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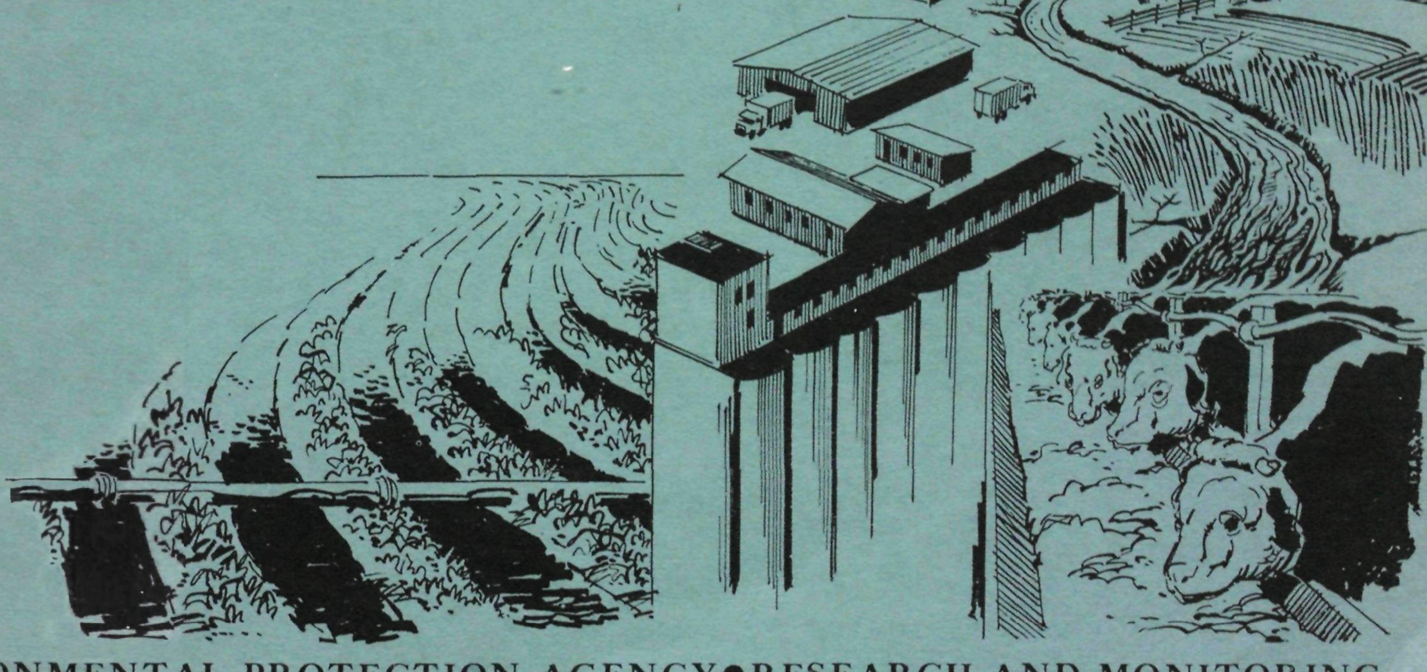
BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE

SAN JOAQUIN VALLEY, CALIFORNIA

DENITRIFICATION BY ANAEROBIC FILTERS AND PONDS

APRIL 1971



ENVIRONMENTAL PROTECTION AGENCY • RESEARCH AND MONITORING

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, "DENITRIFICATION BY ANAEROBIC FILTERS AND PONDS", is one of the three basic reports of this group.

The other three planned reports will cover (1) techniques to reduce nitrogen during transport or storage (2) possibilities for reducing nitrogen on the farm, and (3) desalination of subsurface agricultural wastewaters.

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

DENITRIFICATION
BY
ANAEROBIC FILTERS AND PONDS

Study conducted by

Robert S. Kerr Water Research Center
Treatment and Control Research Program
Ada, Oklahoma

The agricultural drainage study was coordinated by:

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

Paul DeFalco, Jr., Regional Director, Pacific Southwest Region
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

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ABSTRACT

The removal of nitrogen from tile drainage by means of bacterial reduction was investigated at the Interagency Agricultural Wastewater Treatment Center near Firebaugh, California. The major nitrogen form in tile drainage is nitrate (approximately 98 percent). The process required that an organic carbon source be added to the waste to accomplish reduction of the nitrogen. The bacterial process was used in two configurations, anaerobic filters and anaerobic deep ponds. It was found that with the addition of approximately 65 mg/l of methanol 20 mg/l nitrate-nitrogen could be reduced to 2 mg/l or less of total nitrogen within one hour of treatment by filter denitrification at water temperatures as low as 14°C. The same removal was achieved at 12°C in a filter operating at a detention time of two hours. A covered deep pond required an actual detention time of eight days at water temperatures of approximately 22°C and a theoretical detention time of 15 days at temperatures of approximately 16°C to accomplish the same removal. An uncovered pond was not able to achieve the same results at theoretical detention times as long as 20 days. The projected costs for both processes are approximately 90 dollars per million gallons.

This report was submitted in fulfillment of Project No. 13030 ELY under the sponsorship of the Water Quality Office of the Environmental Protection Agency.

Key Words: Agricultural Wastes, Denitrification, Irrigation Return Flows, Nitrate Removal, Anaerobic Treatment.

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 United States 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.

Ultimately, the 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 a 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 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.

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SECTION I

SUMMARY AND CONCLUSIONS

The field feasibility studies of anaerobic denitrification of agricultural tile drainage were completed in December 1969. The experiments were designed to investigate the possibility of removing nitrogen by means of anaerobic filters and anaerobic covered and uncovered deep ponds. It was concluded from the presented experimental work that removal of nitrogen from agricultural tile drainage is technically feasible by means of bacterial denitrification in anaerobic filters and covered anaerobic ponds. Furthermore, according to preliminary cost estimates for the two processes, the cost of treatment for agricultural tile drainage will be 92 dollars per million gallons for anaerobic filters and 88 dollars per million gallons for covered anaerobic ponds. Summaries of secondary conclusions and experimental findings for each of the above processes follow.

Summary of Anaerobic Filter Results

In evaluation studies of various media for use in anaerobic filters, it was determined that the most feasible medium in terms of performance, cost, and operational control was rounded aggregate having a size range of 0.75 to 1.5 inches in diameter. Early performance of an anaerobic filter containing one inch diameter aggregate and operated at a 1-hour hydraulic detention time within a water temperature range of 14 to 20°C showed that an influent nitrate-nitrogen concentration of 20 mg/l could be reduced to 2 mg/l or less. A filter containing the same size medium and receiving the same influent nitrogen concentration but operated on a 2-hour detention time within a temperature range of 12 to 22°C produced an effluent having a total nitrogen concentration of 2 mg/l or less. Preliminary investigations indicate that hydraulic detention times as long as 7.5 hours may be necessary to produce an effluent containing a 2 mg/l or less total nitrogen concentration at water temperatures lower than 14°C and influent nitrate-nitrogen concentrations of up to 35 mg/l. Long term experimentation with anaerobic filters demonstrated that operational problems will eventually occur due to excessive bacterial growth within the filters. The excess growth led to an increase in total Kjeldahl nitrogen in the effluent discharged from a filter. Furthermore, the bacterial mass results in a change in hydraulic patterns within the filter. The change had an adverse effect on the nitrogen removal capacity of the filters. Future experimentation is necessary to determine methods of controlling and removing excess bacterial growth from the filters. Studies with a pilot scale filter have not as yet led to the nitrogen removal results comparable to those obtained with the smaller filters. The operation of the pilot scale filter was adversely affected by operational start-up problems and detention time changes imposed before a sufficient bacterial mass had accumulated.

Results of studies on the use of algae-laden water as an influent to an anaerobic filter indicate that the algae do not interfere with nitrate-nitrite removal. The accumulation of algal cells within the filter and the decomposition thereof, along with suspended algae passing through the filter eventually resulted in the production of excessively high effluent concentrations of total ammonia plus organic nitrogen (range 2 to 5 mg/l-N). Based on studies by the California Department of Fish and Game, it is not expected that full-scale anaerobic filters would offer any major threat to waterfowl by furnishing a possible habitat for Type C Botulism.

Summary of Anaerobic Deep Pond Denitrification

Experimental data obtained with the uncovered pond show that at no time did the pond meet the 2 mg/l total nitrogen effluent criterion. Operational problems which would occur in such a pond would include the prevention and/or elimination of algal blooms that may occur; oxygen production by the algae would hinder the establishment of the anaerobic conditions; and in large ponds, wind mixing would bring about an input of dissolved oxygen that would be much more thoroughly distributed than was the case in the pond used for the studies reported herein. Although an outbreak of botulism in uncovered ponds could possibly occur; outbreaks can be prevented by following suitable operational practices.

The covered pond was capable of reducing an influent nitrate-nitrogen concentration of 20 mg/l to 2 mg/l or less of total nitrogen at water temperatures as low as 14°C at a 15-day theoretical hydraulic detention time. With the temperatures at 20° to 22°C, it could produce an effluent having a total nitrogen concentration of 2 mg/l or less at an actual detention time of 8.2 days. When the actual detention time was shortened to 5 days, the effluent requirement of 2 mg/l total nitrogen could not be met. Instead the average effluent concentration remained at approximately 4 mg/l total nitrogen. In the experiments which have been completed, successful operation at temperatures below 14°C has not been achieved. However, continuing experimentation is expected to show that the 2 mg/l total nitrogen criterion can be met during the colder months of the year. Operational problems with a covered pond would be limited to those pertaining to the hydraulic regime; however, if properly designed these should be minimized. Due to the covering of the pond, no operational problem would be encountered with respect to algal blooms or wind mixing. Additionally, the possibility of Type C Botulism is eliminated by the use of a covered pond, since the water surface would not available to waterfowl.

SECTION II

INTRODUCTION

This report presents the results of the experimental studies on bacterial denitrification of agricultural tile drainage performed at the Interagency Agricultural Wastewater Treatment Center (IAWTC) near Firebaugh, California. Specifically, the report deals with the feasibility portion of a continuing study on the removal of nitrate-nitrogen from subsurface tile drainage waters occurring in the San Joaquin Valley by the use of anaerobic filters and/or anaerobic deep ponds. The studies were initiated in June 1967 and will be continued through December 1970. The last year is being devoted to making operational refinements, the results of which will be published in a future report.

The objectives of the first phase of the studies were to determine the feasibility of the processes under study to remove nitrogen from tile drainage under field conditions, and to develop preliminary information on the treatment costs. To satisfy these primary objectives, the pilot-scale studies discussed in this report were designed to determine: (1) the relationship between the maximum practical nitrogen removal efficiency and the minimum hydraulic detention time for anaerobic covered ponds, uncovered ponds, and filters; (2) the actual organic carbon requirement; (3) the significance of different media on anaerobic filter performance; and (4) the effect of prolonged operation on treatment efficiency and process operation and maintenance costs.

Water Quality Criteria

In a report by the Federal Water Quality Administration, it was recommended that the total nitrogen content in the treated tile drainage not exceed 2 mg/l (1). This recommendation was made the effluent criterion that determined whether or not any treatment process under consideration was technically acceptable. In this report the term "total nitrogen" refers to the sum of the nitrogen concentrations of the following compounds; nitrate, nitrite, ammonia, and organic nitrogen.

Process Background

The relationships existing between the various forms of nitrogen in the biosphere are best illustrated by the diagram of the nitrogen cycle developed by Sawyer (2) and reproduced in this report in Figure 1. The basic biological phenomena involved in the nitrogen cycle are: fixation of atmospheric nitrogen, assimilation of inorganic nitrogen into cellular material, decomposition of cellular organic nitrogen to inorganic nitrogen, and reduction of oxidized inorganic nitrogen forms by bacteria to gaseous nitrogen. The processes described herein entail only the latter part of the above cycle. Bacterial nitrogen reduction is divided into two classes:

assimilatory and dissimilatory nitrogen reduction. In assimilatory nitrogen reduction, nitrate and/or nitrite-nitrogen is reduced to ammonia prior to incorporation into cellular material. In dissimilatory nitrogen reduction, the oxidized anions serve as exogeneous hydrogen acceptors for the oxidation of organic carbon (3). The principle end product of dissimilatory nitrogen reduction is gaseous nitrogen. The process described in this report is primarily dissimilatory in nature.

Dissimilatory Nitrogen Reduction

Dissimilatory nitrogen reduction, commonly spoken of as denitrification, can be brought about by a large number of commonly occurring facultative bacteria (4). It occurs most frequently under anaerobic, or nearly anaerobic, conditions. The exact degree of the inhibition of denitrification by the presence of oxygen is not known (5) (6). However, it is a well accepted fact that the inhibition is a non-competitive type due to a large difference in the reaction rates for oxidized nitrogen utilization and oxygen utilization (7).

Some bacteria can only reduce nitrate to nitrite, others can only reduce nitrite to molecular nitrogen, while a third group can bring about the

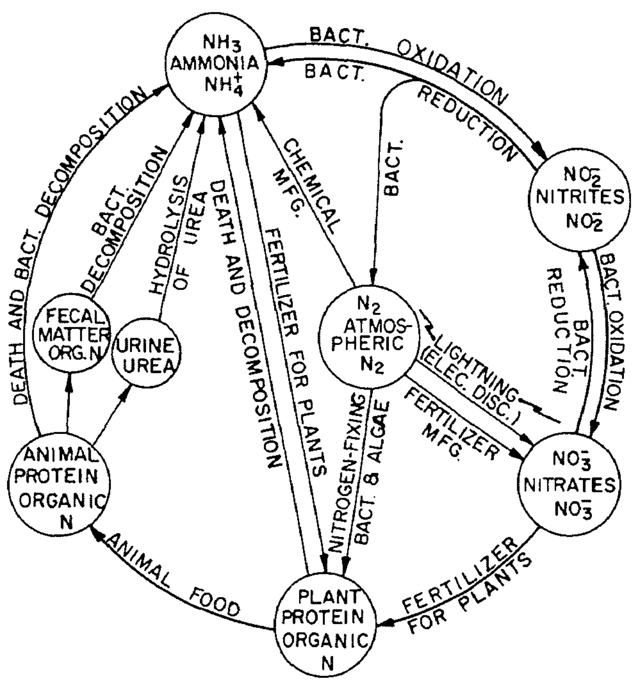


FIGURE 1 - THE NITROGEN CYCLE AS PRESENTED BY SAWYER (2)

reduction of nitrate and/or nitrite to molecular nitrogen (8). However, the enzymatic reactions involved for all of the different organisms are basically the same. Taniguchi, et al, proposed a biochemical pathway for nitrate reduction, which with the exception of the terminal enzyme, is the same as the pathway involved when oxygen is used as the terminal hydrogen acceptor (9). In denitrification, nitrate reductase is the terminal enzyme while cytochrome oxidase is used when oxygen is the terminal acceptor. Heredia and Medina (10) discovered an alternate pathway involving Vitamin K_3 while studying Escherichia coli. This pathway is operative under both aerobic and anaerobic conditions, and is most likely the one associated with assimilatory nitrate reduction. Others have determined that the proposed pathways apparently are reasonably representative of the general pathway of nitrogen reduction (3).

Assuming a heterogeneous population of bacteria, an adequate supply of organic carbon, and relatively anaerobic conditions, any or all of the following half reactions may take place:

$$1/2\ NO_3^- + H^+ + e^- = 1/2\ H_2O + 1/2\ NO_2^- \quad (1)$$

$$1/3\ NO_2^- + H^+ + e^- = 1/3\ H_2O + 1/6\ N_2 + 1/3\ OH^- \quad (2)$$

$$1/5\ NO_3^- + H^+ + e^- = 2/5\ H_2O + 1/10\ N_2 + 1/5\ OH^- \quad (3)$$

By combining these half reactions with the half reaction for the oxidation of a biologically degradable organic carbon source, a set of balanced stoichiometric equations for dissimilatory nitrogen reduction can be derived. For example, the following equations are derived if the organic carbon source being oxidized is methanol (CH_3OH):

$$NO_3^- + 1/3\ CH_3OH = NO_2^- + 1/3\ CO_2 + 2/3\ H_2O \quad (4)$$

$$NO_2^- + 1/2\ CH_3OH = 1/2\ N_2 + 1/2\ CO_2 + 1/2\ H_2O + OH^- \quad (5)$$

$$NO_3^- + 5/6\ CH_3OH = 1/2\ N_2 + 5/6\ CO_2 + 7/6\ H_2O + OH^- \quad (6)$$

Equations 4, 5 and 6 constitute the theoretical foundation upon which waste treatment by dissimilatory nitrogen reduction is based. They are used to determine the amount of organic carbon required for the reduction of a given quantity or concentration of nitrogen in a waste. However, if the quantity of organic carbon determined by these equations were used, denitrification would not be complete. Additional carbon must be added to supply that needed for cell growth. There are little data in the literature to indicate what this additional requirement might be. But it is known that it varies from organism to organism, with the nature of the organic carbon source being used and the environment in which the denitrification is taking place (11)(12).

Consumptive Ratio

The consumptive ratio is defined as one obtained by dividing the actual quantity of organic carbon source required to denitrify and deoxygenate a waste plus the carbon required for cell growth by the stoichiometric requirement for denitrification and deoxygenation of the waste (13). It is used to quantify the carbon source needed to complete the denitrification process. A consumptive ratio value of one would indicate that no chemical was required for cell synthesis. A ratio greater than one is to be expected. The higher the ratio the greater is the chemical requirement for biological growth.

The actual consumptive ratio for a particular set of conditions must be determined experimentally. Once a consumptive ratio value is determined, equations can be developed for predicting the amount of the bacterial cells that will be synthesized. Using a typical empirical formulation of $C_5H_7O_2N$ for bacterial cells (14), the following equations were developed by McCarty, et al, for the denitrification process when methanol is used as the carbon source with a consumptive ratio equal to 1.3, as determined in their study (11).

Overall nitrate removal:

$$NO_3^- + 1.08\ CH_3OH + H^+ = 0.065\ C_5H_7O_2N + 0.47\ N_2 + 0.76\ CO_2 + 2.44\ H_2O \quad (7)$$

Overall nitrite removal:

$$NO_2 + 0.67\ CH_3OH + H^+ = 0.04\ C_5H_7O_2N + 0.48\ N_2 + 0.47\ CO_2 + 1.7\ H_2O \quad (8)$$

Overall deoxygenation:

$$O_2 + 0.93\ CH_3OH + 0.056\ NO_3^- + 0.056\ H^+ = 0.056\ C_5H_7O_2N + 0.65\ CO_2 + 1.69\ H_2O \quad (9)$$

The consumptive ratio of 1.3 was used for Equations 7, 8, and 9 even though the consumptive ratio for deoxygenation alone probably is different from that for denitrification alone (11). However, as long as the ratio of nitrogen to oxygen in the influent waste stream is fairly large, the results of using such predictive equations should be sufficiently accurate for most cases. It should also be noted that even though dissimilatory nitrogen reduction is the principle mode of nitrogen removal, some assimilatory nitrogen reduction takes place. For example, if the influent waste stream contains 20 mg/l of nitrate-nitrogen and 8 mg/l of dissolved oxygen, according to Equations 7, 8, and 9, 1.5 mg/l of the influent nitrate-nitrogen would be assimilated into the organic nitrogen of the 12.1 mg/l of cellular biomass produced. These relationships are more clearly illustrated by converting the molar equivalents in Equations 7, 8, and 9 to milligrams per liter as follows:

10 mg/l of NO_3-N plus 24.7 mg/l of methanol will produce
5.25 mg/l of cells which contain 0.65 mg/l of Organic-N

10 mg/l of NO_2-N plus 15.3 mg/l of methanol will produce
3.22 mg/l of cells which contain 0.4 mg/l of Organic-N

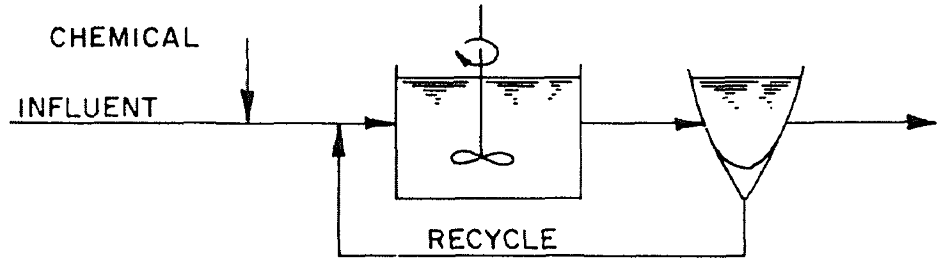
10 mg/l of dissolved oxygen plus 9.3 mg/l of methanol plus
0.35 mg/l of NO_3-N will produce
2.0 mg/l which contain 0.25 mg/l of cells of Organic-N

Because of its relation with process efficiency and treatment costs, the determination of the consumptive ratio for denitrification of agricultural wastewater was of importance in the field work.

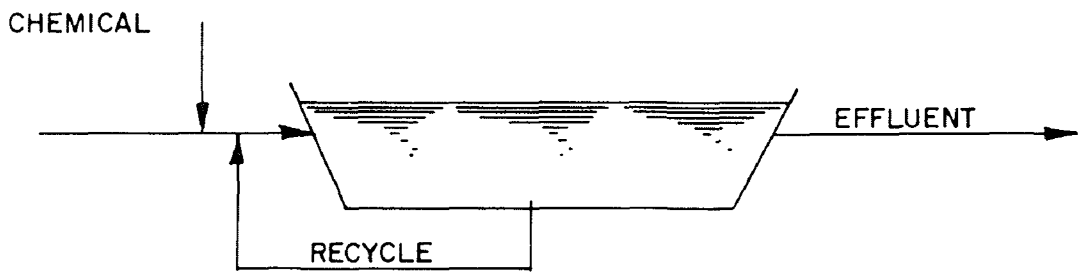
Waste Treatment by Dissimilatory Nitrogen Reduction

As with most biological waste treatment techniques, there are several different process designs that may be used for denitrification. In Figure 2, three denitrification process designs are diagramed: anaerobic activated sludge, anaerobic ponds, and anaerobic filters. In an activated sludge plant, the waste is aerated until it is nitrified. It is then mixed with a small proportion of untreated plant influent which serves as the organic carbon source and is then treated under anaerobic conditions to allow denitrification to take place (15). Because of the short detention times in such a plant, it is necessary to separate the bacteria cells produced from the effluent of the denitrification unit, and recycle them to the influent of the unit. Because of the low cell production that takes place during denitrification, cell separation and recycling can be relatively difficult to accomplish. In addition, due to variations in the quality of municipal and industrial wastes, the anaerobic activated sludge method of denitrification has been found difficult to control (16).

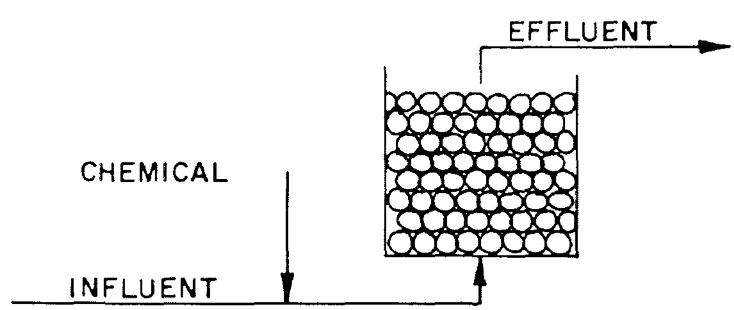
In the anaerobic pond denitrification process the bacteria are "free floating" in the waste. In order to accomplish successful treatment, it is necessary that the reproduction rate of the bacteria be equal to or greater than the hydraulic detention time of the treatment vessel. If this criterion is not met the bacteria population will be washed out of the system. Studies conducted with the use of completely and partially mixed simulated anaerobic ponds, in which methanol was used as the organic carbon source, show that the required hydraulic detention times are on the order of days, rather than of hours as for anaerobic activated sludge process (12)(17)(18). The long detention times requires substantial land area for treatment



ANAEROBIC ACTIVATED SLUDGE



ANAEROBIC POND



ANAEROBIC FILTER

FIGURE 2 - ANAEROBIC PROCESSES FOR DENITRIFICATION

plants using the anaerobic pond system. When land availability is not a problem, the anaerobic pond can be an attractive method.

The third anaerobic process for denitrification utilizes a reactor vessel which is filled with an inert biological support medium. The support medium (or packing material) provides a means of retaining the bacteria necessary for the attainment of efficient denitrification within the treatment vessel. By retaining the bacterial culture on an inert medium, the solids retention time of the process can be prolonged beyond the hydraulic detention time without solids separation and recycle. This type of unit is referred to as an anaerobic filter. The necessary anaerobic conditions are maintained by operating the unit in such a way as to keep the media bed completely submerged with the waste being treated. In 1959, Finsen and Sampson (19) reported on an experimental study in which they passed a nitrified waste upward through a column filled with 1-inch diameter glass marbles using cane sugar molasses as the organic carbon source. The unit was operated with a hydraulic detention time of 2.5 hours, but most of the denitrification took place within 37 minutes after entry into the unit. A few other studies of denitrification in anaerobic filters have been conducted in which glucose or methanol was used as the organic carbon source (20)(21)(22). Findings made in these investigations were similar to those by Finsen and Sampson. They all indicate that anaerobic filter denitrification is a process characterized by high removal efficiency and a short required hydraulic detention time comparable to that for anaerobic activated sludge denitrification, and yet not beset with the operating difficulties characteristic of the latter process.

SECTION III

EXPERIMENTAL PROCEDURES

To determine the technical feasibility of denitrifying agricultural tile drainage under field conditions, it was essential to test the processes under the nearest to actual conditions that were attainable at the time. The following is a description of the water, apparatus and procedures used in the experimental work at the Interagency Agricultural Wastewater Treatment Center (IAWTC) for this purpose.

Water Quality

The water used for the experimental work was taken from a tile drainage system which serviced a 400-acre field. The land was used primarily for the cultivation of rice during the summer and for barley during the winter. The water requirement for the two crops differs greatly, thereby causing the quantity of irrigation water applied to have a large seasonal variance. The variance in turn led to a seasonal change in the dissolved minerals of the drainage from this field. In Table 1 are listed the mineral concentration ranges of the tile drainage used at the IAWTC, and also the average mineral concentrations of the irrigation water. The higher dissolved mineral concentrations are present during the winter when tile drainage return flows decrease.

The nitrogen in the tile drainage was essentially in the form of nitrate. Nitrite-nitrogen was not detected at concentrations greater than 0.1 mg/l; while organic nitrogen generally was constant at a concentration of approximately 0.4 mg/l, and ammonia-nitrogen concentration was usually undetectable. It should be noted that the nitrogen concentration in this particular tile system varied to such an extent that it was necessary during high flow seasons to supplement the tile drainage with sodium nitrate so that the desired nitrate concentrations be maintained. During the low flow season, it was sometimes necessary to supplement the quantity of tile drainage flow in order to have a sufficient supply for the experiments. The supplemental water was taken from the Delta-Mendota Canal which supplies irrigation water for the central San Joaquin Valley. Water from the canal has a total dissolved solids of less than 500 mg/l and a negligible nitrogen concentration. Therefore, when canal water was used, it was necessary to increase the nitrate concentration.

Apparatus

To fulfill the objectives of the study, various pieces of experimental equipment had to be fabricated. The majority of the apparatus used in filter experimentation was made of commonly available materials and was constructed by the Center's personnel. Other apparatus such as large-scale ponds were constructed by contract. The following is a summary of the field apparatus used at the Interagency Agricultural Wastewater Treatment Center.

TABLE 1

CHARACTERISTICS OF TILE DRAINAGE USED AT THE INTERAGENCY AGRICULTURAL WASTEWATER TREATMENT CENTER
and
AVERAGE MINERAL CONCENTRATIONS OF IRRIGATION WATERS

CONSTITUENT	RANGE OF MINERAL CONCENTRATIONS IN TILE DRAINAGE mg/l	AVERAGE MINERAL CONCENTRATION OF IRRIGATION WATER mg/l
Bicarbonate	280-330	90
Boron	4-15	0.3
Calcium	160-390	20
Chloride	310-640	60
Magnesium	70-230	10
Nitrogen	5-25	1
Phosphate	0.13-0.33	0.5
Potassium	4-11	3
Sodium	620-2050	50
Sulfate	1500-3900	65
Pesticides (CHC)	0.001	
Total Dissolved Solids	2500-7600	300
5 Day BOD	1-3	
COD	10-20	
Dissolved Oxygen	7-9	

Anaerobic Filters

Anaerobic filters were constructed in three sizes. Initially, small-scale units were used in studying the process feasibility under field conditions. Once shown that the process did work, larger-scale units were constructed to continue the feasibility work and to conduct operational studies. Having successfully completed this phase, a pilot-scale unit was erected to study the effect of larger-scale operations on process efficiency.

Small-Scale Units. Units used for the initial feasibility studies of filter denitrification were constructed of a 4-inch diameter polyvinyl chloride (PVC) pipe. These filters contained 6.5 feet of media and were plumbed to provide an upward flow of water. Larger-scale experimental units were constructed of 18- and 36-inch diameter reinforced concrete pipe containing six feet of media. In the 18-inch diameter filters the influent distribution system consisted of a perforated PVC pipe extending across the filter bottom. The 36-inch diameter filters had a media support screen located approximately four inches above a flow distribution system which consisted of perforated PVC pipe placed in a cross-configuration. The flow to these units was controlled by rotameters and the methanol was injected by positive displacement chemical feed pumps immediately prior to entrance to the filter. To permit extractions of samples from within the filter, profile sample ports were located at the depth quarter points of the 18-inch diameter filters, and at one-foot intervals of the 36-inch diameter filters. The sampling devices consisted of lengths of perforated PVC pipe placed diametrically across the filter diameter to make it possible to take representative samples.

Media selected for the experimental filters were obtained from local commerical sources or from natural deposits and were graded with two sets of screens. The smaller media were graded to pass a 3/8-inch sieve and be retained on a 1/4-inch sieve. The larger media were graded to pass a 1-1/4-inch sieve and be retained on a 7/8-inch sieve. The media used were activated carbon, aggregate, coal, volcanic cinders, sand, and a commercially produced artificial media.

Pilot-Scale Filter. The successful operation and performance of the small scale experimental units justified the construction of a pilot-scale filter similar in hydraulic and structural design to a projected full-scale unit. Such a pilot filter was constructed in the spring of 1969. A pictorial diagram of the unit is shown in Figure 3. The unit is of wood construction having dimensions of 10-feet by 10-feet square and with a water depth of 7 feet. The medium depth was set at 6 feet, and was supported by a false bottom similar to that used in sand filtration units. The medium surface support was constructed to form an 8.5-inch deep reservoir at the filter bottom. The medium selected for this filter was rounded aggregate graded to pass a 1-1/2-inch sieve and be retained on a 3/4-inch sieve. This selection was based on the success of the smaller filters which contained 1-inch diameter aggregate. The filters influent system was a series of five perforated pipes 9 feet in length installed at equal intervals across the plenun chamber. During most of the time in which the filter was operated, only the center influent pipe was used for distribution of the water.

Flow through the unit was measured by a 60° "V" notch effluent weir. Methanol addition was accomplished by its injection into the influent line just prior to entering the filter. An extensive series of sample taps were installed which allowed a total of 75 samples to be taken from within the media bed. As shown in the pictorial diagram in Figure 3 five sampling levels were provided, and at each level 3 sample manifolds were installed. Each manifold had 5 sampling ports connected to PVC pipe of either 1, 3, 5, 7, or 9 feet in length, thus forming a sampling pattern which transected the medium bed. The sample ports made it possible to monitor nitrogen and pressure profiles. Also installed within the filter were 4 temperature probes, one near each wall approximately at midmedium depth. The probes were used to detect any large temperature differential which might exist between sections of the filter and which could alter the hydraulic regime within the filter.

Temperature Controlled Filter. As experimentation progressed, it became apparent that an in-depth study was needed of the temperature effect on filter denitrification. For this purpose a filter was placed in a temperature controlled environment. A 4-inch diameter filter constructed of PVC pipe was installed within an incubator capable of maintaining high and low temperatures. The total medium depth of the filter was 6 feet divided into 3 sections of 2-foot lengths. Each section was fitted with profile sample taps similar to the larger filters. The medium selected for this filter was .375-inch diameter glass beads. Glass beads were selected to provide a known surface area for the bacteria population. Operation of the unit involved placing a 24-hour tile drainage supply in the incubator prior to introducing it into the filter in order that it could attain the proper temperature. Thus, two water reservoirs were contained within the incubator at one time, one being brought to the

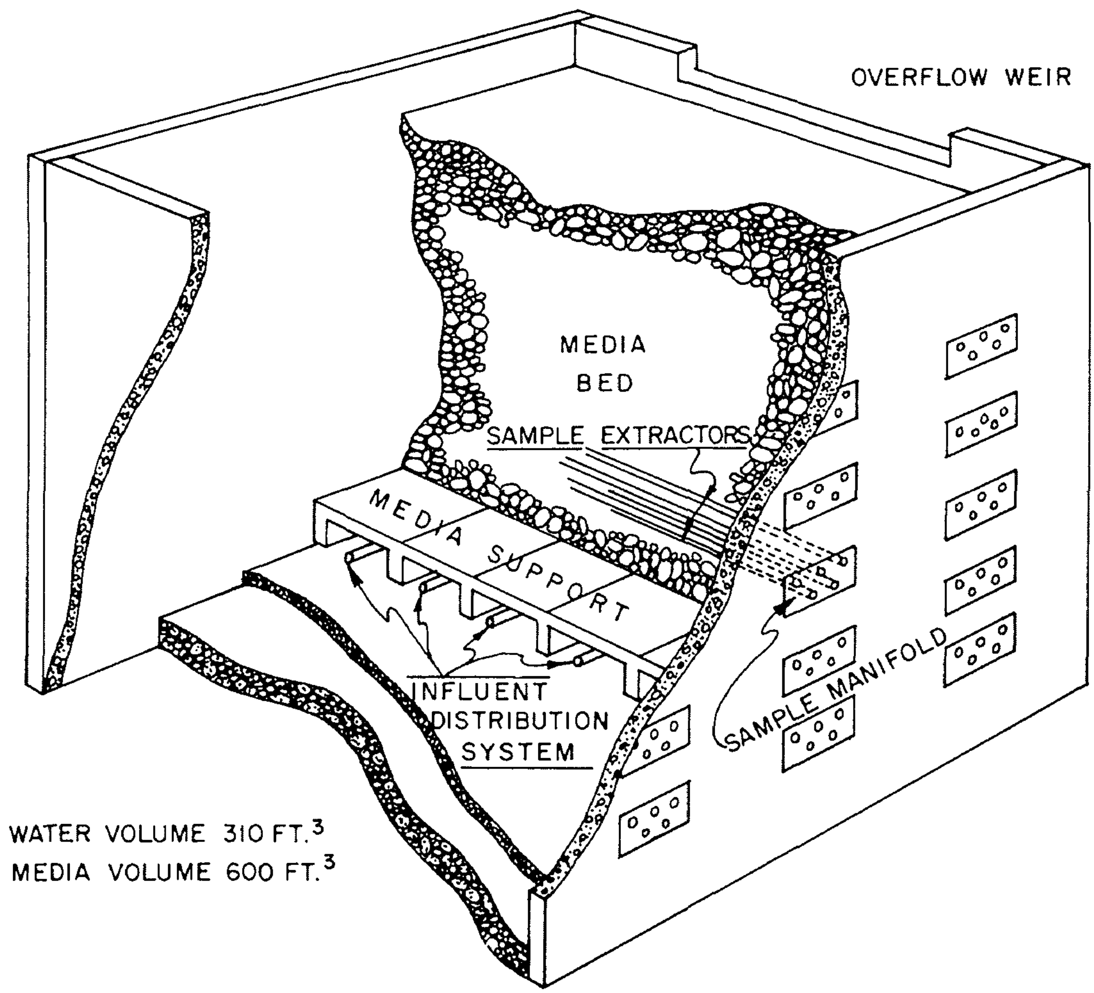


FIGURE 3 - PICTORIAL OF PILOT SCALE FILTER

required temperature while the other was being pumped to the filter. Methanol was premixed with the water entering the filter, precaution being taken to eliminate the development of bacteria within the holding tank which would lead to denitrification of the irrigation return water before it entered the filter. The temperature environment for this filter was varied from 7.5°C to 25°C.

Anaerobic Ponds

Deep pond anaerobic denitrification was studied in two phases. In the first phase, feasibility studies were done in small-scale simulated ponds. One of the objectives of this phase was to confirm under field conditions the laboratory work performed by McCarty (17). In the second phase the results of the initial studies were used in designing and conducting large-scale operations.

Simulated Deep Ponds. A series of six small scale deep ponds, 3 feet in diameter and varying in depth from 6 to 11 feet were constructed of reinforced concrete pipe. Three of the ponds were equipped with covers to eliminate wind mixing and algal growth, while the remaining three were left as open ponds. Flow through the ponds was regulated by positive displacement pumps, and methanol was added to a common intake line for all simulated ponds.

Large-Scale Ponds. Two large-scale earthen ponds were constructed. The larger pond had a water surface dimension of 50 feet by 200 feet and a capacity of approximately 750,000 gallons at a depth of 14 feet. It was covered with 2-feet x 8-feet x 3-inch styrofoam planks. This floating cover served to eliminate light, wind mixing, and provided an insulating layer which reduced temperature differentials within the pond. The cover also functioned as a means of collecting in-pond samples without the need for construction of elaborate scaffolding. Flow through the pond was monitored by means of a 60° "V" notch weir located at its effluent.

A second pond was constructed adjacent to the above described pond. This pond had a water surface dimension of 50 feet x 50 feet and a capacity of 220,000 gallons at a depth of 14 feet. The pond was not covered in order that the effects of wind mix, light, and differential temperatures could be monitored. Flow through the pond was monitored by a recording flow meter. Methanol injection to both ponds was accomplished by positive displacement chemical feed pumps, injection being made into the influent pipes of the ponds.

To maintain bacterial biomass within the ponds, flow from the ponds bottoms between the influent and effluent was recirculated and mixed with the respective influents. The recirculation rates for the ponds were about 50 and 35 gpm for the covered and uncovered ponds respectively and were constant during most of the study period.

Methanol Additions

In the initial studies, the concentration of methanol added to the filters was determined according to the following equation which was developed by McCarty (11):

$$C_m = [1.90\ N_0 + 1.18\ N_1 + 0.67\ D_0]\ C_r \qquad (10)$$

C_m = required methanol concentration, mg/l

N_0 = initial nitrate-nitrogen concentration, mg/l

N_1 = initial nitrite-nitrogen concentration, mg/l

D_0 = initial dissolved oxygen concentration, mg/l

C_r = consumptive ratio for the particular nitrified waste.

Based upon the work of McCarty, et al, a consumptive ratio of 1.3 was assumed to be applicable to agricultural wastewaters (11). Making an allowance for the dissolved oxygen content of the waste being treated (7 to 9 mg/l), an estimate based on Equation 10 indicated 55.5 to 57.2 mg/l of methanol would be required to remove 20 mg/l nitrate-nitrogen. In practice, however, due to normal daily variations of approximately 3 mg/l in the influent nitrate concentrations of the tile drainage, 65 mg/l of methanol were added as a safety factor for the expected average of 20 mg/l nitrate-nitrogen. A similar increase in methanol addition over that required according to Equation 10 was made for the higher nitrate concentrations used in filter experiments.

Process Evaluation Procedures

Evaluation of the aforementioned apparatus required monitoring of both physical and chemical parameters. A description of the procedures employed in maintaining operational control and making process evaluations follows.

Operating and Sampling Procedure

To insure that all experimental factors under consideration were controlled and maintained at the required levels, periodic maintenance and inspection checks of all apparatus were performed at 4-hour intervals for a minimum of 16 hours per weekday and 12 hours per day on weekends. This coverage was found to be sufficient for control of standard operational parameters such as flow rates, methanol addition, etc., and to prevent or correct equipment breakdown.

Hydraulic tracer analyses were performed as needed. Tracer studies were analyzed by means of the volume apportionment technique (23)(24). The advantage of the volume apportionment technique is that a definite tracer response curve is obtained, which allows simultaneous identification of such hydraulic characteristics as short circuiting, stagnant zones, plug flow, and complete mixing. A step increase or decrease of a tracer element in the influent of the reactor is used for this method. Differential equations have been developed which identify the relationships which can occur. The majority of the reactor vessels used at the treatment center had hydraulic response curves which indicated that the vessel volume was partially completely mixed in series with plug flow and contained some stagnant zones. In such a system a step decrease in a tracer concentration from C_o to C would give the following equation:

$$C/C_o = e^{-1/a\,[qt/v\ -\ (1-a-b)]}$$

where

C = Effluent tracer concentration at time = t

C_o = Effluent tracer concentration when time = o

C/C_o = Fraction of tracer element remaining at time = t

V = Total reactor volume

e = Natural logarithm base

q = Flow rate

t = Time after the change in tracer concentration

qt/v = The number of detention times since the change in tracer concentration. (When $qt/v = 1$; $a = 1$; $b = o$ then $C/C_o = e^{-1} = .368$)

a = Fraction of total volume which is completely mixed

b = Fraction of total volume which is stagnant

1-a-b = Fraction of total volume which is plug flow

A typical curve for this equation when plotted on semilog paper is shown in Figure 4. Points A and B on the abscissa are defined as:

$$A = 1-a-b$$

$$B = 1-b$$

In practice the tracer elements used were the chloride ion for the filters and Rhodamine B dye for the deep ponds. A tracer response curve such as Figure 4 is plotted using the values of the vessel's effluent tracer concentration. The numerical values of A and B are then known and the hydraulic patterns for the vessel can then be classified. For more detailed information the reader is referred to the above noted references.

Grab samples for chemical analysis were collected during the morning and were analyzed within a few hours. Studies to determine diurnal variations of chemical and physical factors were also conducted as deemed necessary. Water temperatures were monitored daily with maximum-minimum thermometers and periodically with 8-day recording thermographs. The influent pressure required for an anaerobic filter to maintain a constant hydraulic detention time also was monitored daily. The rotameters used for flow control were calibrated volumetrically.

Analytical Procedures

Laboratory analyses were conducted according to the schedule and method given in Table 2. The majority of the techniques were used as described in Standard Methods (25). Until September 11, 1968, effluent methanol was originally determined by a chromatropic acid method (26)(27)(28). After that date methanol determinations were made with the use of gas chromatograph equipped with a carbowax column and a flame ionization detector. Average influent methanol was calculated over a 24-hour period by measuring amounts injected by the chemical feed pumps.

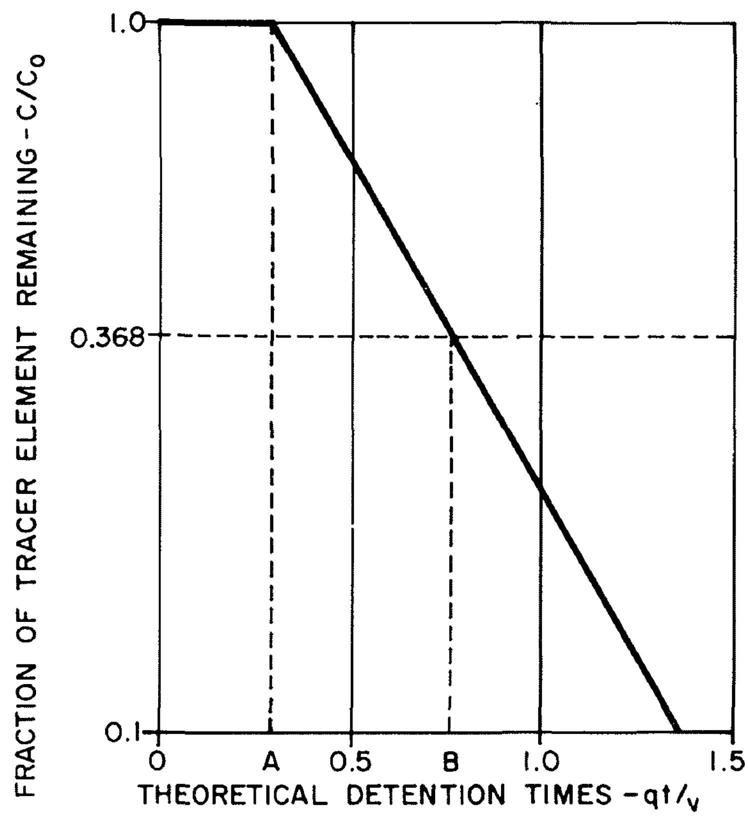


FIGURE 4 - EXAMPLE OF HYDRAULIC TRACER RESPONSE CURVE

TABLE 2

LABORATORY ANALYSIS

CONSTITUENT	FREQUENCY		METHOD OF ANALYSIS
	FILTERS	PONDS	
Nitrate-Nitrogen	3-6/week	3/week	Brucine Method and/or Specific Ion Electrode
Nitrite-Nitrogen	3-6/week	3/week	Diazotization α - napthylamine Method
Total Kjeldahl Nitrogen	1/week	1/week	Kjeldahl Method
Ammonia Nitrogen	1/week	1/week	Distillation Method
Organic Nitrogen	1/week	1/week	Kjeldahl Method
Orthophosphate	1/week	1/week	Stannous Chloride Modification
pH	1/week	1/week	Glass Electrode
Alkalinity	1/week	1/week	pH Titration
Dissolved Oxygen	Daily	Daily	Winkler Method
Suspended Solids	1/week	1/week	0.45 μ Glass Paper, 103°C
Vol. Suspended Solids	1/week	1/week	0.45 μ Glass Paper, 600°C
Methanol	3-4/week	3-4/week	Gas Chromatograph Carbowax Column Flame Ioniz. Detector
Electrical Conductivity	1/week	1/week	Wheatstone Bridge
Total Dissolved Solids	As Needed		Gravimetric Method
Algal Cell Counts & Identification	As Needed		Sedgewick-Rafter Cell
Chloride	As Needed		Silver Nitrate Titration

SECTION IV

RESULTS AND DISCUSSION

The results of the anaerobic denitrification experimental work performed at the Interagency Agricultural Wastewater Treatment Center are presented below. The data obtained for filter denitrification are presented first, followed by a description of the pond denitrification results. Included are sections on the results of botulism research conducted by the California Department of Fish and Game, regrowth studies and projected costs for the denitrification processes.

Filter Denitrification

Field evaluation of filter denitrification was initiated in October 1967. The 4-inch diameter PVC filters and media previously described were used for this phase of the study. It was found that all filters removed a minimum of 80 percent of the incoming nitrogen for at least 30 consecutive days at detention times ranging from 1 to 6 hours. Although results showed that the process did work, the smaller filters were abandoned because their functioning was greatly affected by ambient air temperatures. Larger scale filters were constructed for the subsequent study on start-up procedures, temperature effects, nitrogen loading, and long-term operation effects on denitrification.

Start-Up Procedures

To establish the necessary bacterial populations in the early studies the filters were started on a program of 6- to 8-hour theoretical hydraulic detention times based on void volumes. No bacterial inocula were used. Once adequate denitrification was occurring, the hydraulic detention times were shortened to the desired values. Since the initial experiments took place during the warmer months when water temperatures were as high as 24°C, this procedure proved satisfactory. In fact, some filters placed in operation during the warmer seasons at hydraulic detention times as short as two hours were reducing nitrate-nitrogen from 20 mg/l to less than 2.0 mg/l of total nitrogen within four days.

Placing a new filter into operation as a functioning unit when water temperatures were below 15°C required a more complicated approach. It was necessary to use a mass inoculation of denitrifying bacteria, and to allow the filters to remain stagnant until nitrogen levels are reduced to the desired 2 mg/l of total nitrogen. As the denitrification rate increased, flow-through operations were commenced at hydraulic detention times sufficient to continue the desired rate of denitrification. These experiments demonstrated that a 24-hour start-up detention time may be necessary to achieve adequate nitrate-reduction at water temperatures from 12-15°C and a start-up detention time as long as 72 hours may be required at water temperatures below 12°C. These detention times may need to be maintained for several detention periods before a sufficient bacterial population has been established to permit reduction of the detention period. Reduction of detention times after start-up during cold weather became a matter of operating at the minimum detention time (5-7 hours), which effects the required reduction of nitrogen.

Media Evaluation

Media evaluation for anaerobic filter denitrification was studied from July 1968 to January 1969. An influent containing 20 mg/l of nitrate-nitrogen was used in making the evaluation. The types, size, hydraulic loadings, and filter sizes for all media used in the experiments are summarized in Table 3.

Aggregate media offers a relatively smooth, nonporous, nonsorptive surface, and in addition is very durable. Coal has a limited sorptive capacity (29), and its irregular surface provides more surface area per unit volume than does rounded aggregate. Volcanic cinders were selected because, like coal, they are highly porous and roughly textured with a large surface area per unit volume, although, the adsorptive capacity of cinders is less than that of coal. The activated carbon selected for the study was of the largest size commercially available (0.16-inch diameter). It was used as an extreme in that part of the investigation concerned with the significance of adsorptive quality. Sand was included in the study because of its fineness of gradation and durability. It also provided a good extreme in the study of the significance of medium size on anaerobic filter operation. A filter was also constructed for experimental use with SURFPAC [1/], a commercially available plastic medium designed for use in trickling filters. This medium has a fluted design and a void ratio of approximately nine tenths.

Effect of Medium Characteristics on Nitrogen Removal. In evaluating the effect of medium characteristics on filter performance, a 2-hour detention time was chosen for all media except the SURFPAC which was operated at a 16-hour detention time. The 2-hour detention was selected because the early feasibility results indicated that this was an intermediate detention time at which all media could be fairly evaluated. Furthermore, the detention time required a flow rate through all the experimental filters, which was easily attained and controlled. The SURFPAC required a longer detention time because of the large void volume of the medium. Excepting for the larger aggregate and SURFPAC, nitrogen removal efficiencies attained in the evaluation were essentially equal regardless of the medium. The data are summarized in Table 4.

It was apparent that texture of the medium surface and sorptive quality did not appreciably affect removal efficiencies. There was also no apparent difference between the removal efficiencies of filters containing media of the same type, but of different sizes up to 1 inch in diameter. For these

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1/ Registered trademark of the Dow Chemical Company.

TABLE 3

SUMMARY
OF
MEDIA AND OPERATIONAL CRITERIA

MEDIUM	MEAN DIAMETER (Inches)	FILTER HYDRAULIC DETENTION TIME RANGE (Hours)	FILTER HYDRAULIC LOAD RANGE ($Gal/Ft^2/Min.$)	FILTER SIZE DIAMETER (Inches)	FILTER SIZE DEPTH (Feet)
Activated Carbon	0.07	2 - 9	0.13 - 0.03	4	6.5
	0.16	0.5 - 6	0.50 - 0.04	4 18	6.5 6.0
Rounded Aggregate	0.38	2 - 6	0.13 - 0.04	4 18	6.5 6.0
	1.0	0.5 - 7	0.48 - 0.03	4 18 20	6.5 6.0 6.0
	2.0	2 - 4	0.62 - 0.31	18 36	6.0 6.0
Angular Bituminous Coal	0.31	2	0.12	18	6.0
	1.0	2	0.15	18	6.0
Volcanic Cinders	0.31	2	0.16	18	6.0
	0.62	2 - 8	0.18 - 0.05	18	6.0
	1.0	2	0.21	18	6.0
DOW SURFPAC 1/	-	8 - 16	0.08 - 0.04	20 (square)	6.0

1/ Registered trademark of the Dow Chemical Company

TABLE 4

NITROGEN REMOVAL EFFICIENCIES
OF EXPERIMENTAL MEDIA

	TOTAL NITROGEN REMOVAL PERCENT		
	Min.	Max.	Average
0.016-Inch Activated Carbon	89	99	96
Washed Sand	84	97	93
0.31-Inch Angular Coal	80	98	93
0.31-Inch Volcanic Cinders	85	98	94
0.38-Inch Rounded Aggregate	82	97	94
0.62-Inch Volcanic Cinders	87	97	91
1.0-Inch Angular Bituminous Coal	81	98	93
1.0-Inch Volcanic Cinders	89	97	96
1.0-Inch Rounded Aggregate	89	98	94
2.0-Inch Rounded Aggregate	45	92	72
DOW SURFPAC	80	90	86

Note: Nitrogen removal based on 20 mg/l of nitrate-nitrogen in the influent for a period of 80 days at idenitcal climatic and operational conditions.

reasons and considering the relative merits of each medium, the 0.31-inch coal and the 0.31-inch volcanic cinder-filled filters were abandoned near the middle of October 1968.

Effects of Medium Characteristics on Long-Term Operation. The second phase of the work was concerned with media evaluation. In this phase emphasis was placed on the effect of long-term operation on unit efficiency and on the minimization of hydraulic detention times used. The filters that contained the 0.31-inch coal and volcanic cinders were emptied and refilled with washed sand and 1.0-inch aggregate, respectively. These units were operated at a hydraulic detention time of 0.5 hours. In addition, two 18-inch diameter filters were filled with washed sand and 1.0-inch aggregate and were operated with 1-hour hydraulic detention times. Operation of the remaining filters was not changed except the detention time of the SURFPAC filter was reduced to 8 hours. The factors given major attention in this phase of the medium evaluation were influent pressure required to maintain a constant flow rate through the filters, changes in influent pressure with time, and nitrogen removal variations with time.

The influent pressures required to maintain a constant hydraulic detention time and the corresponding nitrogen removal efficiencies are summarized in Table 5. The data show a definite contrast in required influent pressure and nitrogen removal between the majority of media less than 1 inch in diameter and those 1 inch or larger in diameter. Generally, the trend was an increase in required pressure with decrease in the particle size of the medium. Also, the average nitrogen removal efficiency with the very fine media was lower than that with the coarser media. A good example of these

TABLE 5

INFLUENT PRESSURES AND NITROGEN REMOVAL FOR EXPERIMENTAL MEDIA

Data Obtained With The Use Of 18- and 36- Inch Diameter Filters

MEDIUM	HYDRAULIC DETENTION TIME HOURS	LENGTH OF OPERATION DAYS	REQUIRED INFLUENT PRESSURE, P.S.I.G.1/			TOTAL NITROGEN REMOVAL PERCENT 2/		
			MIN.	MAX.	AVERAGE	MIN.	MAX.	AVERAGE
0.16 Inch Activated Carbon	2.0	193	7.0	15.4	11.7	86	98	96
Washed Sand	0.5	51	4.1	6.2	5.2	0	95	19
Washed Sand	1.0	93	5.5	32.0	10.6	12	98	58
Washed Sand	2.0	183	4.9	12.1	8.1	23	96	82
0.38 Inch Rounded Aggregate	2.0	182	9.6	21.5	15.4	91	97	95
0.62 Inch Volcanic Cinders	2.0	138	8.3	12.0	10.6	60	97	89
1-Inch Angular Bituminous Coal	2.0	132	4.0	7.8	6.0	81	97	93
1-Inch Volcanic Cinders	2.0	130	3.1	6.8	5.1	85	98	95
1-Inch Rounded Aggregate	0.5	92	6.6	6.6	4.7	53	91	75
1-Inch Rounded Aggregate	1.0	106	3.2	5.5	4.2	80	97	92
1-Inch Rounded Aggregate	2.0	183	3.5	7.5	5.5	84	97	93
2.0 Rounded Aggregate	2.0	168	3.6	6.8	4.4	45	92	75
2.0 Rounded Aggregate	4.0	282	3.6	5.5	4.0	50	94	80
SURFPAC	8.0	402	Equal to Static Head			30	94	70
SURFPAC	16.0	67	Equal to Static Head			80	90	86

1/ Pressure data based on equal periods of operation. Pressure includes 2.6 psi water head.
2/ Nitrogen removal based on 20 mg/l of nitrate-nitrogen influent.

characteristics was the pressure and efficiency performances obtained with the sand and the 1-inch diameter rounded aggregate.

For the first 130 days of operation the filter filled with 1-inch diameter aggregate and operated at a 1-hour hydraulic detention time had an average effluent total nitrogen concentration of 1.4 mg/l and an influent pressure for this 130-day period which did not exceed 5.5 psig. The highest influent pressure required by this filter for its entire operational period of 470 days was only 11.5 psig. After 250 days of operation the pressure appeared to become cyclic, which was attributed to a buildup of bacteria within the voids and its dislodgement by the pressure increases. The historical pressure pattern of this filter is shown in Figure 5.

The performance of the 1-inch aggregate filter may be compared with that of the sand-filled filter operated at the same hydraulic detention time. Influent pressure and total nitrogen removal data for the filter are plotted in Figure 6. Examination of Figure 6 shows that by the 52nd day of operation, the required influent pressure exceeded 30 psig. Because of operating difficulties which developed due to this required pressure, a surge of water had to be forced through the filter on the 55th day of operation to break up the bacterial mass. Prior to breaking up the bacterial mass, the effluent total nitrogen concentration was less than 2 mg/l. However, following the bacterial dislodgement the effluent total nitrogen concentration increased to as high as 13 mg/l. This efficiency head loss relationship was observed again approximately one month later

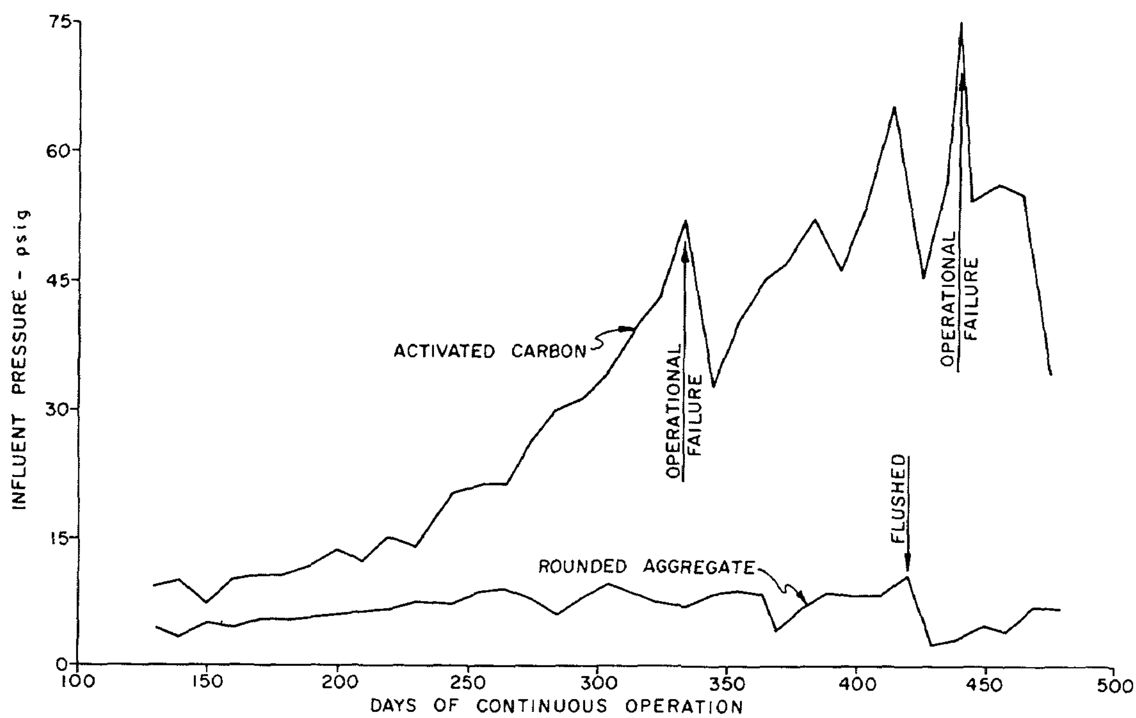


FIGURE 5 - INFLUENT PRESSURE VERSUS TIME FOR ACTIVATED CARBON AND ONE INCH DIAMETER AGGREGATE MEDIAS

when the influent pressure and nitrogen removal rate of the unit had increased to approximately 22 psig and 95 percent, respectively. Directly thereafter, and without surging water through the column, the pressure dropped to less than 10 psig and the nitrogen removal efficiency to less than 20 percent. This drop was attributed to short circuit paths, which were forced through the sand medium by the higher pressure which again caused dislodgement of the bacteria. The average effluent nitrogen concentration for the period of time covered by Figure 6 was 8.8 mg/l. This unit was taken out of operation in January 1969, after 128 days of continuous operation.

The sand-filled filter operated at a 2-hour detention time also had a high average influent pressure and low average nitrogen removal for its period of operation. The low efficiency was assumed to be due to poor hydraulics within the unit. This assumption was verified by observation of the medium upon dismantling the units. For example, the unit contained dark columns of bacteria extending from the filter bottom to the surface. The columns were approximately 3 inches in diameter with no evidence of

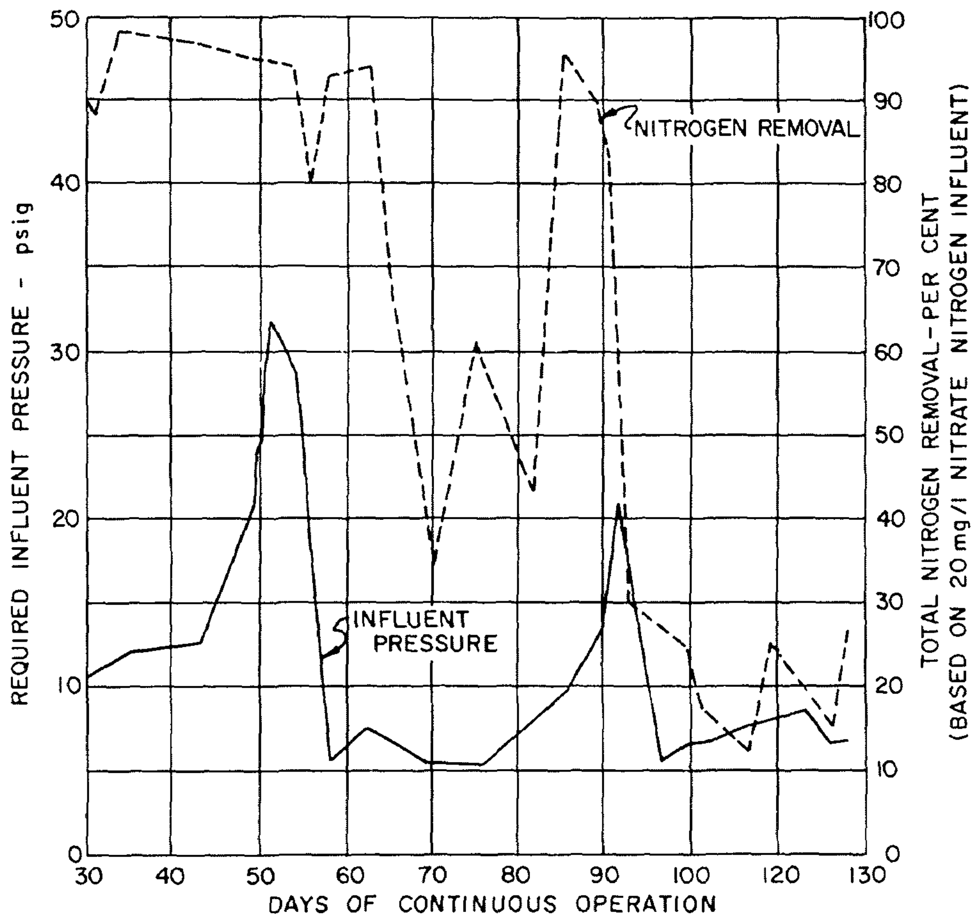


FIGURE 6 - TOTAL NITROGEN REMOVAL AND INFLUENT PRESSURE VERSUS TIME FOR SAND FILLED 18-INCH DIAMETER FILTER WITH ONE HOUR DETENTION

bacterial growth outside of the dark areas, thus indicating that the flow was short circuiting.

The sand-filled filter operated at a one-half hour detention time did not have a pressure build up. This was attributed to the higher flow-through rate of the filter which led to short circuiting and did not allow a bacterial mass to accumulate. This absence of bacteria accumulation was demonstrated by the low nitrogen removal rate (Table 5), and short circuiting determined by tracer analysis.

Although it took longer to develop, the pressure required to force influent into the filter containing activated carbon medium had a pressure variance similar to the sand filter. Pressure variations characteristic of this filter are plotted in Figure 4. The influent pressure normally was above 40 psig after 300 days of operation, and on one occasion exceeded 70 psig. An efficiency-pressure relationship also existed in this filter, although not as dramatic as with the sand filter.

At the higher pressures the activated carbon bed was forced above its normal level after 425 days of operation, thereby, blocking the effluent system and creating a large void at the filter bottom. To alleviate this problem and to make possible the continued operation of the filter, one quarter of the medium was removed and surge of water was applied to loosen the bacteria mass that was causing the blockage. The medium which had been removed was replaced and the filter was then restarted. This displacement of medium was again repeated on the 511th day. However, instead of a single large void forming at the bottom, the entire medium bed had expanded leaving pockets of voids. During the initial pressure variations and the occurrence of operational problems, the nitrogen removal rate of the filter did not suffer greatly. It continued to remain at a high level until the second media displacement. At that point effluent nitrogen concentrations increased to an average 4.6 mg/l, most likely due to a loss of bacterial population and a decline in water temperature. Due to the long-term operational problems encountered and the high cost of activated carbon, this filter was abandoned after 594 days of continuous operation.

The filters containing the 0.375-inch aggregate and 0.62-inch volcanic cinders were not characterized by low nitrogen removal rates. However, the high influent pressures required for operating these units as compared to those for the 1-inch media led to the decision not to use these two media for further experimentation. Another reason for the elimination of volcanic cinders is their poor durability. The cinders left a powdery residue when transported or handled. This slow disintegration could lead to operational troubles within a filter especially if back washing were required. For this reason, all volcanic cinder media were eliminated.

As a result of the work described in the preceding paragraphs, media less than 1-inch in diameter were eliminated from consideration. The determination of the upper limit of medium size was then investigated. Two 18-inch diameter and two 36-inch diameter filters containing rounded aggregate with a size range of 1.5- to 3-inch diameter were used for this purpose. The filters were operated continuously for one year. Although no pressure problems were encountered, the nitrogen removal efficiencies for the filters were never as high as for those containing 1-inch diameter media (cf. Tables 4 and 5). It was observed that a larger mass of bacteria was present at the surface of the filters containing the larger media than at the surface of those containing the smaller media. This indicates that the bacteria were not contained as effectively in the filters having the larger sized media as those containing 1.0-inch diameter and smaller. As a result, the density of the bacterial population in the former was not as great as in the latter.

The SURFPAC was also eliminated for the same reason. It was observed that a mat of bacteria was always present at the top of this filter, and although left in operation over 450 days it was obvious no substantial bacterial mass could accumulate, mainly due to the open design of the medium.

Summary of Media Evaluation. It was concluded that the 1-inch diameter rounded aggregate would be the most effective in the denitrification of tile drainage in up-flow anaerobic filters. The smaller diameter media proved to be conducive to short circuiting and high influent pressures after long periods of continuous operation. These problems were due to the large masses of bacteria retained within the media beds. The larger media on the other hand did not retain adequate cultures and, therefore, required longer hydraulic detention times for efficient operation. SURFPAC was not suitable as a medium for the anaerobic filter process because its design did not permit retention of a bacterial population sufficiently large to accomplish efficient nitrogen removal.

Effect of Temperature and Nitrogen Loading on Nitrogen Removal

Two major factors affecting the required detention period needed to meet a specific effluent nitrogen criterion are water temperature and nitrogen loading. Predicted temperatures and expected nitrate-nitrogen concentrations of the agricultural wastewater are shown in Figure 7. The predicted temperatures are based on recorded temperatures of the Delta-Mendota Canal inasmuch as the agricultural wastewater drain will be exposed to the same climatic conditions as the canal. Nitrate concentrations are based on extensive nitrogen sampling studies of tile drainage systems throughout the San Joaquin Valley (30). To date only preliminary studies of the effect of temperature and nitrogen loading on required detention time have been completed.

The preliminary studies were conducted in two 18-inch diameter filters filled with 1-inch diameter aggregate and operated at 1- and 2-hour detention times. Initially, the filters were used to determine the effect on temperature and nitrogen removal while receiving a constant influent nitrate-nitrogen concentration of 20 mg/l. As seasonal water temperature dropped from those prevailing in the summer of 1968 to the temperatures of 1968-69 winter seasons, the nitrogen concentration of the effluents from both filters met the 2 mg/l total nitrogen criterion until water temperatures fell below 14°C. At that point, only the filter on the

2-hour detention time met the criterion. These data are plotted in Figure 8.

The only observed difference between warm and cold weather operation of the filters with 1- and 2-hour detention times during this period of experimentation was the amount of filter required to achieve a given efficiency. Profile samples for nitrate and nitrite taken at the quarter points of the medium beds showed that as the temperature dropped, the percent of the filter bed required to achieve the same degree of treatment as obtained at the higher temperatures increased (Table 6).

At temperatures above 16°C, the filter operated at the 2-hour detention time was able to reduce the 20 mg/l nitrate-nitrogen in the influent to less than 2 mg/l of nitrate and nitrite by the time the waste had reached the first profile sample location (18 in.) above the influent line. With the detention time at 1 hour the same degree of treatment was attained by the time the second profile location (36 in.) was reached. In both cases the elapsed time was within 0.5 hours after introduction of the waste into the unit. At a temperature range of 12-16°C the "2-hour" filter required three-quarters of the medium depth (54 in.) to produce an effluent containing 2 mg/l of total nitrogen. The "1-hour" filter required the entire medium depth to achieve a 2 mg/l total nitrogen concentration in the effluent at a temperature range of 14-16°C.

On the basis of these encouraging results the influent nitrate concentration to these filters was increased to 40 mg/l nitrogen. This increase was started into the "2-hour detention time" filter in early March 1969 (after

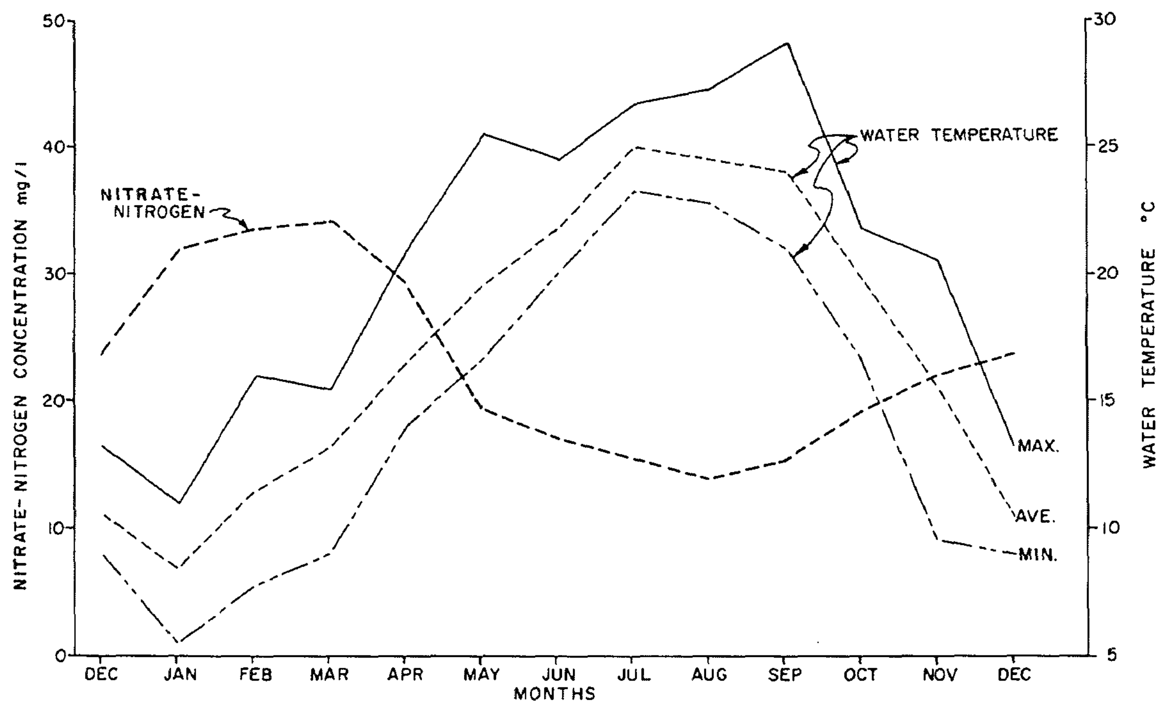


FIGURE 7 - PREDICTED SEASONAL VARIATION OF NITROGEN CONCENTPATION AND TEMPERATURE

TABLE 6

COMPARISON OF PROFILE NITRATE PLUS NITRITE NITROGEN CONCENTRATIONS AT VARIOUS TEMPERATURES FOR SHORT AND LONG TERM OPERATION

Data Obtained With The Use of 18-Inch Diameter Filters Containing 1-Inch Diameter Rounded Aggregate as Media.

TEMPERATURE RANGE °C	DETENTION TIME HOURS	$NO_3 + NO_2$ mg/l-N JUNE 1968 THROUGH MAY 1969				$NO_3 + NO_2$ mg/l-N JUNE 1969 THROUGH DECEMBER 1969			
		SAMPLE LOCATION ABOVE INFLUENT - INCHES							
		18	36	54	EFF.	18	36	54	EFF.
22-24	1.0	NO DATA AT TEMPERATURE				7.21	2.53	1.61	1.08
	2.0	NO DATA AT TEMPERATURE				7.22	3.14	1.84	.58
20-22	1.0	NO DATA AT TEMPERATURE				9.88	3.17	3.14	3.60
	2.0	1.03	0.45	0.22	0.27	7.48	3.68	3.10	2.40
18-20	1.0	6.75	4.65	3.45	0.07	8.74	5.45	4.70	3.64
	2.0	0.73	0.07	-0-	0.07	6.85	5.92	4.44	3.09
16-18	1.0	2.45	0.55	0.15	0.68	NO REPRESENTATIVE DATA			
	2.0	0.74	0.10	0.21	0.03	7.70	6.67	6.99	6.5
14-16	1.0	8.43	4.92	3.21	0.60	NO REPRESENTATIVE DATA			
	2.0	3.22	1.75	0.3	0.47	12.60	6.54	6.13	4.07
12-14	1.0	7.20	5.17	3.32	2.87	3.81	5.26	3.13	3.13
	2.0	2.65	2.73	1.01	1.06	3.97	3.87	4.27	3.60

NOTE: *Data are based on an influent of 20 mg/l nitrate-nitrogen.*

240 days of operation) and to the "1-hour detention time" filter in early April 1969 (after 200 days of operation). The total nitrogen concentration of the effluent during the period of the higher nitrogen dosage is plotted in Figure 8. It is apparent from the data that at the high nitrate concentration neither filter was able to produce an effluent meeting the 2 mg/l or less total nitrogen criterion. It was concluded from these results that longer detention times would be necessary to treat waters having high nitrate concentrations during periods of low temperature.

A further investigation of the effect of temperatures was conducted with the use of a 4-inch diameter filter operated in a temperature controlled environment. It was operated with a theoretical hydraulic detention time of 8 hours, and received an influent containing a constant 20 mg/l nitrate-nitrogen. It was operated at temperatures of 7.5°C, 15°C, 20°C, and 25°C. The relationship developed by Van't Hoff and Arrhenius was

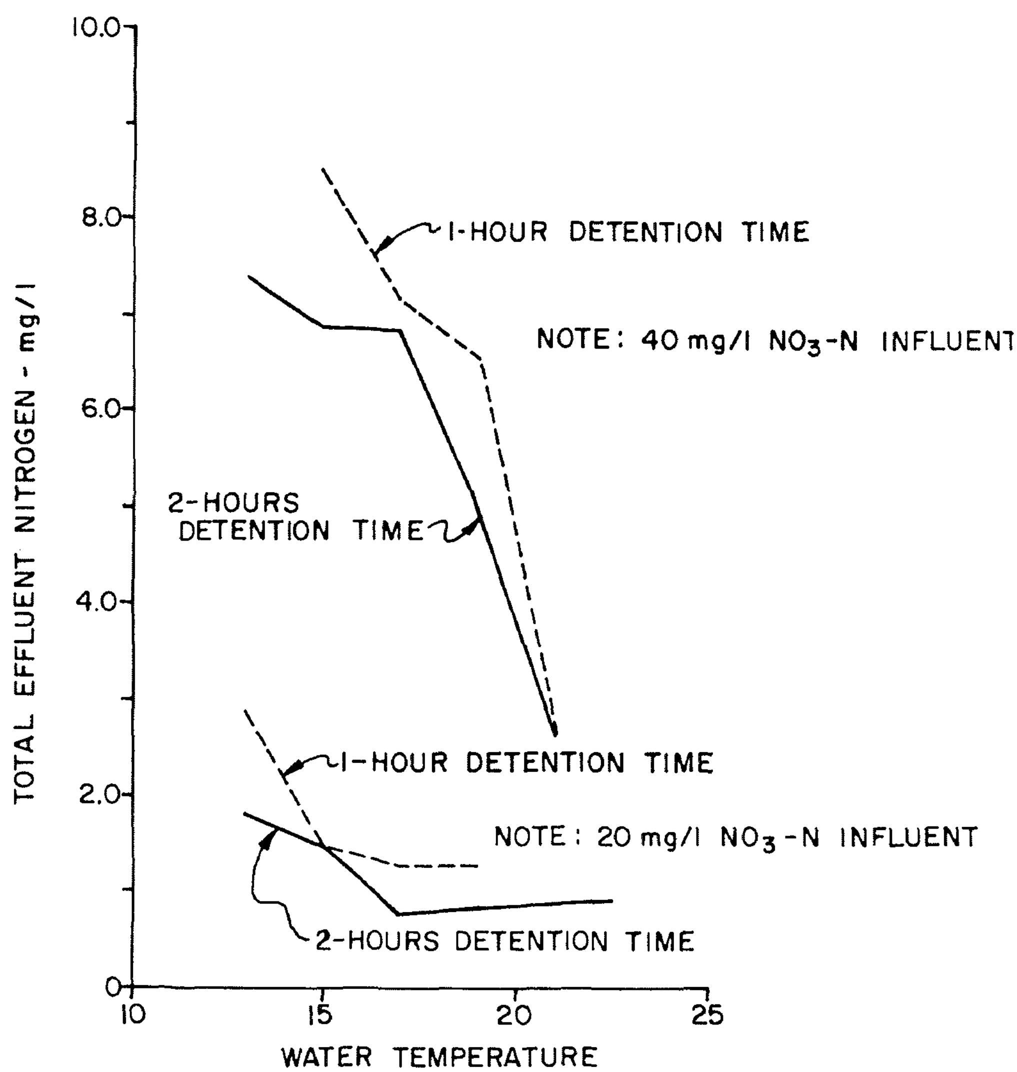


FIGURE 8 - EFFLUENT NITROGEN VERSUS WATER TEMPERATURE

used in analyzing the data gathered. With the relationship developed from this work and upon the removal efficiencies achieved in the field units, a curve (Figure 9) was established that predicts the detention time required to produce an effluent containing 2 mg/1 total nitrogen at the predicted annual temperature ranges and nitrogen concentrations shown in Figure 7. There is an obvious difference between the predicted detention periods and those indicated by the results obtained in the preliminary field experiments in the spring of 1969. The predicted detention times of 1 to 2 hours for the months of March and April correspond to the temperature and nitrogen ranges prevailing at the time the experiments were conducted. In the experimental runs a 2 mg/1 total nitrogen effluent could not be achieved. The difference between predicted and actual results may be due to two reasons. One could be operational control. The field units were exposed to more operational upsets than the temperature controlled filter. The second reason and probably the most critical may be long-term hydraulic changes within the filters, which might have reduced the theoretical detention times. This latter reason is discussed in more detail in a later section. Further studies on the effect of temperature and nitrogen loading are being performed in the operational studies of 1970. The predicted values for temperature and nitrate loading are being duplicated and emphasis is being placed on better operational control to determine the actual detention time necessary to meet a 2 mg/1 total nitrogen criterion.

Effect of Long-Term Operation

As the feasibility studies in the 18-inch diameter filters entered their second year, it became apparent from the nitrogen removal data that

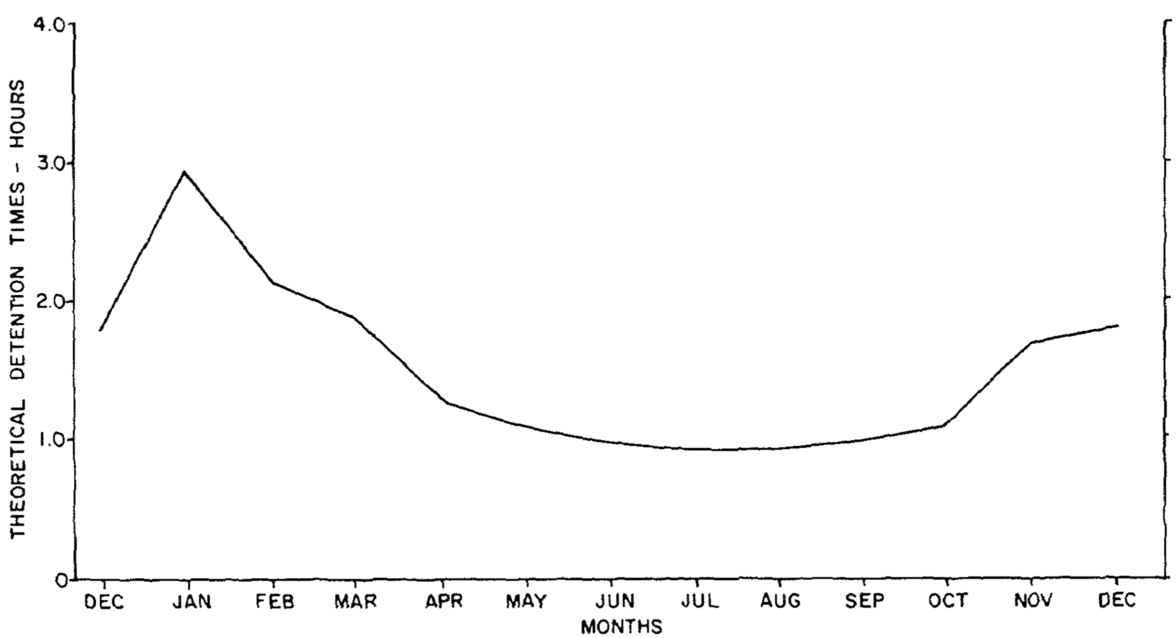


FIGURE 9 - PREDICTED DETENTION TIMES FOR PROJECTED SEASONAL VARIATIONS OF NITROGEN AND PROJECTED MINIMUM WATER TEMPERATURES

efficiencies were not as high as during the previous year. Table 7 contains a summary of the effluent nitrogen concentrations as related to temperature for the time periods involved.

As stated in the preceding section, the only difference between high and low temperature operation was the percentage of filter depth required to achieve the 2 mg/l effluent criterion. Total effluent ammonia plus organic nitrogen during this period averaged approximately 0.8 mg/l. However, during the period of July 1969 through December 1969, duplication of the earlier results was not obtained. At temperatures above 22°C concentrations of total nitrate plus nitrite-nitrogen in the effluent at the 1- and 2-hour hydraulic detentions averaged 1.08 mg/l and .58 mg/l, respectively. However, total effluent ammonia plus organic nitrogen for this period averaged over 1.60 mg/l from both filters, increasing the total nitrogen concentration for both filters to more than 2 mg/l. Further, at temperatures below 22°C, neither the "1-hour" nor the "2-hour" filter was able to produce an effluent containing 2 mg/l total nitrate plus nitrite. Profile samples, as shown in Table 6, had considerably higher concentrations than were obtained in the coldest temperatures of the 1968-69 winter season. These differences showed that with long-term operation major operational problems were occurring which needed to be controlled. Variations of parameters which may have caused these differences are discussed in the sections which follow.

Total and Volatile Suspended Solids. The concentrations of total suspended and volatile suspended solids in the effluent of the filters remained relatively low throughout their operation (Table 8). The higher concentrations were detected in late September of 1969 and only for a period of two to three weeks. The low concentrations of effluent volatile solids indicate that a low concentration of bacteria is emitted from the filter. The nitrogen that could possibly be added to the waste by mineralization of such bacteria is accounted for in the total effluent nitrogen values given for each process in their respective tables of data. Preliminary investigations into the types and number of bacteria contained in the effluent of filters and ponds indicated that the determination of these parameters would be very difficult to achieve satisfactorily. Because this type of information was considered of secondary importance for the field research being conducted, the answers to these questions were not pursued.

Effluent Organic and Ammonia Nitrogen. The data in Table 7 show that the total organic and ammonia nitrogen in the filter effluent increased in the summer of 1969 to more than twice that recorded in the earlier studies of 1968. In Figure 10, total ammonia plus organic nitrogen of the effluent is plotted as a function of "1- and 2-hour detention time" filters with 1-inch aggregate. Initially, this increase in Kjeldahl nitrogen was thought to be an indication of a seasonal slough-off of bacteria similar to that which occurs in a trickling filter. However, as discussed in the preceding section, the variations in filter effluent solids were not substantial. Also, the occurrence of the peak concentrations of total Kjeldahl did not correspond to the occurrence of higher solids concentrations.

TABLE 7

COMPARISON OF EFFLUENT NITROGEN CONCENTRATIONS
AT VARIOUS TEMPERATURES FOR SHORT AND LONG TERM OPERATION

Data Obtained With The Use of 18-Inch Diameter Filters
Containing 1-Inch Diameter Rounded Aggregate as Media

		JUNE 1968 THROUGH MAY 1969			JUNE 1969 THROUGH DECEMBER 1969		
TEMPERATURE RANGE °C	DETENTION TIME HOURS	DAYS AT TEMPERATURE	NO_3+NO_2 mg/l-N	TOTAL N mg/l	DAYS AT TEMPERATURE	NO_3+NO_2 mg/l-N	TOTAL N mg/l
22-24	1.0	0	NO DATA		63	1.08	2.83
	2.0	13	0.25	0.91	63	0.58	2.26
20-22	1.0	0	NO DATA		21	3.60	4.88
	2.0	12	0.27	0.86	21	3.39	4.92
18-20	1.0	20	0.55	1.26	23	3.64	4.70
	2.0	20	0.07	0.83	25	3.09	4.17
16-18	1.0	14	0.68	1.25	0	NO DATA	
	2.0	14	0.03	0.74	34	6.58	9.83
14-16	1.0	34	0.60	1.42	0	NO DATA	
	2.0	33	0.47	1.45	16	4.02	4.65
12-14	1.0	78	2.12	2.87	37	6.44	7.11
	2.0	74	1.06	1.77	36	3.60	4.24

NOTE: Data based on an influent of 20 mg/l nitrate-nitrogen.

TABLE 8
TOTAL AND VOLATILE SOLIDS EFFLUENT DATA
FOR
FILTERS FILLED WITH ONE-INCH DIAMETER AGGREGATE

DETENTION TIME HOURS	NUMBER OF MEASUREMENTS	TOTAL SUSPENDED SOLIDS MEAN mg/l	TOTAL SUSPENDED SOLIDS RANGE mg/l	TOTAL SUSPENDED SOLIDS STD DEV	VOLATILE SUSPENDED SOLIDS MEAN mg/l	VOLATILE SUSPENDED SOLIDS RANGE mg/l	VOLATILE SUSPENDED SOLIDS STD DEV
1	43	4.88	2.0-9.9	2.57	2.54	1.0-6.6	1.47
2	40	4.99	2.4-11.2	2.43	2.56	0.5-7.4	1.78

The major part of the increase in total ammonia plus organic nitrogen was due to an increase in dissolved ammonia nitrogen, most likely generated from the degradation of excess bacterial growth within the filter. The concentration of organic nitrogen in filter effluents remained relatively constant at approximately 0.6 mg/l. The seasonal change in organic nitrogen averaged only 0.2 mg/l; however, ammonia nitrogen concentrations were as much as one milligram per liter greater in warmer seasons than in cooler seasons. Ammonia concentrations ranged from approximately 0.1 mg/l to 1.2 mg/l. It is likely that the peak concentrations of Kjeldahl nitrogen reached in July 1969 (Figure 10) were the result of a higher rate of bacterial decay caused by warmer water temperatures. As the temperature

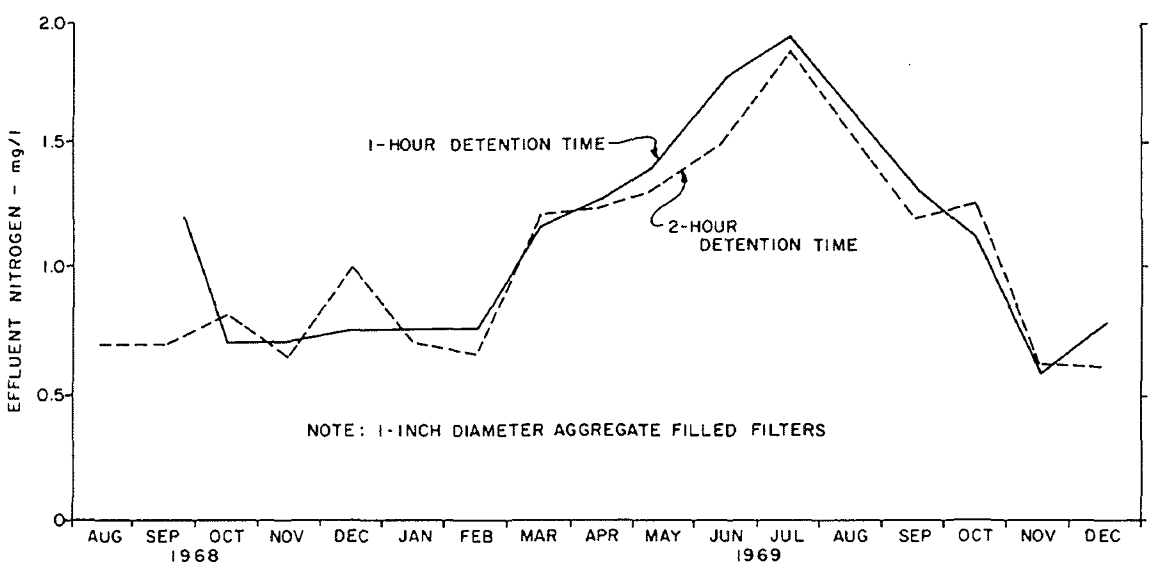


FIGURE 10- TOTAL EFFLUENT AMMONIA PLUS ORGANIC NITROGEN VERSUS TIME

dropped in the autumn, the concentrations of ammonia nitrogen decreased to the levels found in 1968. The rise and fall in ammonia indicates that the variance in this nitrogen form may be cyclic. Further study of the variations and methods of controlling the amount of biomass within the filters are receiving emphasis in the operational studies of 1970.

<u>Changes in Hydraulic Patterns Within Filters</u>. To determine the hydraulic pattern within the filters and their actual hydraulic detention times, tracer studies were performed at intervals throughout the experimental period. Results of several of the tracer studies involving the 18-inch diameter filters containing 1-inch diameter aggregate are plotted in Figure 11. The studies were performed approximately two months after the filters were started. They indicate an excellent agreement between theoretical and actual hydraulic detention times. Furthermore, the mixing pattern within the filters can be regarded as being equivalent to that of two vessels in series, one comprising 75 percent of the filter volume

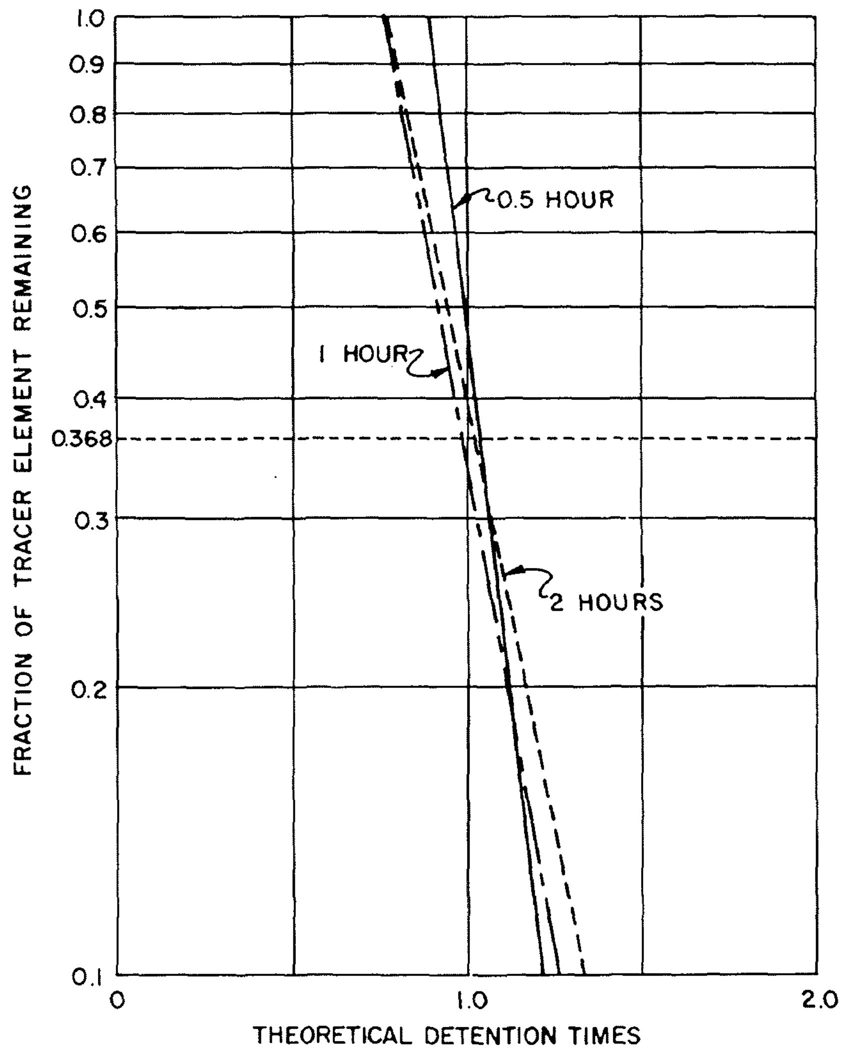


FIGURE 11 - RESULTS OF HYDRAULIC TRACER STUDIES ON ANAEROBIC FILTERS CONTAINING ONE INCH DIAMETER AGGREGATE

and having perfect plug flow and the second comprising the remaining 25 percent and functioning as a completely mixed vessel. As long-term evaluation continued, it became evident from tracer results that the hydraulic patterns within the filters were changing. The results of tracer studies conducted approximately one year after start-up are plotted in Figure 12. The actual hydraulic detention times decreased significantly and the mixing pattern underwent considerable change. The actual detention times for all of the filters were less than the theoretical. The previously verified 2-, 1-, and 1/2-hour detention times were reduced by 25 percent 33 percent, and 57 percent, respectively. This reduction was attributed to the accumulation of excess bacteria, which in turn resulted in reduction of available void volume. The original mixing pattern, the greater part of which was plug flow, had changed to the extent that complete mixing

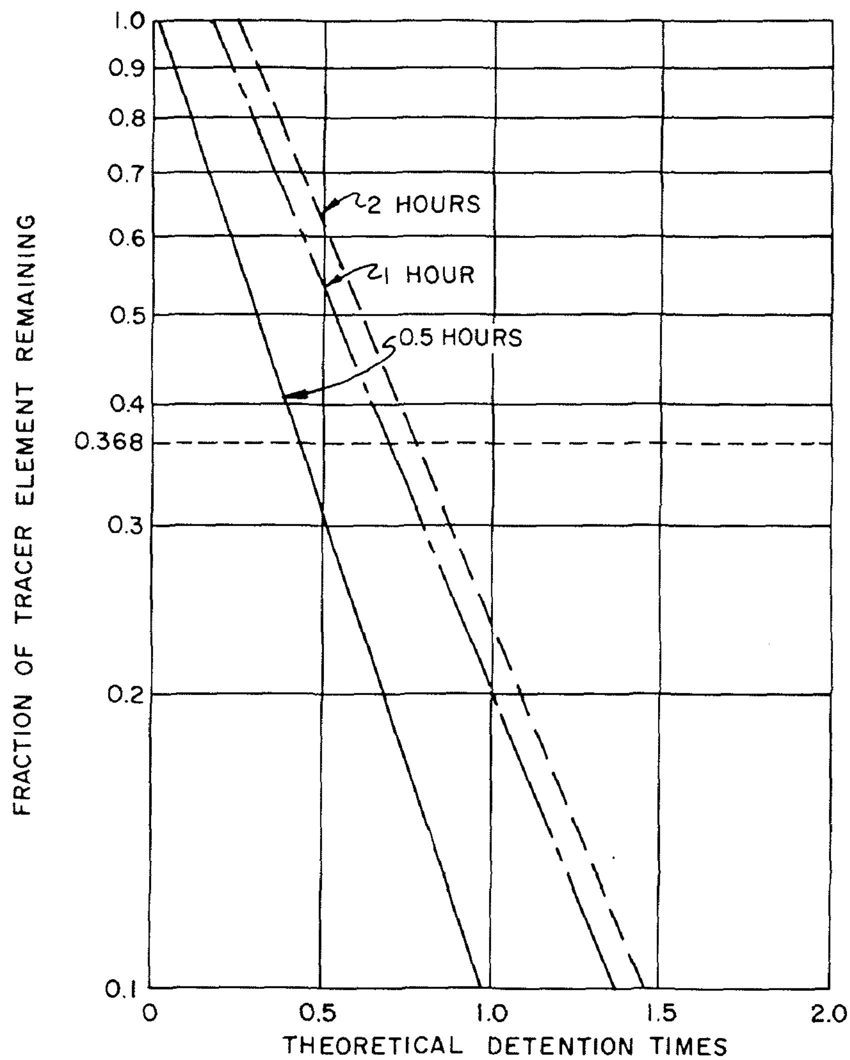


FIGURE 12- RESULTS OF HYDRAULIC TRACER STUDIES ON ANAEROBIC FILTERS CONTAINING ONE INCH DIAMETER AGGREGATE AFTER 12-14 MONTHS OF CONTINUOUS OPERATION

predominated, and plug flow was at a minimum. In the "1- and 2- hour detention time" filters, 50 percent of the filter contents were completely mixed, while 33 percent and 25 percent of the contents were in stagnant zones, respectively. The remaining part of the volume was characterized by plug flow. The filter operated at 1/2-hour detention time contained 37 percent of its volume as completely mixed while 57 percent was in stagnant zones.

The tracer studies showing a high percentage of the filters' volume as completely mixed zones are confirmed by the nitrogen profiles shown in Table 6. Under completely mixed hydraulic conditions, the concentration of nitrogen should be uniform throughout the filter. Data on the profiles for the long-term operating filters do show a fairly even concentration of nitrate-nitrite at all levels, thus demonstrating completely mixed characteristics.

The changes in hydraulic mixing pattern and the reduction in detention times are the major causes of discrepancies between results of 1968 and late 1969. It is believed that the bacterial growth within the filters can be limited so that the original hydraulics of the filters would be maintained, which in return would allow a high nitrate reduction rate.

Removal of Bacteria Mass from Filters

After recognizing the operational problems attendant with excess bacterial mass, attempts were made to dislodge and flush out the excess growth from several of the 18-inch diameter filters. The attempts consisted in forcing water upward through the filter at rates varying from 5 gal/ft^2/min to 70 gal/ft^2/min. Variations of flushing procedures have included use of compressed air at the lower hydraulic rates, and alternate flushing upward and draining the filters several times in succession. These methods are patterned after those discussed by Hamann and McKinney (31) on upflow filtration in sand media.

Attempts to dislodge the bacteria by draining without first breaking up the bacterial mass failed. However, this procedure was attempted on a filter which had been in operation for over one year without any backwashing. Periodic dislodgement and a means of removing the bacteria (i.e., draining) before a large mass becomes established would perhaps be more effective. To date the most effective method found for displacing heavily clogged units is the application of high rate hydraulic loadings. Preliminary cost analyses of the volume and flow-through rate show this method is not economically feasible. Other methods for removal of bacterial mass are being investigated.

Possible Operational Problems

Two studies were conducted which dealt with possible operational problems associated with the use of anaerobic filters for denitrification. These were the effect of algal growth in the agricultural waste prior to treatment and the effect of scale-up on the hydraulics of filters.

Algal Growth. It has been predicted (32) that there will be from 20 to 60 mg/l of algal cells in the influent to any plant treating tile drainage exported from the San Joaquin Valley. Apparatus was constructed in July 1969, to feed a controlled amount of algae to the influent of an operating 18-inch diameter filter containing 1-inch diameter aggregate. The filter was operated with a theoretical hydraulic detention of 2 hours. A data summary for this filter is presented in Table 9.

TABLE 9

EFFLUENT NITROGEN CONCENTRATIONS AT VARIOUS TEMPERATURES FOR AN ALGAE SUPPLEMENTED FILTER INFLUENT

Data Obtained with the use of an 18-Inch Diameter Filter Containing 1-Inch Diameter Rounded Aggregate as Medium

WATER TEMPERATURE •C	DETENTION TIME HOURS	INFLUENT ALGAL CONC. mg/l	DAYS OF OPERATION	EFFLUENT NITROGEN CONCENTRATION		
				$NO_3 + NO_2$ mg/l	NH_3 + ORG N mg/l	TOTAL N mg/l
22-24	4	25	34	0.47	1.83	2.30
22-24	2	25	33	0.80	0.95	1.75
20-22	2	20	5	1.97	2.10	4.07
18-20	2	No Algae Feed	10	0.58	0.88	1.46
16-18	2	10-20	27	1.75	0;85	2.60
14-16	2	50	18	2.26	1.16	3.42
12-14	2	50	31	2.35	2.61	4.96

Note: Data based on an influent of 20 mg/l nitrate-nitrogen.

During the first three months of operation the filter received an influent algal concentration of approximately 20 mg/l with no apparent operational problems. Nitrate-nitrite reduction during these months was equal to the 1968-69 performance of the 2-hour detention time filter (cf. Table 7). Total nitrogen removal generally was lower due to higher concentrations of ammonia and organic nitrogen in the effluent. Results of effluent volatile solids analyses during this period average approximately 3 mg/l. Therefore, it was obvious that little, if any, of the algal cells were passing through the filter. This retention of the cells and their subsequent degradation accounted for the higher effluent concentrations of Kjeldahl nitrogen.

When the algae concentrations were increased to 50 mg/l, it became obvious that algal cells were passing through the filter inasmuch as the effluent volatile solids increased to over 10 mg/l and became blackish-green in color. This substantiated that the filter was clogging, and that algae were decomposing and/or being sloughed off. Analyses of filtered and unfiltered effluent ammonia and organic nitrogen samples showed that of an average total Kjeldahl nitrogen concentration of 4.23 mg/l only 19 percent was dissolved while the remaining 81 percent was in the form of algal and bacterial suspended solids passing through the filter.

The nitrate plus nitrite concentrations at temperatures below 16°C average approximately 2.3 mg/l. This concentration was greater than that of the nitrate plus nitrite concentrations characteristic of the effluent from "2-hour detention time" filter operated without algae feed in the 1968-69 experimental period (Table 7). Probably, the decrease in nitrate-nitrite removal rate was due at least in part to hydraulic changes in the filter. Although it was apparent that at the higher water temperatures the algae-laden influent did not affect denitrification, it would be necessary to remove any algae from the effluent in order to meet the 2 mg/l total nitrogen criterion. Furthermore, a system would have to be provided for flushing out the algae retained within the filter so that the hydraulics of the filter would remain unaffected.

Pilot Scale Filter. In the spring of 1969, a 10-foot square filter was constructed to study the effects of scale-up hydraulics on the performance of an anaerobic filter. The filter was started in May 1969 by allowing it to remain stagnant with an initial methanol concentration of 100 mg/l. The nitrate concentration was reduced to less than 2 mg/l within three days. The flow-through operation was begun with theoretical detention time of 7 hours. A summary of the operational changes and nitrogen removal data obtained with the filter is given in Table 10.

The filter required a long start-up period for two reasons. First, the stagnant period probably was too short; and secondly, as is often the case in experimentation, the start-up of the unit was plagued with mechanical problems. The data show that from days 66 to 89 of continuous operation, the concentration of the effluent total nitrogen averaged less than 2 mg/l when the unit was operated at a theoretical 5.25-hour detention time. At a detention time of 2 hours (days 90 through 193) the effluent nitrogen concentration increased to approximately 6 mg/l. No improved trend in performance was observed until the detention time was lengthened to 3 hours on the 194th day of operation. That change was followed by a decrease in effluent total nitrogen concentration to an average of 3.5 mg/l. Preliminary results in 1970 show that at nitrate loadings exceeding 30 mg/l, an effluent containing 2 mg/l or less total nitrogen could be produced at a theoretical detention time of 5.5 hours. Further studies are being undertaken to determine the proper operating procedures for the filter.

Results of tracer studies performed on the large filter are plotted in Figure 13. Data analysis revealed that the theoretical and actual hydraulic detention times for the first two studies performed on the 58th

TABLE 10

OPERATIONS AND EFFLUENT NITROGEN SUMMARY
FOR PILOT SCALE FILTER

DAYS OF OPERATION	DETENTION TIME HOURS	TEMPERATURE °C	EFFLUENT NITROGEN CONCENTRATION $NO_3 + NO_2$ mg/l	TOTAL NITROGEN mg/l
0-39	7.23	18-20	2.49	3.20
40-65	5.25	20-22	3.43	4.35
66-89	5.25	20-22	0.73	1.51
90-134	2.0	20-22	5.38	5.76
135-147	2.0	18-20	6.00	6.87
148-186	2.0	16-18	4.72	5.41
187-193	2.0	14-16	No Data	
194-224	3.0	12-14	2.71	3.53

Note: Data based on influent of 20 mg/l nitrate-nitrogen.

and 161st day of operation showed excellent agreement. As with smaller filters, analysis indicated that the filter volume could be likened to two vessels operating in series, one having a plug flow and the other being completely mixed. The first analysis of detention time indicated the existence of a 17 percent zone of plug flow, a 77 percent zone of complete mixing and a 6 percent stagnant zone. According to the second analysis, the zone arrangement was 38 percent plug flow, 62 percent completely mixed, and no stagnant zone. The third tracer study performed after 311 days of operating revealed a distinct hydraulic change. According to Figure 13, the actual detention time was 4.1 hours instead of the theoretical 5.5 hours. The hydraulic characteristics of the filter were estimated to be 40 percent plug flow, 42 percent completely mixed, and 18 percent stagnant zones. The decrease in detention undoubtedly was due to an increase in the bacterial mass within the filter, which caused the stagnant zones similar to the smaller filters. The biomass increase has been monitored throughout the life of the filter by measuring the pressure within the filter with the use of the in-filter sample extraction tubes.

Several pressure profiles of the filter are shown in Figure 14 as well as their increase with time. It is obvious that the greater pressure is in the bottom layers of the medium bed as would be expected. The increase in pressure from day 156 to day 188 and the relative stability of the pressure through day 294 indicated a build up of bacterial mass which accounted for some of the formation of stagnant zones observed in the previous tracer study. An unexpected characteristic of the hydraulic pattern changes was the continuing increase in the percentage of volume of plug flow observed with each successive tracer analysis. This trend is not comparable to that in the 18-inch diameter filters, in which the amount

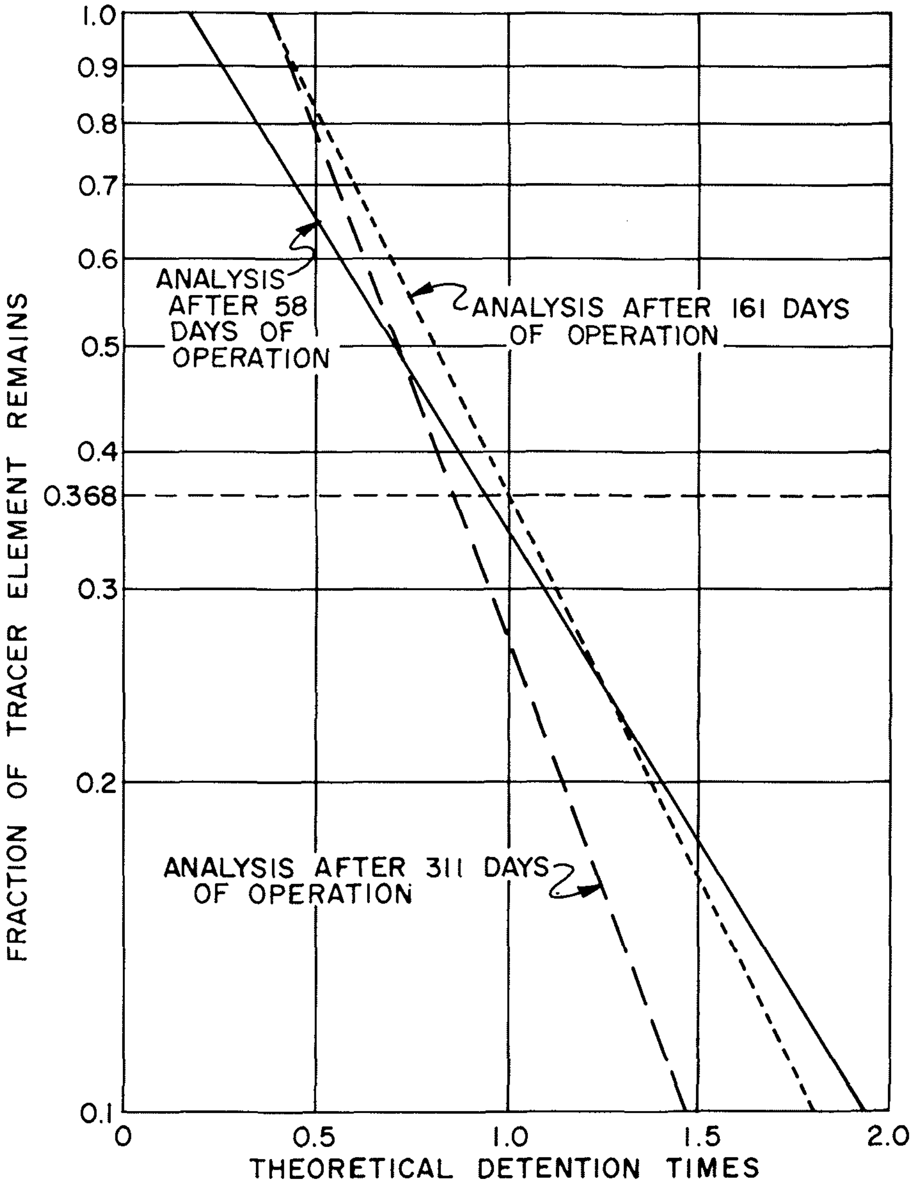


FIGURE 13 - RESULTS OF HYDRAULIC TRACER STUDIES PERFORMED ON PILOT SCALE FILTER

of plug flow decreased as the biomass increased. No operational change or other possible cause was observed that may have reversed the decreasing plug flow trend observed in the smaller filters.

It was concluded from results and observations made in the first eight months of operation of the pilot scale unit that no particular or unusual problem was encountered. It was realized that operational control methods of the unit must be refined in order to eliminate variations in nitrogen reduction efficiency. A reduction in theoretical detention time may be expected with long-term operation if biomass controls within the filter are not taken. Again, such controls are expected to be developed for the filter during the second year of study.

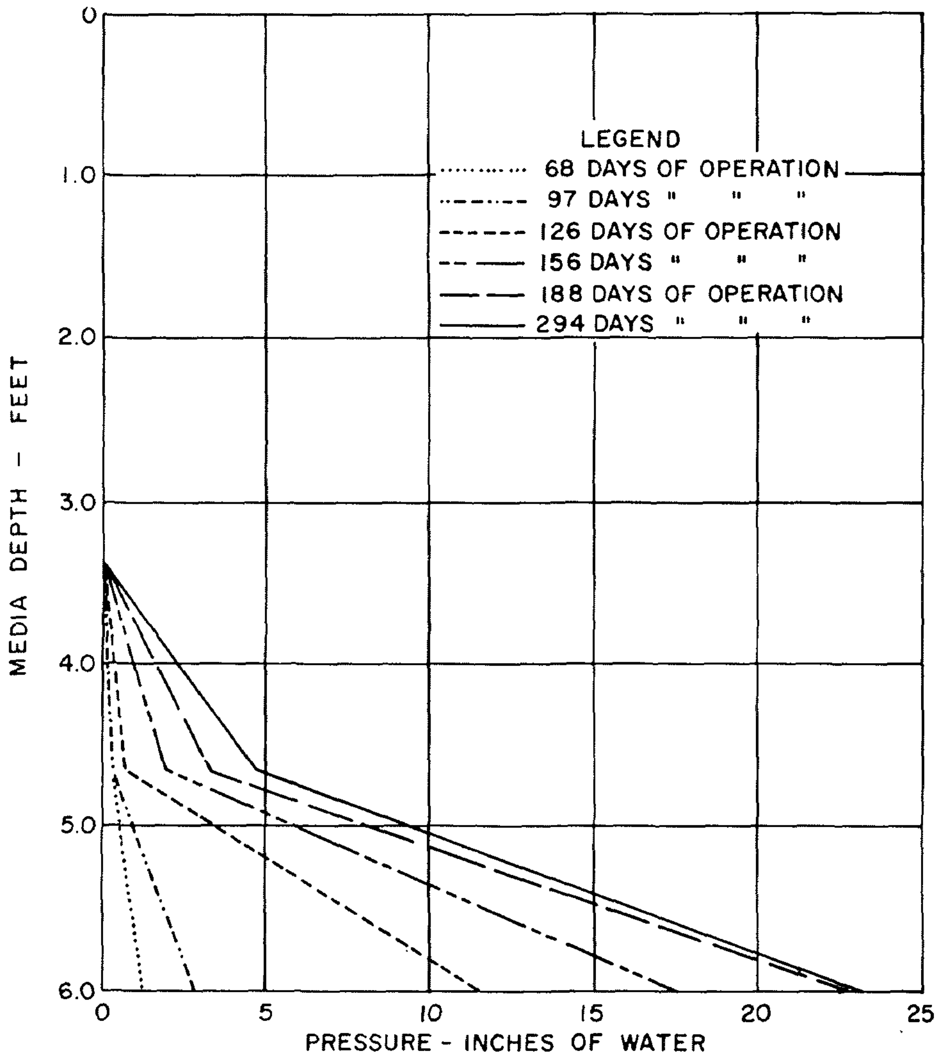


FIGURE 14 - RESULTS OF PRESSURE PROFILES FOR PILOT SCALE FILTER

Pond Denitrification

The pond denitrification studies were begun in June of 1967 with the use of the pilot scale deep ponds. The work is described in a report entitled "Field Evaluation of Anaerobic Denitrification in Simulated Deep Ponds" (18). During the experiments the nitrate-nitrogen content of the influent was maintained at 20 mg/l. Results of the studies indicated that in uncovered simulated ponds, removal efficiencies would not exceed 50 to 60 percent. Furthermore, it appeared that removal efficiency in the open ponds was almost independent of detention time. Data obtained with the uncovered ponds indicated that nitrogen removal rates remained the same at detention times ranging from 5 to 14 days. Experiments with covered simulated ponds indicated nitrogen removal efficiencies of 90 percent at about a 10-day detention time or 80 percent at about 5-day detention were possible. Based on these initial feasibility results, large-scale experiments involving uncovered and covered ponds were begun in early 1969.

Uncovered Pond

The uncovered pond was filled with irrigation return water in late February of 1969 and was operated for a total of 222 days. Methanol was added until an in-pond concentration of 100 mg/l was reached. The pond was continuously mixed by means of the recirculation line but flow-through operation was not started. These procedures were followed in an attempt to develop a bacterial culture.

Nitrogen Removal Performance. Results obtained with the uncovered pond and operational changes are tabulated in Table 11. During the early weeks of operation practically no nitrogen reduction took place. The little reduction that did occur probably can be attributed to an algal bloom which occurred in the pond. Apparently the bloom delayed the development of anaerobic conditions and the establishment of a denitrifying bacterial population by keeping the dissolved oxygen concentration at or near the saturated level of 10-15 mg/l. After 67 days of stagnant operation an herbicide (simazine) was applied to the pond surface in an attempt to eliminate the algal bloom. This resulted in a decrease in the algal cell count from 124,000 cells/ml to less than 2,000 cells/ml. The dissolved oxygen concentration decreased to undetectable levels at the pond bottom, and anaerobic conditions were established. Algal cells were not detected in any significant concentration during the remainder of the operation of the pond.

Anaerobic conditions were allowed to remain undisturbed for an additional 12 days after the herbicide was applied. During this time the in-pond nitrogen concentration decreased from approximately 15 mg/l to 10 mg/l. At the end of 12 days, flow-through operation was started at a theoretical detention time of 20 days. As indicated by the data in Table 11, effluent nitrogen concentrations declined through day 200 except for a short period following a reduction in detention time from 20 days to 10 days. As

TABLE 11

OPERATION AND NITROGEN CONCENTRATION SUMMARY FOR THE UNCOVERED DEEP POND

OPERATION	THEORETICAL HYDRAULIC DETENTION TIME DAYS	TEMPERATURE °C	EFFLUENT OR IN-POND CONCENTRATION NITRATE + NITRITE mg/l	TOTAL NITROGEN mg/l
0-35	Infinite	14-18	16.1	16.9
36-73	Infinite	18-20	14.8	15.5
74-80	Infinite	20-22	10.7	12.0
81-135	20	22-24	7.26	8.76
136-155	20	24-26	3.08	4.63
156-166	10	24-26	4.90	6.40
167-200	10	22-24	1.90	3.39
201-221	10	20-22	4.23	5.52
222-224	10	18-20	6.64	7.85
225-260	10	16-18	12.7	14.0

Note: Data based on an influent of 20 mg/l nitrate-nitrogen.

temperature dropped, nitrogen removal efficiencies decreased significantly. The major nitrogen form present in the effluent throughout the pond operation was nitrate. Nitrite was present in insignificant concentrations averaging approximately 0.6 mg/l at the 20-day detention time, and 0.35 mg/l at the shorter detention time. Moore (12) also noted the appearance of low levels of nitrite in a continually mixed vessel. Total Kjeldahl nitrogen averaged 1.51 mg/l at the 20-day detention time and 1.37 mg/l at the 10-day detention time. It is significant that at no time, even during the warmest temperatures, did the pond produce an effluent having a total nitrogen content as low as 2 mg/l. According to the data, the highest efficiency that may be expected with the influent nitrogen concentration at 20 mg/l would be approximately 85 percent nitrogen removal under favorable environmental conditions. The nitrogen removal rates as attained in the uncovered pond indicate that the 2 mg/l total nitrogen criterion for the effluent would not be consistently met throughout the year.

Hydraulics. A determination of pond hydraulics was made to learn of their effect on pond performance. Results of a tracer study performed when the pond was at a theoretical detention time of 10 days are plotted in Figure 15. The actual detention was calculated to be nine days. The mixing pattern was estimated to be 28 percent plug flow, 61 percent completely mixed, and 11 percent stagnant zones. Although the actual detention time was less than the theoretical, the difference was small and, therefore,

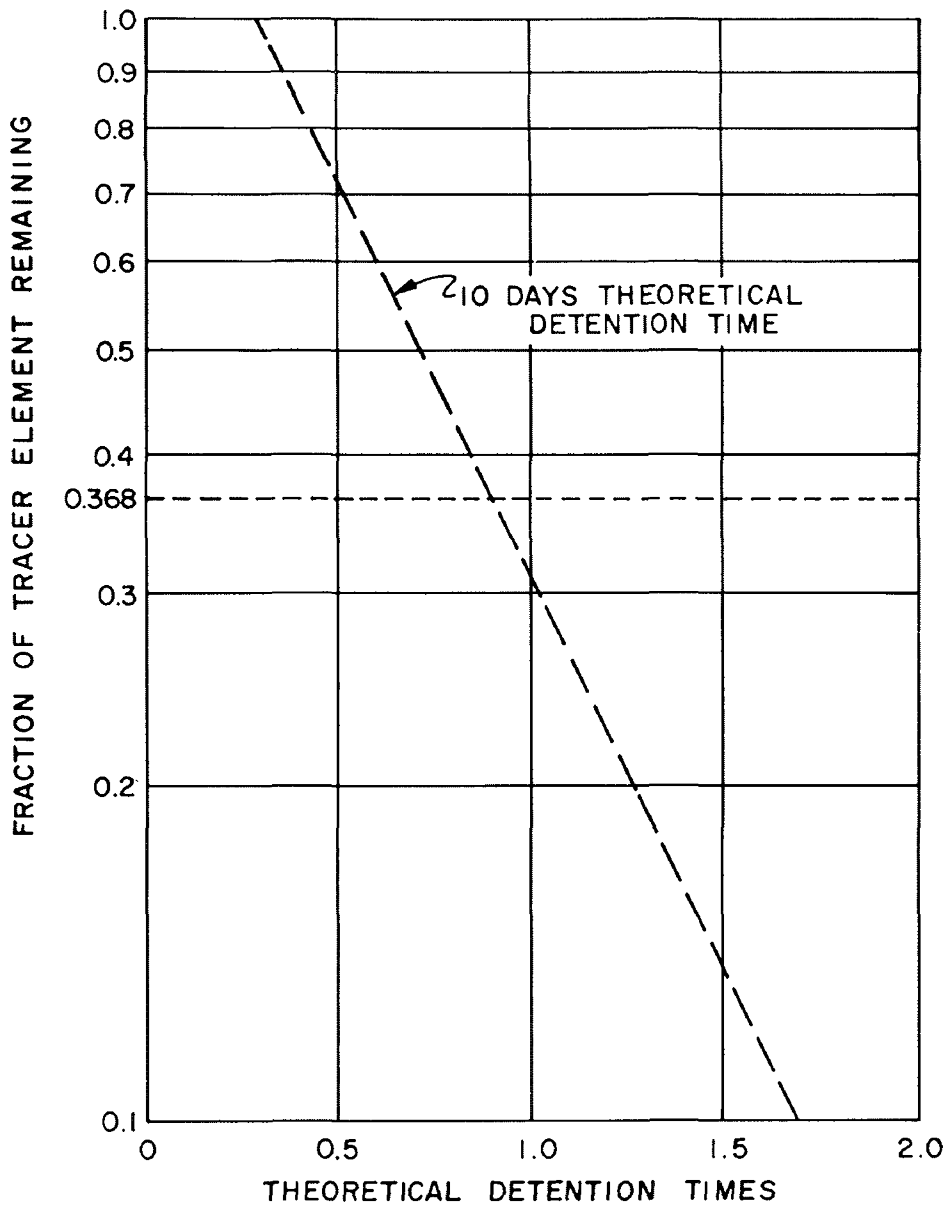


FIGURE 15- HYDRAULIC TRACER RESULTS FOR THE UNCOVERED DEEP POND

only a small proportion of the pond's poor nitrogen removal was attributed to the short detention time.

Suspended and Volatile Suspended Solids. Table 12 shows a summary of the total and volatile suspended solids results in the uncovered pond taken at various sample locations within the pond after flow-through operation was begun.

Exclusive of the influent, the samples were essentially equal in solids concentration. The uniform distribution of solids throughout the pond further affirms the results of the tracer analysis that the pond volume was mostly completely mixed. The essentially equal values of suspended solids concentrations in the recirculation line and effluent indicated that seeding of the influent could be done by recycling a portion of the effluent rather than using a separate recycle from the pond bottom. Facilities should be present for draining the ponds to remove flocculant organisms which might accumulate in the sludge layer.

Temperature Variance. The temperature of the surface and bottom levels of the pond was studied to detect the occurrence of a daily or seasonal "overturning" of the pond. It was found that a temperature differential always existed between the surface and bottom. The extent of the differential was seasonal. During cooler months, the differential was as much as 10°C and the surface temperature alone had a daily variance of 5°C. Despite the daily temperature variances, no evidence of overturning of the pond was observed.

TABLE 12

DATA SUMMARY OF THE TOTAL AND VOLATILE SUSPENDED SOLIDS FOR THE UNCOVERED ANAEROBIC DEEP POND

SAMPLE LOCATION	NO. OF MEASUREMENTS	TOTAL SUSPENDED SOLIDS MEAN mg/l	TOTAL SUSPENDED SOLIDS RANGE mg/l	TOTAL SUSPENDED SOLIDS STD.DEV.	VOLATILE SSUPENDED SOLIDS MEAN mg/l	VOLATILE SSUPENDED SOLIDS RANGE mg/l	VOLATILE SSUPENDED SOLIDS STD.DEV.
Influent	25	8.34	1.5-15.0	4.5	3.50	0.3-7.0	2.2
Surface	29	12.1	7.4-23.2	3.0	7.50	3.3-14.5	2.7
Bottom	26	12.9	9.3-30.6	3.2	6.60	3.8-15.3	2.0
Recirculation	28	12.4	6.9-45.9	3.3	7.50	4.6-27.6	1.5
Effluent	24	13.0	7.9-18.0	2.7	6.90	3.2-12.3	1.7

Covered Pond

The covered pond was started on a continuously mixed basis in early March of 1969. At the time, the in-pond nitrogen concentration was 10 mg/l. Methanol was added to bring its concentration to approximately 100 mg/l. Within 7 days bacterial population was active inasmuch as the nitrogen concentration decreased to less than 2 mg/l so flow-through operations were begun.

Performance. The initial detention time used for flow-through operation was a theoretical 20 days. As time progressed a series of reductions in hydraulic detention were made, depending on the extent of nitrogen removal and upon the prevailing environmental conditions. The data are summarized in Table 13.

Except for a period in which mechanical problems affected the covered pond's nitrogen removal (days 63-97) a theoretical detention period of fifteen days was found to be long enough to produce an effluent containing a concentration of 2.0 mg/l or less total nitrogen in a water temperature range of 14° to 22°C. The theoretical detention time was reduced to ten days on the 125th day of operation. Water temperatures were approximately

TABLE 13

OPERATING AND EFFLUENT NITROGEN CONCENTRATION SUMMARY
FOR THE COVERED DEEP POND

DAYS OF OPERATION	THEORETICAL HYDRAULIC DETENTION TIME DAYS	WATER TEMPERATURE RANGE °C	EFFLUENT NITROGEN CONCENTRATION NITRATE + NITRITE mg/l	TOTAL NITROGEN mg/l
0-27	20	14-16	1.05	2.00
28-39	14	14-16	0.51	1.96
40-62	15	16-18	0.35	1.42
63-97	15	18-20	1.08	2.58
98-124	15	20-22	0.54	1.80
125-166 & 187-197	10	20-22	0.29	1.49
167-186	7.5	20-22	2.48	3.79
198-218	10	18-20	1.39	2.57
219-249	10	16-18	3.03	4.19
250-260	10	14-16	2.44	3.73
261-268	10	12-14	6.83	7.79

20-22°C. This detention period was also capable of meeting the 2 mg/l total nitrogen criterion. These results verified on a large scale basis the conclusions reached in the feasibility studies. A further verification of the feasibility results was made when the pond was operated at a theoretical detention time of 7.5 days from day 167 through day 186 in a water temperature range of 20-22°C. At the 7.5 day theoretical detention time the average total nitrogen concentration of the effluent was approximately 4 mg/l. This performance is in agreement with the efficiencies predicted on the basis of the field feasibility studies, i. e., 80 percent nitrogen removal with the influent nitrate concentration at 20 mg/l-N. Upon returning the pond to a theoretical 10 day detention time on day 187 (water temperatures 20-22°C) the nitrogen removal rate of the pond recovered to produce an effluent containing a total nitrogen concentration of less than 2 mg/l. As temperatures dropped to below 20°C it was found that 10 days were not sufficient length of time to meet the 2 mg/l total nitrogen criterion. Nitrogen removal efficiency decreased as water temperature decreased. At the end of this operational period the total nitrogen concentration within the pond exceeded 7 mg/l-N. It is believed that by increasing the detention time to a suitable period the effluent criterion can be met.

Observed nitrogen forms were similar to those reported by Moore (12) and those found in the uncovered pond. Nitrite was rarely detected at concentrations exceeding 1 mg/l of nitrogen. In the case of the ponds, organic nitrogen was the predominant form of the ammonia plus organic nitrogen component. Organic nitrogen usually remained within a range of 0.8 to 1.5 mg/l-N, while the total ammonia plus organic nitrogen varied between 1.0 to 2.0 mg/l-N. This indicated an obvious difference between the make-up of the effluent Kjeldahl nitrogen of the ponds and that of the filters. As stated above, the pond's Kjeldahl nitrogen was almost entirely organic nitrogen, while the filter effluent Kjeldahl consisted mostly of ammonia. This was as expected on the basis of the physical make-up of the two processes, since the ponds allow the bacteria to flow out with the effluent, while the filters retain them. Thus, in the filter effluent, the ammonia would be most prominent due to bacterial decay, and in the pond effluent the organic nitrogen would be the prevailing form due to the greater concentrations of bacteria. When nitrogen removal of the pond decreased, for example at the theoretical detention time of 7.5 days or at the colder temperatures, the most prevalent form found was nitrate. The other monitored forms remained relatively constant in concentration.

<u>Temperature Effect and Variance</u>. As noted in the previous section, the nitrogen removal rate in the covered pond decreased in proportion to the decline in water temperature. Although the criterion of an effluent nitrogen concentration of 2 mg/l or less was not met, the seasonal discharge of agricultural wastewater from the San Joaquin Valley is such that in practice it will be possible to lengthen the detention periods in the winter to produce the required effluent nitrogen concentration. A projection of the expected detention time required in operating a covered pond to produce an effluent having a maximum nitrogen concentration of 2 mg/l

is shown in Figure 16. The projection is based on empirical results and the dashed portion of the curve has not as yet been verified.

Temperature variance within the pond was minimal. In thirty-six hour studies, in which temperatures were measured at various points within the pond, it was found that the differential between any portion of the pond volume and/or daily variance of the average pond temperature was less than 0.2°C. In addition to the studies, continuous records made with the use of 8-day temperature recorders placed at the pond bottom and surface showed no noticeable variation between the temperatures of these locations. These observations indicate that the styrofoam cover had a definite effect on temperature control within the pond.

<u>Hydraulics</u>. Tracer analyses of the pond mixing patterns were performed when the pond was operated at theoretical detention times of 10 and 7.5 days. The analyses were made on the 140th and 183rd days.

Fluorescence readings of cross-sectional samples taken as a part of the analysis of the theoretical 10-day detention time indicated that the pond was completely mixed inasmuch as the dye was uniformly distributed throughout the pond. The tracer response curve shown in Figure 17 is verification of the observed distribution of dye. The mixing pattern of the pond may be classified as being 82 percent completely mixed with 18 percent of the pond volume considered stagnant. About 4 percent of the flow through the pond was short-circuited, while the remaining 96 percent

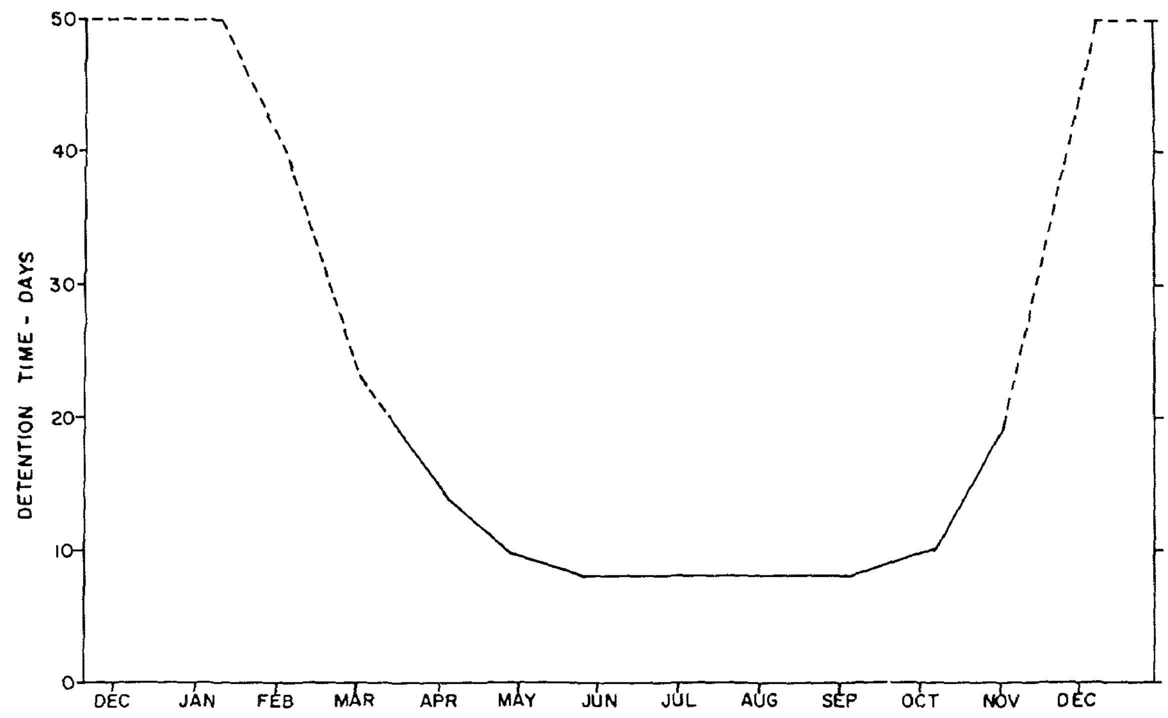


FIGURE 16- PREDICTED DETENTION TIME FOR TREATMENT OF AGRICULTURAL RETURN WATERS BY COVERED POND DENITRIFICATION

was passed into the mixed zone. The actual detention time as indicated by the tracer was 8.2 days.

A final tracer analysis was performed when the pond was being operated on a 7.5-day theoretical detention time. At the flow-through rate required by this detention time, the response curve and the cross-section samples indicated the existence of a definite change in the mixing pattern. The initial in-pond samples showed that the dye formed a uniform layer across the bottom of the pond. This layer gradually rose to the surface becoming somewhat diffused at the influent end because of the recirculation.

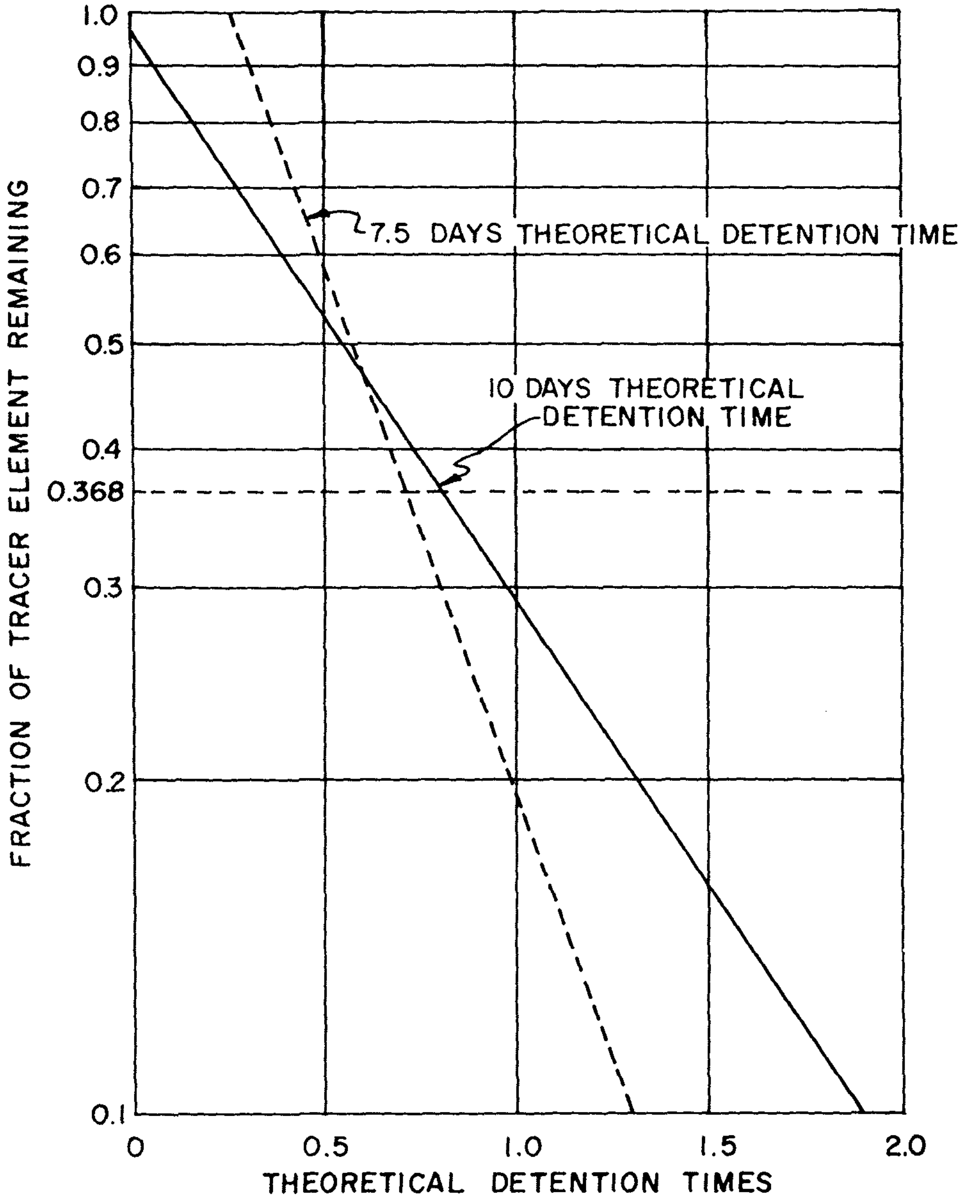


FIGURE 17 - HYDRAULIC TRACER RESULTS FOR THE COVERED DEEP POND

These samples suggested a pond which was partially plug flow and partially completely mixed. The effluent concentration curve (Figure 17) indicates that this was the case. The mixing pattern was 27 percent plug flow, 44 percent completely mixed, and 24 percent stagnant zones. The short-circuiting noted in the previous analysis was not observed in this study. Because of the relative size of the stagnant zones, instead of functioning on a theoretical detention time of 7.5 days, the pond was actually operating on a 5.3-days detention time.

<u>Total and Volatile Suspended Solids</u>. A summary of the total and volatile suspended solids concentrations in the covered pond is shown in Table 14.

TABLE 14

DATA SUMMARY OF SUSPENDED AND VOLATILE SUSPENDED SOLIDS IN THE COVERED ANAEROBIC DEEP POND

SAMPLE LOCATION	NO. OF MEASUREMENTS	TOTAL SUSPENDED SOLIDS			VOLATILE SUSPENDED SOLIDS		
		MEAN mg/l	RANGE mg/l	STD.DEV.	MEAN mg/l	RANGE mg/l	STD.DEV.
Influent	47	6.7	1.5-14.2	4.6	3.3	0-5.7	2.6
Surface	143	18.2	4.1-44.4	8.7	10.2	2.5-29.5	5.4
Middepth	120	18.3	5.2-44.2	9.1	9.3	1.3-24.0	4.4
Bottom	138	19.5	4.7-36.0	11.9	9.7	1.2-22.7	4.7
Recirculation	47	17.0	3.1-32.5	8.1	8.8	1.1-24.0	4.5
Effluent	47	17.2	4.3-40.7	10.8	9.7	2.4-25.5	6.6

Values for the surface, middepth, and bottom represent samples taken from nine locations at each depth. The high range does not represent differences due to the locations at which the samples were taken, but rather to seasonal differences in solids concentration. In comparison to the summer of 1969, lower volatile solids concentrations were seen during the 1969-70 winter operation when the 10-day detention time proved to be too short and the bacterial population was washed out faster than it could reproduce.

The uniform concentration of solids of the in-pond, effluent and recirculation samples indicated that the pond was mostly completely mixed, and thus confirms the findings of the tracer studies. Since the concentrations of solids of the effluent and recirculation line were essentially equal, it is feasible that mass inoculation of the influent could be done directly from the effluent line, thus eliminating a separate recirculation line for each pond. A drain for removal of any accumulated sludge should be included in the design.

Consumptive Ratio for Field Processes

As previously stated, the consumptive ratio assumed in Equation 10 for the denitrification of the tile drainage was 1.3. To insure an adequate supply of carbon it was standard procedure to inject from 10 to 50 mg/l more methanol than was indicated by Equation 10 when starting filters or ponds. The start-up methanol feed rate was cut back by degrees when an excess of methanol appeared in the effluent and nitrogen removal efficiencies became acceptable. In this way, a practical lower limit of 65 mg/l of methanol for 20 mg/l nitrate-nitrogen and 8.0 mg/l dissolved oxygen was determined to be suitable in the experimental work. As continuous operation of the filters and ponds progressed, a consumptive ratio of 1.47 with a standard deviation of $\pm$.36 was determined for the units being operated at the Interagency Agricultural Wastewater Treatment Center. The high standard deviation more likely is due to inherent difficulties in conducting field studies than to fluctuations in system requirements. The ratio 1.47 was used as the consumptive ratio in Equation 10 when calculating the amount of methanol to be used when making cost estimates for the projected nitrogen loadings.

Regrowth Studies

A series of laboratory experiments were performed to determine whether or not removal of nitrogen from tile drainage would effectively reduce any biostimulatory effect caused by the drainage prior to treatment. These experiments are described in detail in a report entitled "Effects of Agricultural Wastewater Treatment on Algal Biossay Response" (33). It was found from the experiments that invariably mixtures containing wastewaters treated by bacterial filter systems had lower bioassay responses than did untreated wastewater. "Respiking" the bacterial filter sample with nitrate-nitrogen resulted in bioassay responses equal statistically to those of untreated wastewater. It was concluded in the report that under the environmental conditions imposed in the regrowth experiments, tile drainage which had undergone treatment by bacterial denitrification with subsequent removal of nitrogen to a 2 mg/l or less concentration did not have a biostimulatory effect when added to San Joaquin river water. Furthermore, it was apparent from the studies that nitrogen was the nutrient required to create a biostimulatory response in waters receiving the tile drainage.

Botulism Studies

A special study was made by the California Department of Fish and Game on the possibility of outbreaks of Type C Botulism in water fowl having contact with full scale denitrification filters or ponds. Details of the experiments used in the study are available in a report published by the Department of Fish and Game (34). On the basis of their research, members of the Department concluded that a botulism potential would exist in filters and ponds if large invertebrate populations developed in them. Many invertebrates contain botulism bacteria or spores in their digestive tracts. The bacteria multiply and the spores develop into "vegetative" forms as the invertebrate carcass decays. Another foreseeable hazard which could occur in deep ponds would be the occurrence of decaying animal carcasses on which fly maggots can thrive. The maggots could be ingested by waterfowl and a botulism outbreak could occur. However, since the water surface area would be relatively small, any botulism outbreak would not be considered serious because the birds could be excluded by a mechanical barrier or avian scaring device.

The Department of Fish and Game recommended that construction of any ponds for use as water impoundment, such as an anaerobic denitrification ponds, *should include in their design steep-sloped levees, a minimum of shoreline* area, and a water depth as deep as possible. These recommendations are in keeping with the basic design of the ponds used for anaerobic denitrification.

Among the management practices of anaerobic filters and deep ponds recommended by the Department of Fish and Game would be the burning of all vegetation prior to flooding of the pond and removal of vegetation from all filter surfaces and from pond levees during operation. Removal of the vegetation would eliminate food sources for invertebrates and, therefore, toxic bacteria which use dead invertebrates as a substrate. Moreover, removal of levee or filter vegetation would insure that an outbreak of botulism could not go undetected by being obscured. Another recommended practice was to maintain the water at a constant level since fluctuations of water levels are accompanied by invertebrate die-off. Ponds should not be allowed to become stagnant for long intervals since this also may lead to invertebrate die-off because of the development of adverse conditions in the water. Animal carcasses found in ponds or on filter surfaces should be removed immediately and disposed of in a sanitary manner.

Process Cost Estimates

A second objective of the feasibility studies at the Interagency Agricultural Wastewater Treatment Center was to develop preliminary cost estimates for the processes found to be technically feasible. Of the anaerobic denitrification processes, only the anaerobic filter and covered pond met the criterion of technical feasibility. Hence, cost estimates were made only for these two processes. In making the estimates it was necessary to determine the critical design period of the year. The predicted seasonal variations of tile drainage flow and nitrogen concentrations in tile drainage from the San Joaquin Valley are shown in Figure 18. These data show that April is the critical month in which both high irrigation return flows and high nitrogen concentrations are expected to occur. Adding these facts to the effects of the prevailing environmental conditions for the month (low water temperatures, etc.) indicates that cost estimates should be based on the detention times required in April. In making the estimates, it was assumed that the total flow in the San Luis Drain will be treated at a plant near the Kesterson Reservoir (Gustine, California). Within 30 years, drainage flows from the San Luis unit service area are expected to reach a maximum annual quantity of over 50 billion gallons.

Basis for Estimates

In addition to the above stated elements, there are other factors which are common to the estimates.

1. All costs are based on January 1970 dollars.

2. Debt service is calculated for 50 years at 5 percent.

3. Costs per million gallons treated are calculated by dividing the total annual cost (debt service plus operations and maintenance costs) by the design capacity.

4. An engineering and contingency factor of 57 percent was assumed for capital cost items whose design and operation were based on the experimental data obtained at the treatment center. A lower engineering and contingency factor was selected for items which were common waste treatment facilities or the price of which was obtained from the manufacturer. (See footnotes in Tables 16 and 19).

5. All land is acquired at the start of the project at $500 per acre.

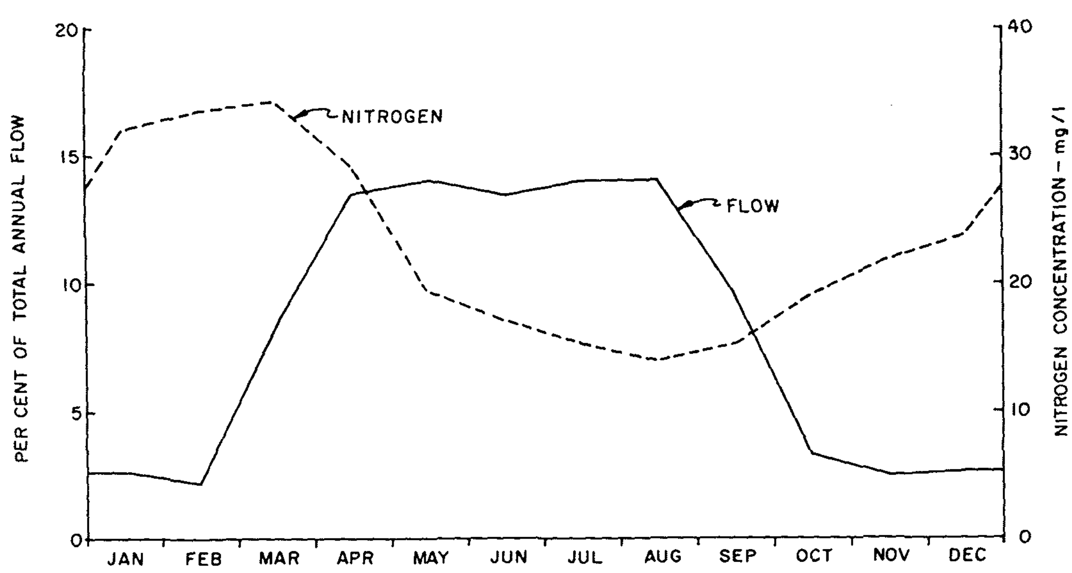


FIGURE 18- PREDICTED SEASONAL VARIATION OF TILE DRAINAGE FLOW & NITROGEN CONCENTRATIONS FROM SAN JOAQUIN VALLEY, CALIFORNIA

6. The laboratory, office building, maintenance, and storage areas are basically the same as those at the San Jose, California Sewage Treatment Plant. Capital costs for these facilities are based on information published by Guthrie (35).

7. Sedimentation tank loadings and separation chemical additions for denitrification pretreatment are: 900 gpd/ft^2 and 10 mg/l Fe $(SO_4)_3$ plus 0.5 mg/l cationic polyelectrolyte. Capital costs for sedimentation are from figures published by Smith (36).

8. Electric power costs are calculated on the basis of 1c/kw-hr.

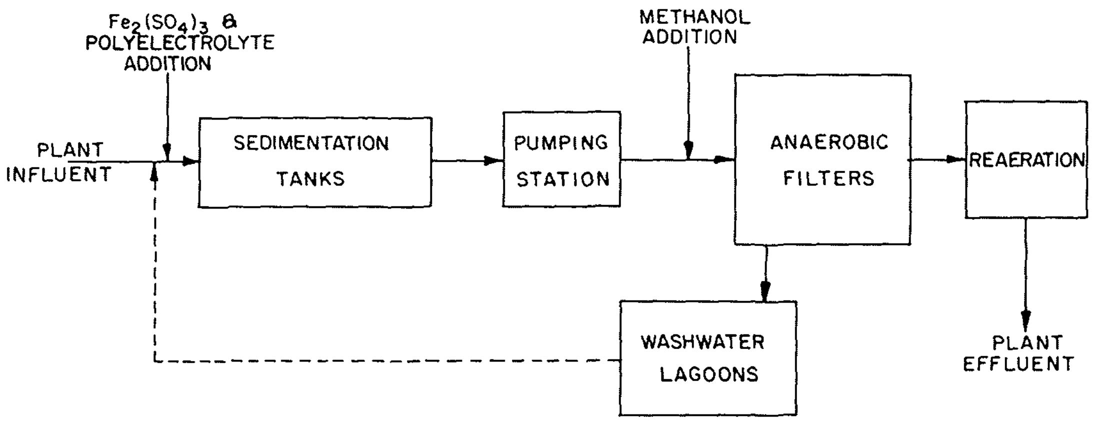
9. General plant operation and maintenance (O&M) costs are based on curves published by Smith for trickling filter O&M (36). It is assumed that the general plant O&M costs include replacement and power costs for all plant operations except for the items indicated in Tables 17 and 20.

10. The cost of reaeration was taken from figures published by Smith (36).

Filter Denitrification Design Criteria and Cost Estimates

The schematic diagram for the filter denitrification process is presented in Figure 19. Sedimentation tanks are included in the design to remove any suspended solids (i.e. algae) which would be likely to clog the filters and/or by degradation release excess ammonia or organic nitrogen. Flow through the sedimentation tanks is by gravity, after which the water is pumped through the filters. Flow from the filters through the aerators (reaeration step) is also by gravity. Design criteria for the filter denitrification plant are presented in Table 15.

Methanol feed pumps are provided for each of the filters. The filter boxes are fabricated of tilt-up panels connected by way of columns. For



FILTER DENITRIFICATION

FIGURE 19 SCHEMATIC DIAGRAM

ease of operation, maintenance, and construction the box is subdivided by walls similar to the external box walls into sections 100 feet by 100 feet on a side. The floor of the box is made of a 12-inch thick reinforced concrete slab.

Filter washing (removal of excess bacterial cells) is accomplished by: (1) closing a sliding effluent gate, (2) pumping compressed air into the bottom of the filter while the influent line is still open, and (3) when the total water depth in the filter box reaches 13 feet the influent is stopped and two 24-inch drain lines are opened rapidly. The water and bacterial solids flow by gravity to the washwater lagoons. Once the solids settle, the washwater is decanted and pumped back to the headworks of the plant. After denitrification has taken place the dissolved oxygen concentration of the treated waste is brought up to 4 mg/l by mechanical aeration. The capital costs for the filter plant having a 228 MGD capacity are itemized in Table 16.

TABLE 15

FILTER DENITRIFICATION DESIGN CRITERIA

Ultimate Design Capacity	228 MGD
Sedimentation Tank Surface Loading	900 gpd/ft^2
April Filter Hydraulic Detention Time	3 hours
Filter Medium Depth	6 feet
Filter Box Wall Height	14 feet
Average Annual Methanol Concentration	68 mg/l
Washwater Lagoons	2,690,000 ft^3/phase
Reaeration	Plant effluent D.O. = 4 mg/l

TABLE 16

CAPITAL COSTS FOR FILTER DENITRIFICATION
DESIGN CAPACITY - 228 MGD

NUMBER	ITEM	CAPITAL EXPENDITURE 1970 DOLLARS (Engineering and Contingency Included)	
	Pretreatment		
1	Separation Facilities		$5,400,000
	Nitrogen Removal		
2	Filter Construction	$28,100,000	
3	False Bottoms	10,000,000	
4	Pumps	1,100,000	
5	Wash Water System	600,000	
		$39,800,000	39,800,000
	Post Treatment		
6	Reaeration Equipment		1,500,000
	Other		
7	Land Acquisition	100,000	
8	Buildings	700,000	
		$800,000	800,000
	GRAND TOTAL		$47,500,000

NOTE: Items Numbers 1,3,4,6, and 8 received a 25 percent engineering and contingency factor.

Items Numbers 2 and 5 include a 57 percent engineering and contingency factor furnished by the U.S. Bureau of Reclamation in its "reconnaissance" estimates.

No engineering and contingency factor was assigned to the land cost.

The unit costs for the filter treatment plant are presented in Table 17. These costs are based on the assumptions stated in the previous section. From the data in the Table, the cost for treatment by filter denitrification would be approximately 92 dollars per million gallons for a plant operated at full capacity.

TABLE 17

TREATMENT COSTS FOR FILTER DENITRIFICATION
DESIGN CAPACITY - 228 MGD

ITEM	COST/MG (1970 DOLLARS)	PERCENT OF TOTAL COST
CAPITALIZED COSTS		
Pretreatment		
Separation Facilities	6	6
Nitrogen Removal		
Filter Construction False Bottoms Pumps Wash Water System	43	47
Post Treatment		
Reaeration	2	2
Other		
Land, Buildings, and Miscellaneous	1	1
ANNUAL O&M COSTS		
General O&M	21	23
Methanol	19	21
TOTAL	$92/MG	100 Percent

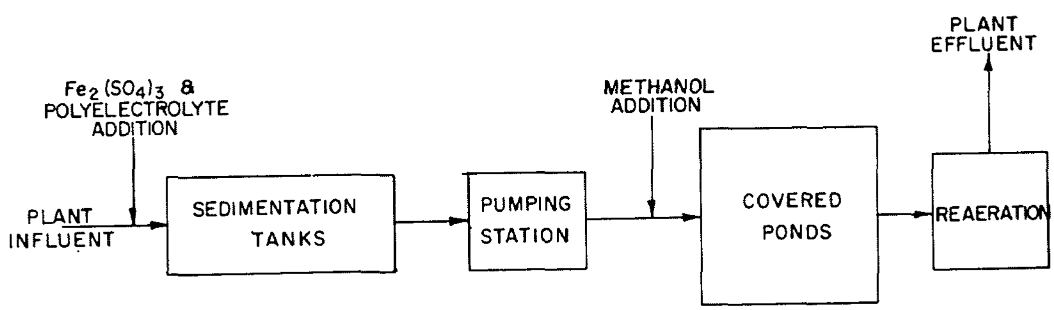
Pond Denitrification Design Criteria and Cost Estimates

The schematic for covered pond denitrification is presented in Figure 20. In this configuration, any algae present in the influent to the treatment plant are removed in standard sedimentation tanks. The essentially algae-free waste is pumped into covered ponds designed according to the specifications listed in Table 18. Six covered ponds grouped about a common effluent line and one recycle pumping station are provided per phase of construction. The ponds have 3 feet of freeboard, and levees having sides with a 1:1 slope and a crest 15 feet wide. To prevent seepage into or out of the ponds, 14 percent of the internal area is sealed with soil cement. The remaining 86 percent is sealed by compaction of the native soil. The pond covers used for this cost estimate were assumed to be of the same type used at the treatment center (DOW STYROFOAM - WT). The cost of covering the ponds is based on information provided by the DOW Chemical Company. Individual methanol feed pumps are provided for each pond. The 25 percent recycle is taken from the common effluent line and pumped around the six ponds as a group. Reaeration is accomplished by mechanical aeration. The capital costs for the covered ponds are itemized in Table 19.

TABLE 18

POND DENITRIFICATION DESIGN CRITERIA

Ultimate Design Capacity	228 MGD
Sedimentation Tank Surface Loading	900 gpd/ft^2
April Pond Hydraulic Detention Time	15 days
Pond Water Depth	15 feet
Pond Length to Width Ratio	5
Recycle	25 percent
Average Annual Methanol Concentration	68 mg/l
Reaeration	Plant effluent D.O. = 4 mg/l



POND DENITRIFICATION

FIGURE 20 SCHEMATIC DIAGRAM

TABLE 19

CAPITAL COSTS FOR DEEP POND DENITRIFICATION
DESIGN CAPACITY - 228 MGD

NUMBER	ITEM	CAPITAL EXPENDITURE 1970 DOLLARS (Engineering and Contingency Included)	
	Pretreatment		
1	Separation Facilities		$ 5,400,000
	Nitrogen Removal		
2	Pond Construction	$ 9,000,000	
3	Pond Covers	19,000,000	
4	Pumps	1,000,000	
		$29,100,000	29,100,000
	Post Treatment		
5	Reaeration Equipment		1,500,000
	Other		
6	Land Acquisition	$ 800,000	
7	Buildings	700,000	
		$ 1,500,000	1,500,000
	GRAND TOTAL		$37,500,000

NOTE: Items numbers 1,4,5, and 7 received a 25 percent engineering and contingency factor.

Item number 3 received a 20 percent engineering and contingency factor.

Item number 2 includes a 57 percent engineering and contingency factor furnished by the U.S. Bureau of Reclamation in its "reconnaissance" estimates.

No engineering and contingency factor was assigned to the land cost.

The unit costs for a covered pond denitrification plant are presented in Table 20. The cost of 88 dollars per million gallons is based on the construction assumptions listed previously.

TABLE 20

TREATMENT COSTS FOR POND DENITRIFICATION

ITEM	COST/MG (1970 DOLLARS)	PERCENT OF TOTAL COST
CAPITALIZED COSTS		
Pretreatment		
Separation Facilities	6	7
Nitrogen Removal		
Pond Construction	11	12
Pond Covers	20	23
Post Treatment		
Reaeration	2	2
Other		
Land, Buildings and Miscellaneous	2	2
ANNUAL O&M COSTS		
General O&M	21	24
Methanol	19	22
Pond Cover O&M	7	8
TOTAL	$88/MG	100 Percent

Treatment Costs of San Joaquin Valley Drain Flows

The actual costs of treatment of agricultural tile drainage by either anaerobic filters or covered ponds will depend on the time of staging plant construction. It is expected that the unit cost of each process will be higher than the values given in Tables 17 and 20. It is believed that plant construction most likely will be staged so that the 30 year period of increasing flows can be treated in an economical manner. With staged construction there would occur a time period in the early part of each stage when a portion of the treatment facilities will not be in use. Because of this excess capacity, the cost per million gallons treated will be higher than if the unit cost was based on design capacity.

SECTION V

ACKNOWLEDGMENTS

This phase of the field investigations concerned with bacterial denitrification of tile drainage was performed under the joint direction of Messrs Percy P. St. Amant, Sanitary Engineer, Environmental Protection Agency; Louis A. Beck, Sanitary Engineer, California Department of Water Resources; and Donald G. Swain, Sanitary Engineer, United States Bureau of Reclamation.

The field work was the responsibility of Messrs Thomas A. Tamblyn and Bryan R. Sword, Sanitary Engineers, Environmental Protection Agency. Mr. Tamblyn was the major contributor to the theoretical section of this report and also developed the basic process designs and cost criteria upon which the economics were based.

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:

Robert G. Seals . . . . Chemist, Environmental Protection Agency
William R. Lewis . . . Chemist, California Department of Water Resources
Norman W. Cederquist . . . . Technician, US Bureau of Reclamation
Gary E. Keller . . . . Technician, US Bureau of Reclamation
Gary L. Rogers . . . . Technician, US Bureau of Reclamation
Mathew C. Rumboltz. . . . . Technician, US Bureau of Reclamation
Clara P. Hatcher. . . .Laboratory Aid, California Dept. of Water Resources
Elizabeth J. Boone. . .Laboratory Aid, California Dept. of Water Resources
Betty A. Smith. . . . . . . .Clerk-Typist, Environmental Protection Agency

Consultants to the Project

Dr. Perry L. McCarty. . . . . Stanford University, Palo Alto
Dr. William J. Oswald . . . . University of California, Berkeley
Dr. Clarence G. Golueke . . . . University of California, Berkeley

Report Prepared by:

Bryan R. Sword . . . . .Sanitary Engineer, Environmental Protection Agency

SECTION VI

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SECTION VII

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 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

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2 *Subject Field & Group*

05D

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 *Organization*

Environmental Protection Agency
Office of Research & Monitoring
Robert S. Kerr Water Research Center, Ada, Oklahoma

6 *Title*

DENITRIFICATION BY ANAEROBIC FILTERS AND PONDS

10 *Author(s)*

Sword, Bryan R.

16 *Project Designation*

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21 *Note*

22 *Citation*

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE
Report Number 13030ELY04/71-8
Pages-68, Figures-20, Tables-18, References-36

23 *Descriptors (Starred First)*

*Agricultural Wastes, *Denitrification, *Irrigation Water, *Return Flows, *Nitrate, *Anaerobic Treatment

25 *Identifiers (Starred First)*

*San Joaquin Valley, California, Bacterial Denitrification, Anaerobic Filters, Anaerobic Ponds

27 *Abstract*

The removal of nitrogen from tile drainage by means of bacterial reduction was investigated at the Interagency Wastewater Treatment Center near Firebaugh, California. The major nitrogen form in tile drainage is nitrate (approx. 98%). The process required that an organic carbon source be added to the waste to accomplish reduction of the nitrogen. The bacterial process was used in two configurations; anaerobic filters and anaerobic deep ponds. It was found that with the addition of 65 mg/l [illegible] of methanol, 20 mg/l nitrate-nitrogen could be reduced to 2 mg/l or less of total nitrogen within one hour of treatment by filter denitrification at water temperatures as low as 14°C. The same removal was achieved at 12°C in a filter operating at a detention time of two hours. A covered deep pond required an actual detention time of eight days at water temperatures of approximately 22°C and a theoretical detention time of 15 days at temperatures of approximately 16°C to accomplish the same removal. An uncovered pond was not able to achieve the same results at theoretical detention times as long as 20 days. The projected costs for both processes are approximately $90 per million gallons.

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Abstractor Sword | *Institution* Environmental Protection Agency

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