	114	41	52
O&M	63	47	40
Byproduct Income	-42		
Net Cost	135 (45)*	88 (30)*	92 (30)*

*Approximate cost in dollars per acre-foot

The cost estimates include engineering and contingency factors and were developed to determine which components of the various systems were the most costly. With this information, the 1970 operational studies could be used to determine methods of reducing the cost of the more expensive components.

ACKNOWLEDGMENTS

The nitrogen removal studies at the IAWTC and the regrowth studies were conducted under the joint direction of Messrs. Donald G. Swain, Sanitary Engineer, U. S. Bureau of Reclamation; Percy P. St. Amant, Jr., Sanitary Engineer, Environmental Protection Agency; and Louis A. Beck, Sanitary Engineer, California Department of Water Resources.

Direction of the algae study in the field was the responsibility of Randall L. Brown (DWR), Bruce A. Butterfield (DWR), and Joel C. Goldman (DWR), and James A. Arthur (EPA). Desalination and bacterial denitrification were the responsibility of Bryan R. Sword.

The cooperation and assistance given by the interagency staff of the treatment center was a major contribution to the success of the field studies. These personnel were:

James R. Jones . Engineer, U. S. Bureau of Reclamation
William R. Lewis . . Chemist, California Department of Water Resources
Robert G. Seals . . . . Chemist, Environmental Protection Agency
Norman W. Cederquist . . . Technician, U. S. Bureau of Reclamation
Gary E. Keller . . . . . . Technician, U. S. Bureau of Reclamation
Dennis L. Salisbury . Technician, California Department of Water Resources
Elizabeth J. Boone . Laboratory Aid, California Department of Water Resources
Clara P. Hatcher . . Laboratory Aid, California Department of Water Resources
William L. Baxter . Laborer, California Department of Water Resources

Consultants to the Project were:

Dr. William J. Oswald . . . . University of California
Dr. Clarence G. Golueke . . . University of California
Dr. Perry L. McCarty . . . . Stanford University

Report Prepared by:

Randall L. Brown . . . . California Department of Water Resources

LIST OF REFERENCES

1. Brown, Randall L. 1971. Removal of Nitrate by an Algal System. California Department of Water Resources Bulletin No. 174-10, EPA No. 13030 ELY 4/71-7, USBR No. REC-R2-71-7.

2. Federal Water Pollution Control Administration. 1967. Effects of the San Joaquin Master Drain on Water Quality of the San Francisco Bay and Delta.

3. Sword, Bryan R. 1971a. Denitrification by Anaerobic Filters and Ponds. Water Quality Office, Environmental Protection Agency No. 13030 UBH 4/71-8, USBR No. REC-R2-71-8, California Department of Water Resources Bulletin No. 174-11.

4. Sword, Bryan R. 1971b. Desalination of Agricultural Tile Drainage. Water Quality Office, Environmental Protection Agency No. 13030 UBH 5/71-12, USBR No. REC-R2-71-12, California Department of Water Resources Bulletin No. 174-15.

5. Tunzi, Milton C. 1971. The Effects of Agricultural Wastewater Treatment on Algal Bioassay Response. Water Quality Office, Environmental Protection Agency No. 13030 ELY 9/71-9, USBR No. REC-R2-71-9, California Department of Water Resources Bulletin No. 174-12.

6. Williford, John W. and D. R. Cardon. 1971. Techniques to Reduce Nitrogen Concentration of Drainage Effluent During Transport or Storage. U. S. Bureau of Reclamation No. REC-R2-71-10, California Department of Water Resources Bulletin No. 174-13, EPA No. 13030 ELY 2/71-10.

PUBLICATIONS

SAN JOAQUIN PROJECT, FIREBAUGH, CALIFORNIA

1968

"Is Treatment of Agricultural Waste Water Possible?"
Louis A. Beck and Percy P. St. Amant, Jr. Presented at Fourth International Water Quality Symposium, San Francisco, California, August 14, 1968; published in the proceedings of the meeting.

1969

"Biological Denitrification of Wastewaters by Addition of Organic Materials"
Perry L. McCarty, Louis A. Beck, and Percy P. St. Amant, Jr. Presented at the 24th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana. May 6, 1969.

"Comparison of Nitrate Removal Methods"
Louis A. Beck, Percy P. St. Amant, Jr., and Thomas A. Tamblyn. Presented at Water Pollution Control Federation Meeting, Dallas, Texas. October 9, 1969.

"Effect of Surface/Volume Relationship, CO_2 Addition, Aeration, and Mixing on Nitrate Utilization by *Scenedesmus* Cultures in Subsurface Agricultural Waste Waters"
Randall L. Brown and James F. Arthur. Proceedings of the Eutrophication-Biostimulation Assessment Workshop, Berkeley, California, June 19-21, 1969.

"Nitrate Removal Studies at the Interagency Agricultural Waste Water Treatment Center, Firebaugh, California"
Percy P. St. Amant, Jr., and Louis A. Beck. Presented at 1969 Conference, California Water Pollution Control Association, Anaheim, California, and published in the proceedings of the meeting. May 9, 1969.

"Research on Methods of Removing Excess Plant Nutrients from Water"
Percy P. St. Amant, Jr., and Louis A. Beck. Presented at 158th National Meeting and Chemical Exposition, American Chemical Society, New York, New York. September 8, 1969.

"The Anaerobic Filter for the Denitrification of Agricultural Subsurface Drainage"
T. A. Tamblyn and B. R. Sword. Presented at the 24th Purdue Industrial Waste Conference, Lafayette, Indiana. May 5-8, 1969.

1969

"Nutrients in Agricultural Tile Drainage"
W. H. Pierce, L. A. Beck and L. R. Glandon. Presented at the 1969 Winter Meeting of the American Society of Agricultural Engineers, Chicago, Illinois. December 9-12, 1969.

"Treatment of High Nitrate Waters"
Percy P. St. Amant, Jr., and Perry L. McCarty. Presented at Annual Conference, American Water Works Association, San Diego, California. May 21, 1969. American Water Works Association Journal. Vol. 61. No. 12. December 1969. pp. 659-662.

The following papers were presented at the National Fall Meeting of the American Geophysical Union, Hydrology Section, San Francisco, California. December 15-18, 1969. They are published in Collected Papers Regarding Nitrates in Agricultural Waste Water. USDI, FWQA, #13030 ELY December 1969.

"The Effects of Nitrogen Removal on the Algal Growth Potential of San Joaquin Valley Agricultural Tile Drainage Effluents"
Randall L. Brown, Richard C. Bain, Jr. and Milton G. Tunzi.

"Harvesting of Algae Grown in Agricultural Wastewaters"
Bruce A. Butterfield and James R. Jones.

"Monitoring Nutrients and Pesticides in Subsurface Agricultural Drainage"
Lawrence R. Glandon, Jr., and Louis A. Beck.

"Combined Nutrient Removal and Transport System for Tile Drainage from the San Joaquin Valley"
Joel C. Goldman, James F. Arthur, William J. Oswald, and Louis A. Beck.

"Desalination of Irrigation Return Waters"
Bryan R. Sword.

"Bacterial Denitrification of Agricultural Tile Drainage"
Thomas A. Tamblyn, Perry L. McCarty and Percy P. St. Amant.

"Algal Nutrient Responses in Agricultural Wastewater"
James F. Arthur, Randall L. Brown, Bruce A. Butterfield, Joel C. Goldman.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1972—484-484/139

1 Accession Number	2 Subject Field & Group	
W	05 D	**SELECTED WATER RESOURCES ABSTRACTS** **INPUT TRANSACTION FORM**

5 Organization

Dept. of Water Resources
San Joaquin District
Fresno, California

Water Quality Office
Environmental Protection Agency
Pacific Southwest Region
San Francisco, California

6 Title

Removal of Nitrogen from Tile Drainage - A Summary Report

10 Author(s)

Brown, Randall L.

16 Project Designation

13030 ELY-Contract #14-06-200-3389A

21 Note

Available from
Department of Water Resources
P. O. Box 2385
Fresno, California 93723

22 Citation

Agricultural Wastewater Studies
Report No. 13030 ELY 7/71, DWR Bulletin 174-9
Pages 28, Figures 6, Tables 2

23 Descriptors (Starred First)

*Agricultural Wastes, *Water Pollution Control, Biological Treatment, Nitrates, Treatment Facilities

25 Identifiers (Starred First)

*Algal Growth and Harvesting, *Bacterial Denitrification, Desalination, Nitrogen Removal

27 Abstract

Studies by an interagency group have shown that it is technically feasible to reduce 20 mg/l nitrate-nitrogen in agricultural tile drainage to 2-5 mg/l by either algae stripping or bacterial denitrification. Conditions necessary for maximum algal growth included 8- to 12-inch pond depth, addition of small amounts of nutrients (CO_2, Fe, and P), up to four hours of daily mixing and detention times of from 5 to 16 days, depending on the season. The algae were harvested by coagulation-sedimentation followed by vacuum filtration. Bacterial denitrification was tested in anaerobic deep ponds and filters using methanol as a carbon source. Required detention times were on the order of 8 to 50 days for covered ponds (uncovered ponds were not suitable) and 1 to 2 hours for filters. During long-term operation of the filters periodic flushing was required to remove accumulated bacterial bi biomass. Preliminary cost estimates were $90 and $135 per million gallons for bacterial denitrification (either pond or filter) and algae stripping respectively. Laboratory studies indicated that nitrogen removal effectively lowered the biostimulatory nature of the waste with respect to algal growth in potential receiving waters.

Two desalination processes were also studied -- electrodialysis and reverse osmosis. Both processes effectively reduced total dissolved solids but neither removed boron, or reduced nitrate to the desired level.

Abstractor: Brown

Institution: Department of Water Resources

ENVIRONMENTAL PROTECTION AGENCY
Publications Distribution Section
Route 8, Box 116, Hwy. 70, West
Raleigh, North Carolina 27607

Official Business

POSTAGE AND FEES PAID
ENVIRONMENTAL PROTECTION AGENCY

If your address is incorrect, please change on the above label; tear off; and return to the above address.
If you do not desire to continue receiving this technical report series, CHECK HERE ☐ ; tear off label, and return it to the above address.