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PERFORMANCE EVALUATION

OF

TERTIARY WASTEWATER TREATMENT SYSTEMS

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CONTENTS

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by Ralph Evans, Donald Schnepper, Gene Brooks, and Jack Williams

INTRODUCTION

As part of the effort to enhance the water quality of surface waters in Illinois there is a trend toward the installation of a third waste treatment unit, as an addition to the conventional secondary treatment system. These 'tertiary' units, particularly as they apply to waste stabilization ponds, do not have operational records in Illinois of sufficient length to permit comfortable reliance on current design criteria. Unlike conventional treatment units, suitable relationships have not been developed for any of the tertiary units that will allow quantitative predictions of performance from knowledge of influent characteristics and/or design parameters. For these reasons the Illinois Environmental Protection Agency (IEPA) funded the work on which this report is based and permitted the Illinois State Water Survey to examine some representative types of tertiary units under prevailing operating conditions.

The rules and regulations (Illinois Environmental Protection Agency, '972) governing deoxygenating waste effluent requirements for sewage treatment facilities in Illinois are based principally on dilution ratios, i.e., the ratio of the rate of flow of the receiving stream to the rate of flow of the sewage effluent. The design low flow of the stream is that flow that is likely to occur once in 10 years and to persevere for a duration of 7 days, generally designated the '7-day 10-year low flow.' For Illinois streams these flows have been determined by Singh and Stall (1973). The effluents of waste stabilization ponds are an *exception* to the dilution ratio concept, provided the waste load to them is less than 2500 population equivalents and the pond system employs a 3-cell arrangement. Effluent requirements for waste stabilization ponds, hereafter called lagoons, are based on the water quality standards of the receiving stream, but generally the effluent from the lagoon system must not exceed 30 mg/l 5-day biochemical oxygen demand (BOD_5) and 30 mg/l suspended solids.

It is now apparent that another effluent requirement is pertinent to lagoon effluent. The current (1977) stream standard does not permit total ammonia nitrogen (NH_3+NH_4^+) to exceed 1.5 mg/l. Many sewage treatment facilities, especially those serving small communities, discharge to streams waters that do not provide sufficient dilution year-round to substantially reduce the concentration of waste residues in effluents. In these cases the water quality standards for stream water are applicable to the effluent and in effect become effluent standards.

Lagoon systems in Illinois have performed well in producing satisfactory effluents from a BOD_5 standpoint. However, their inherent dependence on a prolific algal population, within the systems, results in concentrations of suspended solids, namely algal cells, higher than acceptable in treated effluent.

Types of Treatment

The basic design and construction requirements for sewage works in Illinois are set forth in the *Recommended Standards for Sewage Works* prepared by the Great Lakes Upper Mississippi River Board of Sanitary Engineers (1970). These requirements are modified from time to time by the IEPA through the issuance of technical policy and advisory releases. A WPC Technical Policy 20-24 release sets forth the basic requirements for supplemental treatment (IEPA, 1970). It is within the framework of this technical policy that certain tertiary units have been permitted for treating the wastes from lagoons. Those units include lagoon bottom sand filters (LBSF), intermittent sand filters (ISF), submerged rock filters (SRF), and granular media filters (GMF).

Lagoon bottom sand filters are units located in the bottom of the last cell of a 3-cell lagoon system. They are provided in duplicate and operate continuously submerged by 3 to 5 feet of overlying lagoon effluent. Their principal function is to retain algae developed in the lagoon system. The sand depth, atop a gravel base, is about 24 inches and the filtered waste is removed by a system of underdrains. The hydraulic loading is generally limited to 10 gallons per day per square foot (gpd/ft^2) and the effective sand size varies from 0.3 to 1.0 millimeters (mm) with a uniformity coefficient less than 4. Concentrations of 30 mg/l BOD_5 and suspended solids, or less, are anticipated in the effluent.

Flow through the units is not regulated and varies with head loss. General practice is to draw down each filter 2 times yearly, during early summer and late fall, to remove the residue atop the sand and to rework the top 2 to 4 inches of the sand. During this study 3 installations were examined; they are the facilities serving the communities of Table Grove, Liberty, and Teutopolis.

Intermittent sand filters are specially prepared beds of sand, usually 24 to 30 inches in depth. Unlike the LBSF, treated sewage is applied on their surface intermittently. Filters are usually provided in pairs with each being dosed no more than twice daily at equal alternating periods. An underdrain system collects the filtered waste for effluent discharge. A hydraulic loading of 15 gpd/ft^2 is permitted for lagoon treatment; for wastes with only primary treatment the hydraulic loading is limited to 3 gpd/ft^2. Sand size and uniformity coefficient are similar to that for the LBSF. When ISF units are used in conjunction with lagoon systems, concentrations of 10 mg/l BOD_5 and 12 mg/l suspended solids, or less, are anticipated in the effluent.

Flow through the filter units is not generally regulated. When a mat of organic material accumulates on the sand surface, to the extent that the filtration rate is adversely affected, cleaning of the sand surface is required. During the study, there were no lagoon systems in operation that employed ISF units. However, there are several units in operation filtering waste from primary treatment, i.e., settling and Imhoff tanks. Three of these were selected for examination. These were the units serving the communities of Bluford, Thompsonville, and Cisne.

Submerged rock filters are screening units consisting of crushed limestone aggregate that are incorporated in the last cell of a lagoon system near the outlet. The aggregate, ranging from 2 to 6 inches, is placed to form a berm, with about a 3:1 side slope, and at an elevation at least 12 inches above the maximum operating water level within the lagoon. The wastewater passes through the rock which screens out floating solids and algae. Hydraulic loadings range from 3 to 9 gallons per day per cubic foot (gpd/ft^3) of submerged aggregate. Current practices provide drain collection systems within the filter instead of an 'open water' collection arrangement on the effluent side of the filter. Concentrations of 30 mg/l BOD_5 and suspended solids, or less, are expected from the system. However, examination of effluents by personnel of IEPA has not been encouraging, and a moratorium is currently (1977) in effect regarding their construction. Two units were observed as part of this study; these serve the communities of Fairview and Paw Paw.

Granular media filters, as used in Illinois, are the gravity feed downflow type. Influent wastewater enters the filter and passes downward through the media, normally 36 inches deep, depositing solids on top and within the bed material. Eventually the pressure drop across the filter becomes excessive. The filter is cleaned by a backwash operation. The effective size of the media varies with the depth provided; the deeper the bed the larger the media size permitted. Hydraulic loadings range from 1 to 2 gpm/ft^2 with peak flows approaching 5 gpm/ft^2. Concentrations of 10 mg/l BOD_5 and 12 mg/l, or less, suspended solids are anticipated in the treated effluent when used with lagoons.

Two units were examined that handled effluent from lagoons; they were at the Freeburg East plant and Smithton. One other unit studied, the Freeburg West plant, operates in conjunction with an activated sludge treatment facility.

Methods and Procedures

The influent and effluent of 11 treatment units were collected on 10 to 12 occasions during the period April through October 1977. Field measurements were made for temperature, dissolved oxygen, and flow rate of treated waste flow. Survey personnel made analyses for total suspended solids, volatile solids, total and soluble chemical oxygen demand, total ammonia, nitrate, and total phosphorus. Personnel of IEPA performed analyses for BOD_5 and fecal coliform on the samples collected. All analyses were made in accordance with the procedures outlined in Standard Methods (American Public Health Association, 1975).

The flow rates of treated effluents were determined by various methods dependent upon the location and shape of the discharge appurtenance. In most cases a v-notch weir was used; in some cases a container and timer were used satisfactorily, and in one case the California pipe method (Van Leer, 1922, 1924) was useful.

All samples were collected on a grab basis. Effluent samples from ISFs were collected at the mid-time of their unloading. Lagoon influents are considered composited within themselves, and the effluent from their filtering devices would not be expected to change significantly during a 24-hour period.

Scope of Report

This report contains all the data considered useful for evaluating the performance of the 11 sewage treatment works. A detailed description of each facility is presented including the basis of design and current operating mode. Liberal use is made of figures and tables to document their operating characteristics. Recommendations are offered that may be helpful for developing design criteria for tertiary units as applied to waste stabilization ponds and other treatment facilities serving small communities in Illinois.

Acknowledgments

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Among the superintendents of the sewage treatment works who gave freely their time and advice, we are particularly indebted to Vic Wood at Bluford, Gene Palfreeman at Cisne, Boyd Jones at Fairview, Terry Groth at Freeburg, Lawrence Haley at Liberty, Glenn Worthington at Table Grove, Bradley Smith at Teutopolis, Gene Lager at Thompsonville, Belmont Valentine at Smithton, and Larry Thompson at Paw Paw.

LITERATURE REVIEW

The lagoons used for sewage treatment are shallow man-made impoundments designed to enhance the degradation of wastewater by natural biological means. For convenience, waste-treatment lagoons have been classified into five general types (Environmental Protection Agency, 1973): high rate aerobic, facultative, anaerobic, tertiary, and aerated. In Illinois the facultative and aerated types are the most numerous. The facultative lagoon, as defined by Gloyna (1976), provides an aquatic environment in which photosynthetic and surface oxygenation supplies an aerobic zone in the upper strata, a facultative zone throughout most of its depth, and an anaerobic bottom layer. Aerated lagoons are basically the facultative type in which aeration devices, either air diffusers or mechanical aerators, are placed to supplement the oxygen produced by algal activity.

In Illinois, lagoons without aeration devices are designed for BOD_5 loads ranging from 22 to 30 pounds per acre per day (1bs/ac/da) with lower limits for the northern portion of the state and the upper limit for the southern portion (IEPA, 1971). The maximum permissible depth is 5 feet and BOD_5 removals of 75 percent are anticipated from each cell in a series. Aerated lagoons in series are permitted a BOD_5 loading of 170 1bs/ac/da on the first cell with loadings to subsequent cells not exceeding 100 1bs/ac/da. The maximum allowable depth is 10 feet and the BOD5 removals anticipated are similar to the unaerated lagoons. Where lagoon bottom sand filters, intermittent sand filters, and submerged rock filters are proposed to remove suspended solids from lagoon effluents, a 3-cell series arrangement must be provided (Busch, 1976). Where granular media filters are proposed, a 2-cell series arrangement is permissible.

A 3-cell lagoon system in series will produce an effluent BOD_5 containing 30 mg/l or less at least 90 percent of the time (Pierce, 1974). The suspended solids, predominantly algae, will generally exceed 30 mg/l especially during the spring and summer months.

Middlebrooks et al. (1974) summarized 14 basic techniques for removing algae from the effluents of lagoon systems, as follows:

1. In-pond removal of particulate matter
2. Biological disks, baffles, and raceways
3. In-pond chemical precipitation
4. Autoflocculation
5. Complete containment

6. Biological harvesting
7. Coagulation-flocculation
8. Dissolved air flotation
9. Oxidation ditches
10. Centrifugation
11. Microstraining
12. Soil mantle disposal
13. Granular media filtration
14. Intermittent sand filters

For reasons based principally on ease of operation, minimum maintenance and costs, dependability of operations, and efficiency of particulate removal, the authors concluded that the techniques numbered 1 through 9 are unsatisfactory for communities of 5000 people or less. Parker and Uhte (1975) take issue with these conclusions. The two papers excellently detail the considerations that must be given in selecting a design for algal removal.

Of the 14 techniques cited by Middlebrooks et al. (1974), only two have thus far been considered promising for lagoons handling domestic waste in Illinois. These are the intermittent sand filters and granular media filters. Lagoon bottom sand filters and submerged rock filters were not included in the authors' appraisal. Presumably operating data were not available for these types of units prior to 1974. The first full scale submerged rock filter research was reported by O'Brien (1974, 1975) for an installation in Eudora, Kansas. The first summary for lagoon bottom sand filter design was developed by Williams (1976). The remainder of this discussion is limited to sand filters, rock filters, and granular media filters.

Sand Filters

Williams' (1976) functional concept of a LBSF is based on the likelihood of algal cells being repulsed by sand particles. The theory suggests that electrokinetic forces exerted by algae and sand particles, both being negatively charged, create a mutual repulsive force that minimizes the escape of algae through sand. Williams recommends a flow rate of 15 gpd/ft^2 when using a sand bed (0.6 to 0.8 mm effective size) 18 inches deep atop 18 inches of graded gravel at an overlying water depth of 5 feet.

For the same reasons Williams (1976) gives for effective removal of algae by a sand bed, Foess and Borchardt (1969) conclude that algae will channel their way through a sand bed because of the lack of surface interaction between algal cells and sand grains. They found that lowering the pH diminished the negative charge of algae and enhanced algal removal simply because conditions were more favorable for contact between algal cells and sand grains. Parker (1976) also concludes that the negative charge and small size of algae render sand filtration an ineffective process for algae removal. He points out that the common green algae like *Chlorella* and *Scenedesmus* with equivalent diameters of less than 0.02 mm and the blue-green algae, *Oscillatoria*, less than 0.3 mm diameter, are not likely to be removed by the sand sizes usually employed in sand beds.

It is probable that all these authors, though correct in assuming that straining through sand is not an important removal mechanism for algae when applied to a *discrete* sand bed, overlook the fact that a sand bed soon after it commences operation is no longer an inert layer of clean, porous, well-defined grains of sand but becomes a biological filter with entirely different characteristics and behavior patterns than that exhibited by a bed of clean sand. The fact that the rate of filtration increases and the life of a sand filter is prolonged after the removal of the top 1 to 3 inches of sand indicates that a straining mechanism of some type is at work. It is likely that a combination of physical straining and biological alteration occurs as wastewater passes through the sand. As mentioned earlier, prior investigations of LBSF in operational modes have not been reported. The results of this study will provide some insight to their effluent characteristics.

The work of Grantham et al. (1949) in Florida led to the development of a rational design for the intermittent sand filter as a secondary unit for treating settled sewage. The initial studies used once-a-day doses of sewage spread on sand beds at a 6-inch depth. The removal of suspended solids was found to be independent of hydraulic loading rates but dependent on sand size and depth. BOD_5 removals varied with hydraulic loading rates, sand size, and filter bed depth. It was found that purification proceeded well into the nitrification stage with depth being a factor as far as nitrification was concerned. With 0.3 to 0.45 mm effective sand size and hydraulic loading rates of 3.5 gpd/ft^2, concentrations of 6 mg/l BOD_5 and 5 mg/l suspended solids were consistently achieved in the effluent. Furman et al. (1955) studied the effects of more frequent dosages, i.e., two doses per filter per day, and achieved similar effluent results at loadings of 5 gpd/ft^2 at a sand size of about 0.5 mm. They also observed that 89 percent of the BOD_5 was removed In the top 12 inches of the sand.

Calaway et al. (1952) had earlier observed that zoogleal bacteria generally extended into the sand bed to a depth of 12 inches. These findings lead to the conclusion that the zoogleal organism *Zoogleal ramigera* is responsible for most of the organic removal in the sand bed. Calaway (1957) later summarized the biology of an intermittent sand filter emphasizing its role as an *aerobic* habitat not only for bacteria and protozoa but also for aquatic worms which consume sludges and slimes thereby keeping the sand bed open and active.

The most difficult problem encountered in the operation of the ISF is dosing them in such a manner as to quickly and completely flood them. This requires careful design of the dosing mechanism to insure an almost instantaneous loading.

More recent work has been done at Utah State University where lagoon effluents were dosed on a once-a-day interval to sand beds. Consistent high quality effluents are reported by Middlebrooks et al. (1977) with BOD_5 of less than 5 mg/l about 93 percent of the time. Suspended solids concentrations were less than 3 mg/l. Pit run sand was used at a 36-inch depth atop 12 inches of graded gravel (1/4 to 1/2 inch). The effective size was 0.17 mm with a uniformity coefficient of 9.7. Hydraulic loading rates were 23 gpd/ft^2 in the summer with 8-day filter runs and about 5 gpd/ft^2 in the winter with 188-day filter runs. Harris et al. (1975) used the same beds at differing hydraulic loading rates and concluded optimum rates varied from about 9 to 14 gpd/ft^2. At these loadings BOD_5 and suspended solids concentrations of less than 10 mg/l were achievable in the effluents for filters loaded once daily. A significant finding was that a filter constantly submerged developed *anaerobic* conditions within it.

The work at Utah State University did not explore nitrification of the lagoon effluent as it passed through sand filter beds. However, Stone et al. (1975) found that lagoons serving the City of Sunnyvale, California, contain nitrifying bacteria even though significant nitrification was not occurring in the lagoons. Efforts to encourage nitrification in the lagoons were not successful. Nevertheless, the application of the lagoon effluent to an on-site reactor, similar in arrangement to a trickling filter, resulted in significant ammonia reduction by the nitrification process. Breakpoint chlorination (10 lbs Cl_2 per lb of NH_3 removed) was an efficient back-up removal system to trim ammonia-nitrogen concentrations from the nitrification facilities.

Submerged Rock Filters

The first field scale investigation of submerged rock filters was reported by O'Brien (1974) about an installation at Eudora, Kansas. Earlier pilot scale work had been performed at the University of Kansas as part of graduate work. Over a 15-month period two field scale filters of varying rock size were observed (O'Brien, 1975). The 'large rock' filter had an average size of 1 inch diameter, and the 'small rock' filter an average size of 0.5 inch. The small rock filter clogged after 12 months of operation at hydraulic loading rates varying from 0.5 to 16.4 gpd/ft^3. The large rock filter did not clog at hydraulic load rates of 4.0 to 22.3 gpd/ft^3 during the 15-month period. Throughout most of the year total BOD_5 in the effluent was between 10 to 25 mg/l. Total suspended solids were usually between 40 to 70 mg/l. O'Brien concluded that submerged rock filters, with rock greater than 1 inch but less than 5 inches, can produce an effluent of 30 mg/l BOD_5 and total suspended solids, or less, provided hydraulic loading rates do not exceed 9 gpd/ft^3 during the summer and early fall and 3 gpd/ft^3 during the winter and spring.

One of the disadvantages observed with submerged rock filters is that they become anaerobic throughout the summer and fall months. Under these conditions ammonia concentrations in the filter effluent exceed concentrations in the influent and if sulfate is present sulfide will be produced. Dissolved oxygen concentrations will also be minimal during this time as well as when the lagoon system becomes ice covered.

Bryant et al. (1977) prepared an excellent report summarizing data obtained for submerged rock filter installations at Chadwick, Illinois, and California, Missouri, as well as Eudora, Kansas. They conclude that the moratorium imposed by the IEPA in mid-1976 should remain in effect because the effluent requirement of 30 mg/l total suspended solids is not likely to be achieved by submerged rock filters. On the other hand, they suggest that an effluent requirement of 37 mg/l total suspended solids might be met by SRF.

Granular Media Filters

Grandular media filters as used here are designed for high rates of flow with provision for periodic backwashing. The filtering media may be sand, a combination of anthracite and sand (dual-media), or a synthetic granular substance. The direct application of lagoon effluent to GMFs has been discouraged by the findings of Davis and Borchardt (1966) and Foess and Borchardt (1969). Their findings indicate that the bulk of the algae must be removed before reaching the filter by either flocculation-sedimentation or coagulation-flotation sequences. Stone et al. (1975), in a pilot scale set-up, concluded that algae could be effectively removed by alum flocculation-dissolved air flotation preceding a dual-media filter about 66 inches deep at hydraulic loading rates of 5.6 gpm/ft^2. A similar arrangement is proposed for Stockton, California, with dual-media filters (48 inches anthracite coal atop 18 inches sand) being preceded by an alum dosage of 250 mg/l and air flotation. Eight-hour filter runs are anticipated.

Earlier work by Dryden and Stern (1968) demonstrated that dual-media filtration (18 inches of 0.55 mm anthracite atop 8 inches of No. 20 sand), preceded by a typical water treatment plant flocculator (300 mg/l aluminum sulfate) and sedimentation basin, reduced suspended solids of a lagoon effluent from 75 to 6 mg/l and total phosphate from 40 to 0.25 mg/l.

Cleasby and Baumann (Environmental Protection Agency, 1974) outline the design considerations for removing residual biological floc in settled effluents from secondary treatment by direct application to GMFs. It Is doubtful that the authors had in mind the effluents of lagoons when outlining the considerations for proper design of such filtration units. In contrast to the sand filters previously discussed, a GMF should employ a coarse-to-fine filtration system that allows the penetration of suspended solids into the media. The media size on the influent side, according to Cleasby and Baumann, should be at least 1 to 1.2 mm to achieve reasonable filter run lengths. Schnepper and Evans (1976) observed that a granular media installation serving an activated sludge treatment plant at Washington, Illinois, produced an effluent with suspended solids concentrations less than 5 mg/l. Filter runs averaged 22 hours; filtration rates averaged 2 to 5 gpm/ft^2. The effluent from the final clarifiers was applied directly to the filters without further treatment. A review of the literature did not reveal any operations where lagoon effluent was applied directly to a GMF.

DESCRIPTION OF TREATMENT FACILITIES

The 10 communities in Illinois being served by the 11 sewage treatment facilities examined during this study are shown in figure 1. This section describes the treatment facilities for each community with particular reference to their design features and filter characteristics.

Table Grove is a community of about 500 persons located in Fulton County. Daily water pumpage averages about 18,000 gallons. This is about 37 gallons per capita per day (gpcpd). The sewage treatment facilities consist of a 3-cell lagoon arrangement with dual bottom sand filters. The filters are located in the bottom of the third cell. The system, which was completed in 1973, is designed for sewage flows of 75,000 gallons per day (gpd). Design loadings for the lagoon system are 26 1bs/ac/da for BOD_5 on the initial cell with an anticipated reduction of 75 percent applied BOD_5 in each cell thereafter. Total detention time within the system at design flow is about 160 days. During the period of sampling, effluent flows averaged 8000 gpd.

The lagoon bottom sand filters consist of 0.28 mm sand at a depth of about 18 inches atop a 12-inch layer of graded gravel. The hydraulic loading at design flow is 19 gpd/ft^2. During the study the hydraulic loading averaged 2 gpd/ft^2. Water depth atop the filters varies from 3 to 5 feet and the filters are cleaned twice a year. Provision is made for chlorinating the effluent. Flow is by gravity through the system. A layout of the lagoon bottom filters is shown in figure 2.

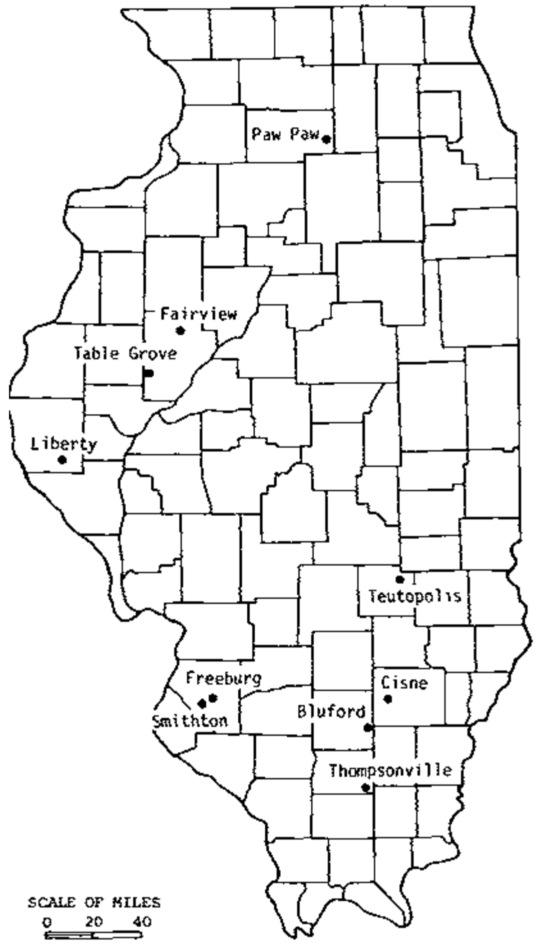

Figure 1. Locations of sewage treatment facilities evaluated

Liberty is located in Adams County and has a population of about 400 persons. Daily water pumpage averages about 26,600 gallons, or about 67 gpcpd. Its sewage treatment facilities are identical in terms of arrangement and design loadings to that described for Table Grove. The facilities, completed in 1973, are designed for a flow of 76,500 gpd. During the period of sampling, effluent flows averaged 10,000 gpd.

The lagoon bottom sand filters are constructed the same as those for Table Grove with a similar hydraulic loading of 19 gpd/ft^2 at design flow. During the study the hydraulic loading was estimated to average 2.5 gpd/ft . A layout of the filters is shown in figure 3.

Teutopolis is a community of about 1300 persons located in Effingham County. Daily water pumpage averages about 110,000 gallons, or about 85 gpcpd. The sewage treatment system consists of a 3-cel1 lagoon arrangement in series followed by a lagoon bottom sand filter. The system completed in 1976, is designed for sewage flows of 200,000 gpd. In terms of design loadings for BOD_5 it is similar to that described for Table Grove. During the period of sampling, effluent flows averaged about 60,000 gpd.

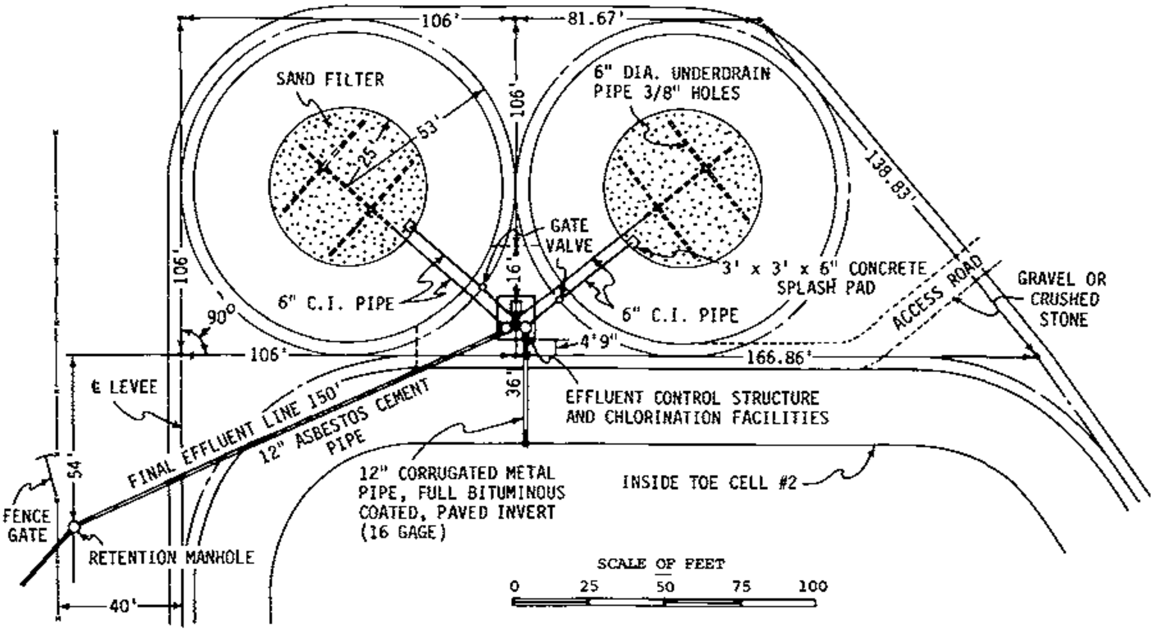

Figure 2. Lagoon bottom sand filter at Table Grove

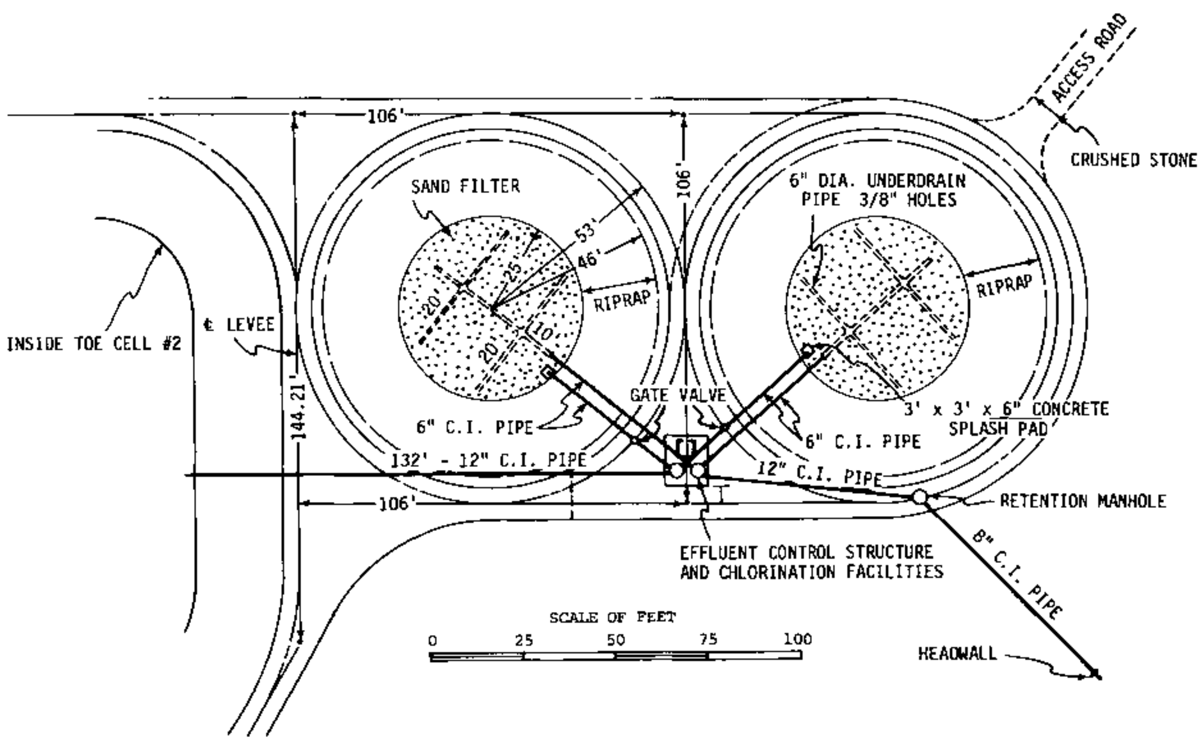

Figure 3. Lagoon bottom sand filter at Liberty

The lagoon bottom sand filter consists of 0.24 mm sand at a depth of 6 inches atop an 18-inch layer of graded gravel. Although two filters were originally conceived, the berm separating them is submerged during normal operation and the filters function as a single unit. The hydraulic loading at design flow is 5 gpd/ft^2. The loading during the period of study was about 1.5 gpd/ft^2. Water depths vary from 3 to 4 feet. Flow is by gravity through the system and provision is made for chlorinating the effluent. A layout of the filters is shown in figure 4.

Bluford is a community of 600 persons located in Jefferson County. Daily water pumpage averages 36,800 gallons, or about 61 gpcpd. The sewage facilities consist of settling tanks for primary treatment, followed by intermittend sand filters. Two pumps are used to alternately dose the filters with settled sewage. Provision is made for 100 percent recirculation of the filtered effluent. The system, completed in 1976, is designed for sewage flows of 65,000 gpd. Settling tank capacity allows for 24-hour detention at design flow, and the dosing tank and pumps *are* designed for a 3-inch sewage depth on the filters per dose.

The sand filters consist of 0.3 to 0.6 mm sand at a depth of 30 inches atop 6 to 12 inches of graded gravel. The hydraulic loading at design flow is 3 gpd/ft^2. During the study effluent flow averaged 35,000 gpd. Because of sewage flows substantially below design, only one-half of the filter bed is being used and the hydraulic loading is about 3 gpd/ft^2. The effluent is chlorinated. A layout of the system is shown in figure 5.

Thompsonville is located in Franklin County and has a population of about 500 persons. Daily water pumpage averages 35,800 gallons, or about 70 gpcpd. The sewage treatment facilities are the same as those serving Bluford, including design flows and structural dimensions. It commenced operation in 1972. During the study effluent flows averaged 30,000 gpd. As in the case of Bluford only one-half of the filter bed is being used and the hydraulic loading is about 2.6 gpd/ft^2. A layout of the facilities is shown In figure 6.

Cisne is located in Wayne County and has a population of about 700 persons. Daily water pumpage averages 65,000 gallons, or about 93 gpcpd. Sewage treatment facilities consist of an Imhoff tank, dosing siphons, and inter—mittent sand filters. The system is designed for a sewage flow of 70,000 gpd. The Imhoff tank was completed in 1949; the intermittent sand filters were added in 1953. During the period of sampling, effluent flows averaged 70,000 gpd.

The intermittent sand filters consist of 0.35 to 0.5 mm sand at a depth of 30 inches atop an 8-inch graded gravel base. The hydraulic loading at design flow is 3 gpd/ft^2. The filter is divided into two equal parts with each part being alternately dosed to a depth of 2 to 4 inches of settled sewage twice daily. The hydraulic loading averaged 3 gpd/ft^2, the design loading, during the study. A layout of the system is shown in figure 7.

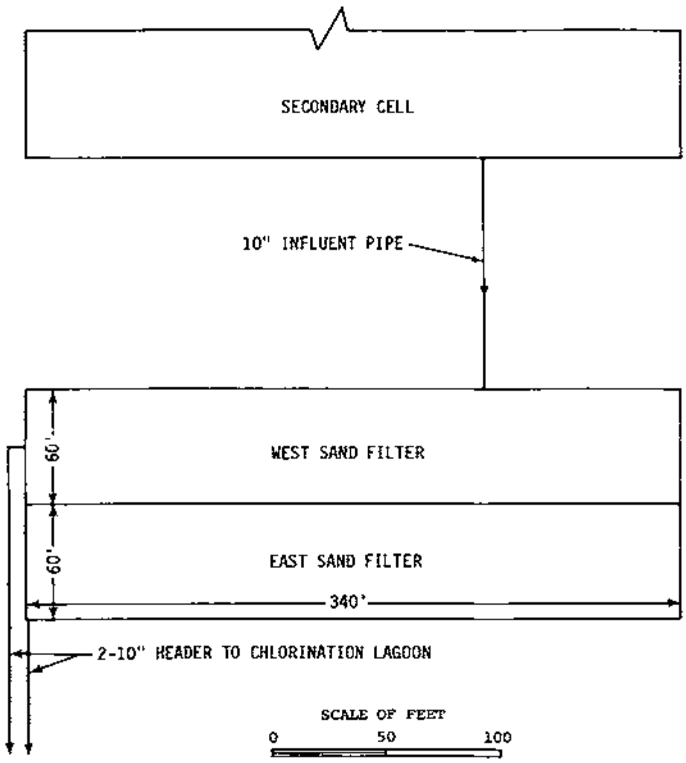

Figure 4. Lagoon bottom sand filter at Teutopolis

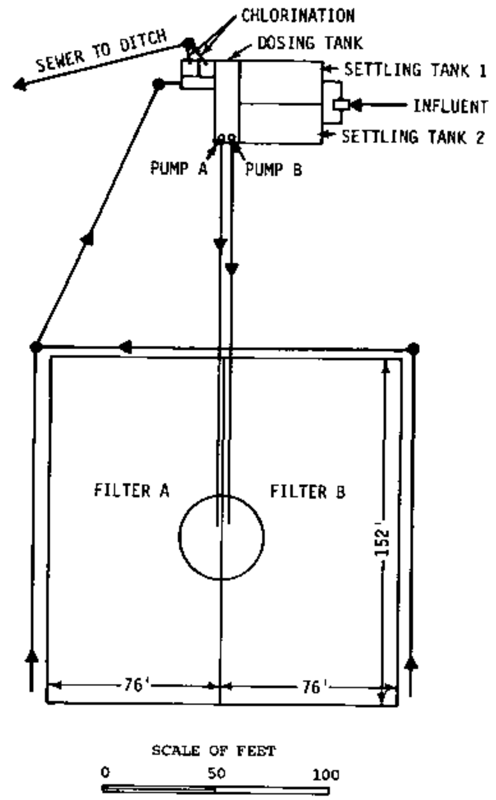

Figure 5. Intermittent sand filter at Bluford

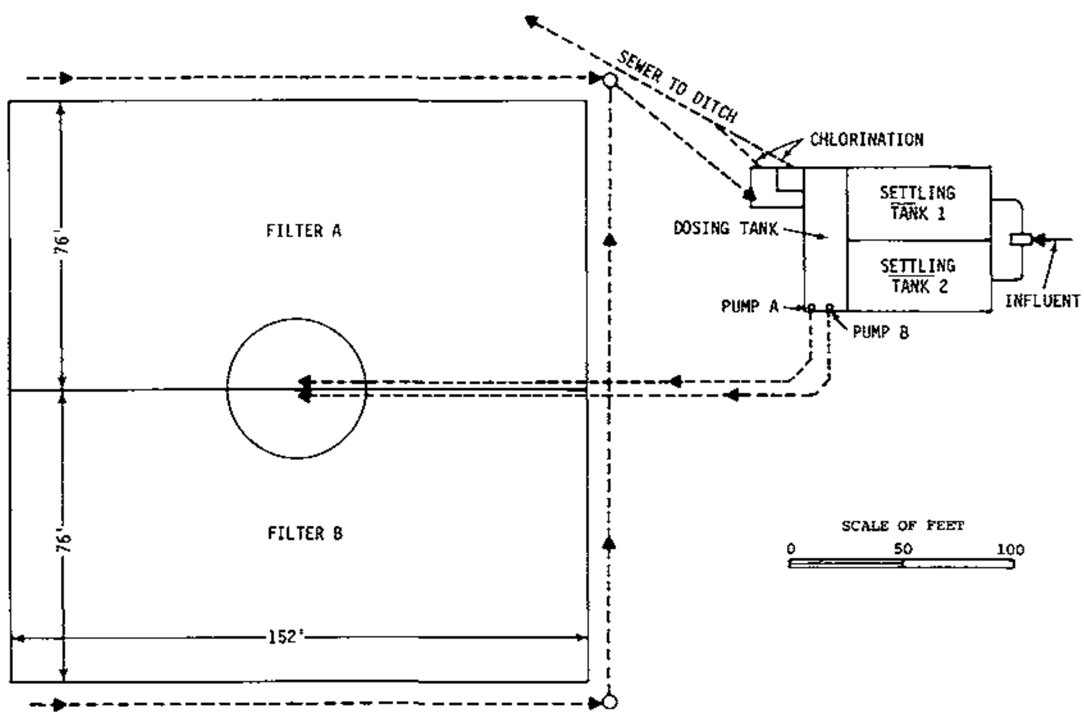

Figure 6. Intermittent sand filter at Thompsonville

Fairview is located in Fulton County and has a population of 600 persons. Daily water pumpage averages 40,000 gallons, or about 67 gpcpd. Its sewage treatment facilities consist of a 3-cell aerated lagoon system employing a submerged rock filter. The filter is located in the third cell. The system, completed in 1973, is designed for an average flow of 80,000 gpd. Design loadings for the lagoon system were 170 1bs/ac/da for BOD_5 on the first cell with an anticipated reduction of 75 percent applied BOD_5 in each cell thereafter. Average water depths in the lagoon system are about 10 feet. During the period of sampling, effluent flows averaged 28,500 gpd.

The submerged rock filter consists of 1- to 5-inch rock with a freeboard of about 6 inches. The hydraulic loading at design flow is 4.6 gpd/ft^3. During the study the hydraulic loading averaged 1.6 gpd/ft^3. An open water area, with an estimated 24-hour detention time at design flow, exists on the effluent side of the filter. A layout of the filter is shown in figure 8.

Paw Paw is a community of 1000 persons located in Lee County. Daily water pumpage averages 155,000 gallons, or about 155 gpcpd. Its sewage treatment facilities consist of a 3-cell aerated lagoon system with a submerged rock filter. As in the case of Fairview, the filter is located in one of the corners of the third cell. Unlike Fairview it does not have any open water on the effluent side of the filter. The system, completed in 1977, is designed for a flow of 150,000 gpd. Design loadings for the first cell were 67 lbs/ac/da. About 70 days of detention is provided within the lagoon system. Average water depths of about 4.5 feet are maintained. During the period of sampling, flow through the system averaged 100,000 gpd. Flow from the final cell was released on an average of one day per week. During the summer period rooted aquatic vegetation (pondweed) became established in the third cell covering about 75 percent of the water surface. A die-off of the weeds commenced in the fall months.

The submerged rock filter consists of 2- to 5-inch rock with a freeboard of about 4 inches. The hydraulic loading at design flow is 7.4 gpd/ft^3. During the study period the hydraulic loading averaged 4.9 gpd/ft^3. There is provision for chlorination. A layout of the filter is shown in figure 9.

Freeburg is a community of 2500 persons located in St. Clair County. It is served by two sewage treatment works. One is named the East plant, the other the West plant. Both plants were examined during this study. The features of the Freeburg East plant are discussed here.

It is estimated that daily water pumpage for the east part of Freeburg is 96,800 gallons for a population of 1100 persons, or about 88 gpcpd. The sewage treatment facilities consist of a 2-cell aerated lagoon system utilizing five granular media filters operating in parallel. The system is designed for a flow of 310,000 gpd and was completed in 1976. The first cell is designed for 64 1bs/ac/da; the second cell for about 102 1bs/ac/da. At design flow the detention time is about 50 days. A settling tank collects the lagoon effluent with provision for chemical treatment if required. From the settling tank, flow is to a wet well from which it is pumped to the five tertiary filter units. During the study, effluent flow averaged 100,000 gpd.

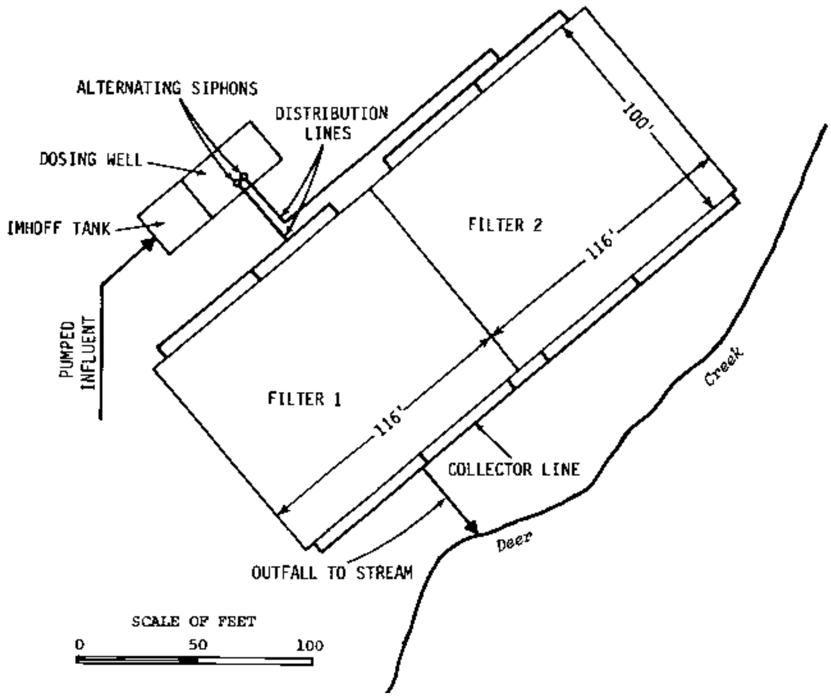

Figure 7. Intermittent sand filter at Cisne

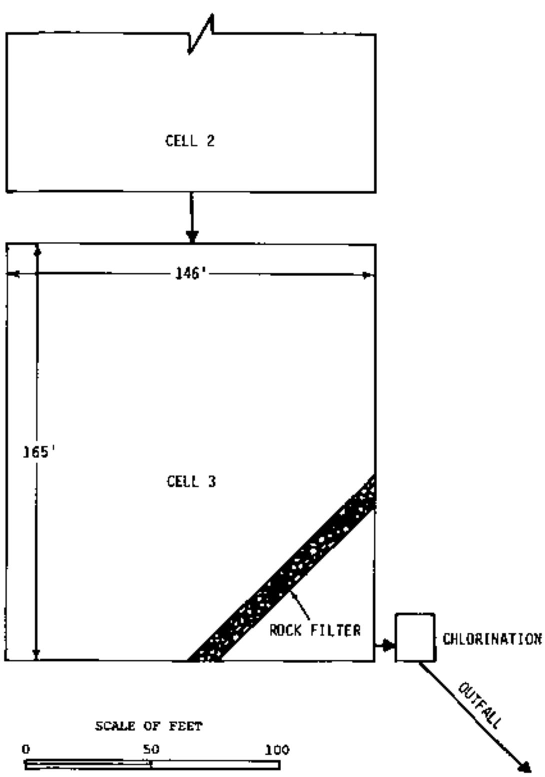

Figure 8. Submerged rook filter at Fairview

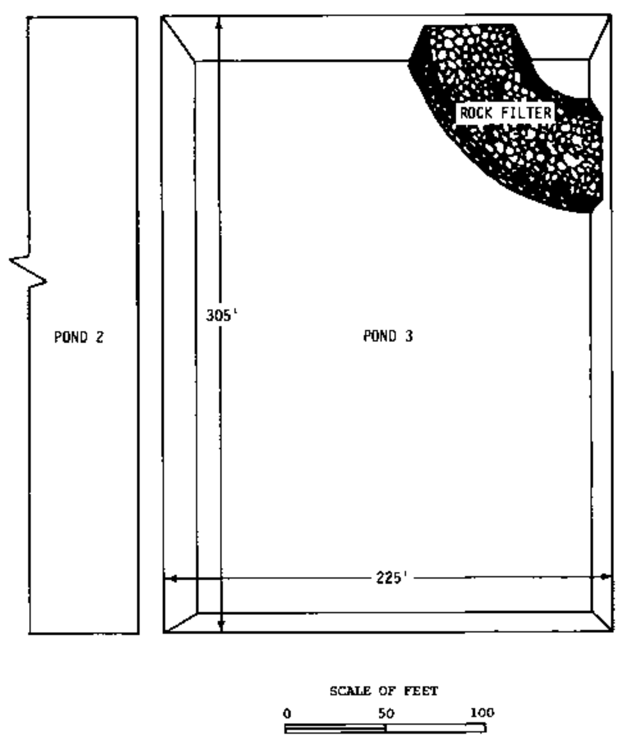

Figure 9. Submerged rook filter at Paw Paw

Each of the five filter units contains 36 inches of 'Filter Ag,' similar to perilite, atop an 8-inch base of graded gravel. The hydraulic loading at design flow is 1.8 gpm/ft^2. During the study the hydraulic loading averaged 0.55 gpm/ft^2. Backwash is currently performed once-a-week for each filter at a rate of 8 gpm/ft^2. The filtrate of four units is used to backwash a single unit. Air scour facilities are available when required. Post chlorination is practiced. A layout of the treatment units is shown in figure 10.

Smithton is a community in St. Clair County with a population of 900 persons. Daily water pumpage averages 75,000 gallons or about 83 gpcpd. Sewage treatment facilities consist of a 2-cell aerated lagoon arrangement with lagoon effluent applied to two settling chambers operating in parallel and thence to two granular media filters also operating in parallel. The system, completed in 1975, is designed for sewage flows of 240,000 gpd. Design loading for the first lagoon is 170 1bs/ac/da BOD_5 and that for the second lagoon is 50 1bs/ac/da. Detention time at design flow is about 50 days. During the period of sampling, effluent flows averaged 83,000 gpd.

The granular media filters consist of 0.45 mm sand at a 12-inch depth atop 8 inches of graded gravel. Flow is by gravity through the system. A backwash cycle of two times a day is currently practiced for each filter. The hydraulic loading at design flow is 1.2 gpm/ft^2. During the study the hydraulic loading averaged 0.41 gpm/ft^2. The lagoon effluent can be chemically treated when required, but it is not now being treated. Effluent from the filters is chlorinated. A layout of the filter units is shown in figure 11.

Freeburg (West) has a population of 1400 persons. Daily water pumpage in the area averages 123,200 gallons, or about 88 gpcpd. Sewage treatment facilities consist of a contact stabilization (activated sludge) system employing two units in duplicate, each equipped with two granular media filters. Design flow is 400,000 gpd. The facilities were completed in 1976. During the period of study, effluent flows averaged 150,000 gpd.

The filter units consist of 2 to 3 mm sand about 48 inches deep atop a 17-inch gravel base. Hydraulic loading at design flow is 2 gpm/ft^2. During the study, the hydraulic flow averaged 0.74 gpm/ft^2. The filters are backwashed about once-a-week at a rate of 8 gpm/ft^2. Air scour is available if required and flow through the units is by gravity. The effluent is chlorinated. A layout of the sewage treatment facilities is shown in figure 12.

A summary of some of the operating and design features is given in table 1. As indicated in the preceding discussion and the table, all the treatment units except Cisne are not operating at their design capacity. There are several reasons for this. Except for Cisne, the oldest plants examined had been in operation only 4 years prior to evaluation. In some cases the daily water pumpage exceeded substantially the daily sewage flow. This is probably because house sewer connections are less than water connections, a common occurrence for new sewage systems. It is probable also, since the study was performed during the warmer months of the year, that evaporation from the surface of the lagoons may have lessened effluent flows significantly below expectation. This could also account for less sewage flow than water pumped. Though not documented, seepage from the lagoons may also have been significant

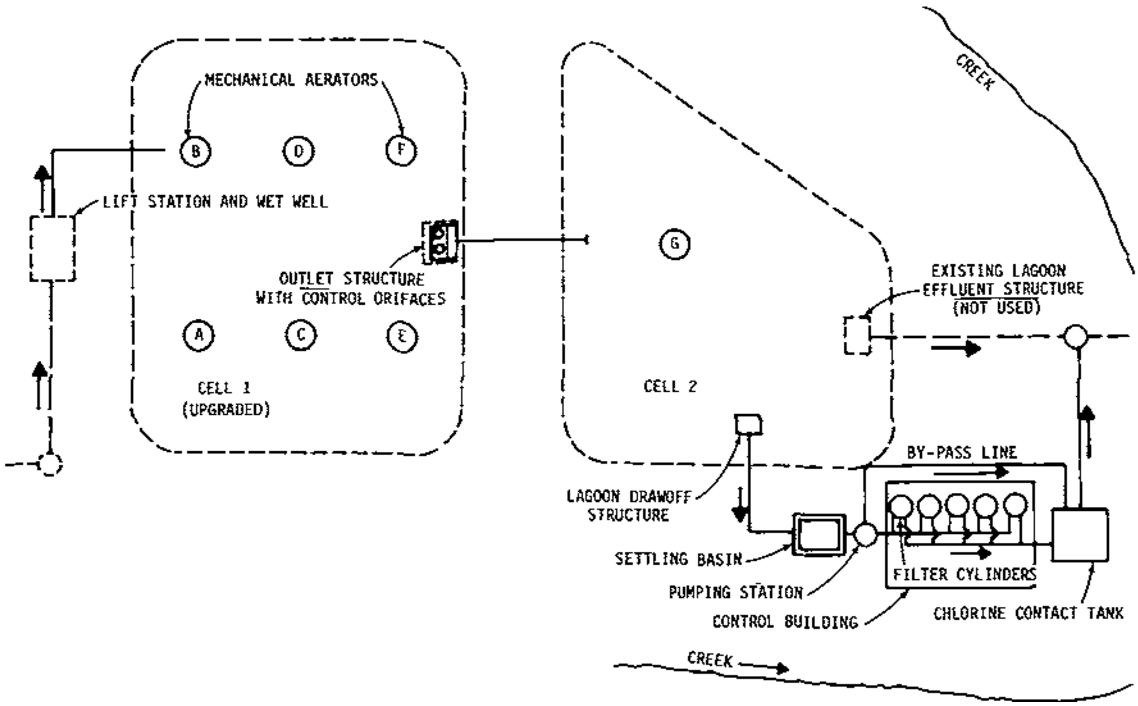

Figure 10. Granular media filter at Freeburg (East)

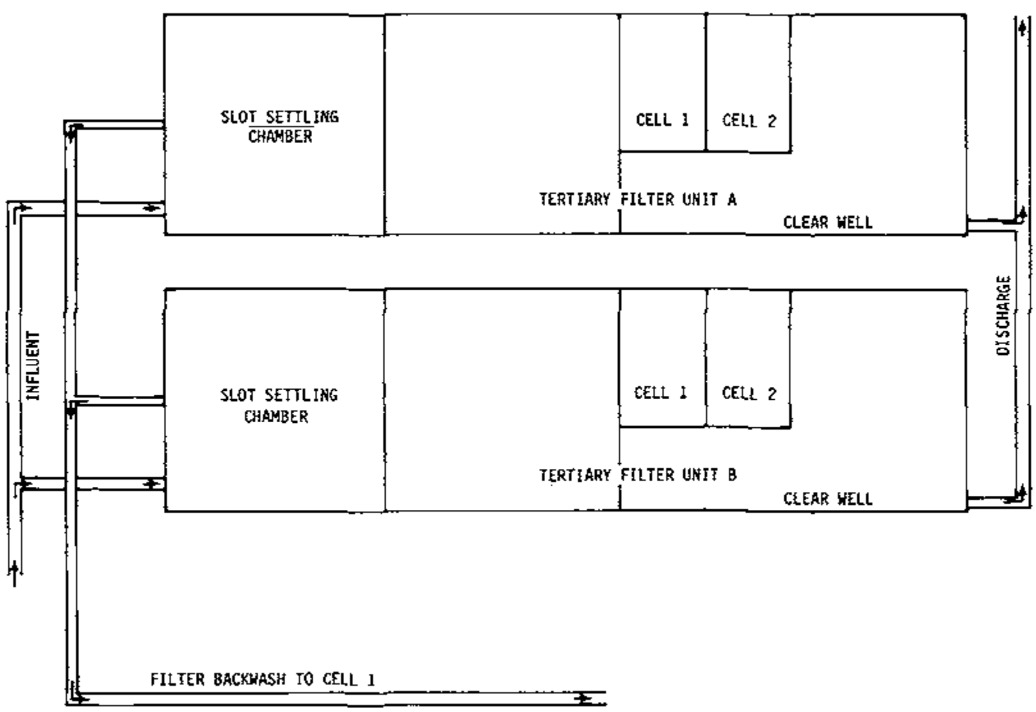

Figure 11. Granular media filter at Smithton

Table 1. Some Operating and Design Features of Tertiary Treatment Units

	Design sewage flow (gpd)	*Current sewage flow (gpd)*	*Design hydraulic loading on filters (gpd/ft^2)*	*Current hydraulic loading on filters (gpd/ft^2)*	*Potable water pumpage (gpd)*
Table Grove	75,000	8,000	19	2	18,000
Liberty	76,500	10,000	19	2.5	26,600
Teutopolis	200,000	60,000	5	1.5	110,000
Bluford	65,000	35,000	3	3*	36,800
Thompsonville	65,000	30,000	3	2.6*	35,800
Cisne	70,000	70,000	3	3	65,000
Fairview	80,000	28,500	4.6†	1.6†	40,000
Paw Paw	150,000	100,000	7.4†	4.9†	155,000
Freeburg East	310,000	100,000	1.81	0.55	96,800
Smithton	240,000	83,000	1.2	0.41	75,000
Freeburg West	400,000	150,000	2.0	0.74	123,200

	Population	*Per capita water use (gpcpd)*	*Secondary treatment*	*Tertiary treatment*	*Year plant completed*
Table Grove	500	37	Lagoon	LBSF	1973
Liberty	400	67	Lagoon	LBSF	1973
Teutopolis	1300	85	Lagoon	LBSF	1976
Bluford	600	61	Settling tank**	ISF	1976
Thompson	500	70	Settling tank**	ISF	1972
Cisne	700	93	Imhoff tank**	ISF	1953
Fairview	600	67	Lagoon	SRF	1973
Paw Paw	1000	155	Lagoon	SRF	1977
Freeburg East	1100	88	Lagoon	GMF	1976
Smithton	900	83	Lagoon	GMF	1975
Freeburg West	1400	88	Activated sludge	GMF	1976

**Using one-half filter*
***Primary treatment*
†gpd/ft^3

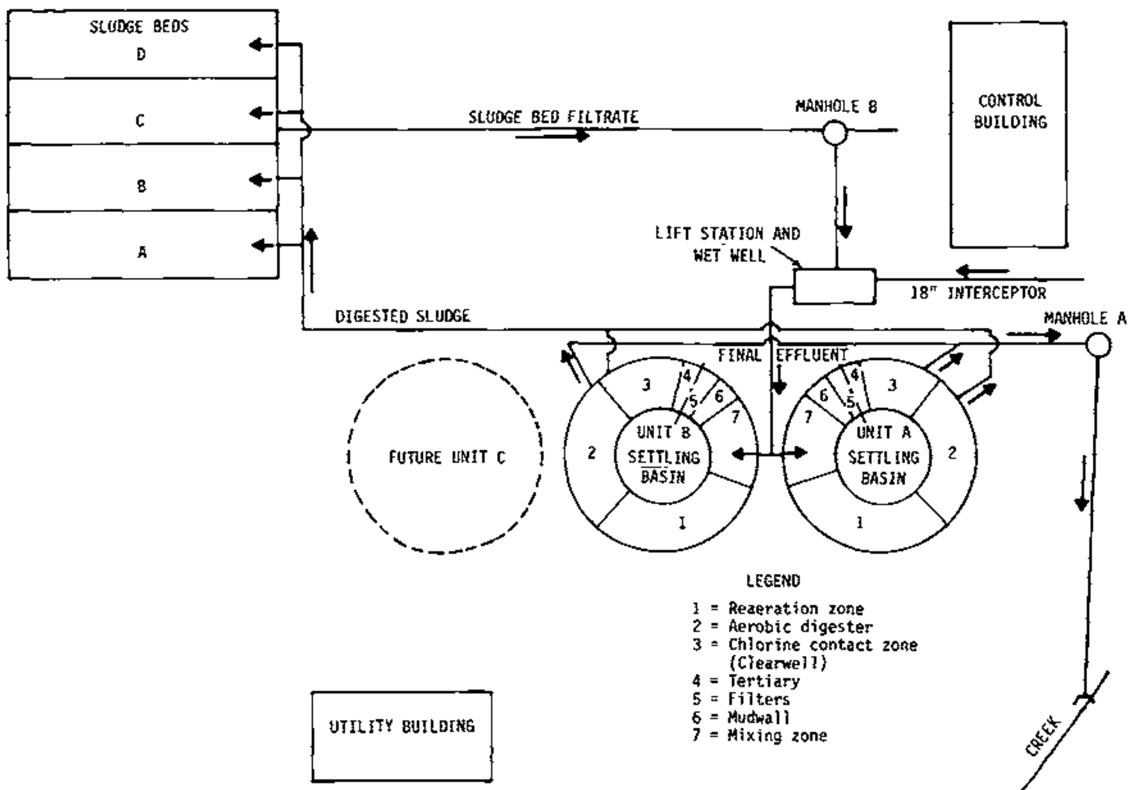

Figure 12. Granular media filter at Freeburg (West)

during this early stage of their use. Because the tertiary units examined except intermittent sand filters are recent innovations, it is to be expected that the units would not be functioning at their design capability. This does pose problems in extrapolating the observations made to that period in time when design loadings are applied to the treatment units.

DATA REDUCTION AND RESULTS

The number of samples collected from each of the sewage treatment facilities varied from 11 to 14. The results obtained were evaluated for each class of treatment rather than for each treatment facility. Where a particular facility reflected operational features that departed from others in its class, its data were examined independently as well.

Relative to other units in the sewage treatment chain, tertiary units are not heavily loaded in terms of suspended solids and BOD_5. For this reason the use of percent removal as a measure of efficiency is not appropriate. The concentrations in the effluents are a more proper measurement of their effectiveness. Although a maximum permissible value is often specified for an effluent, it is well known that variations do occur and that the specified standard is often exceeded (Evans, 1976). During this evaluation considerable

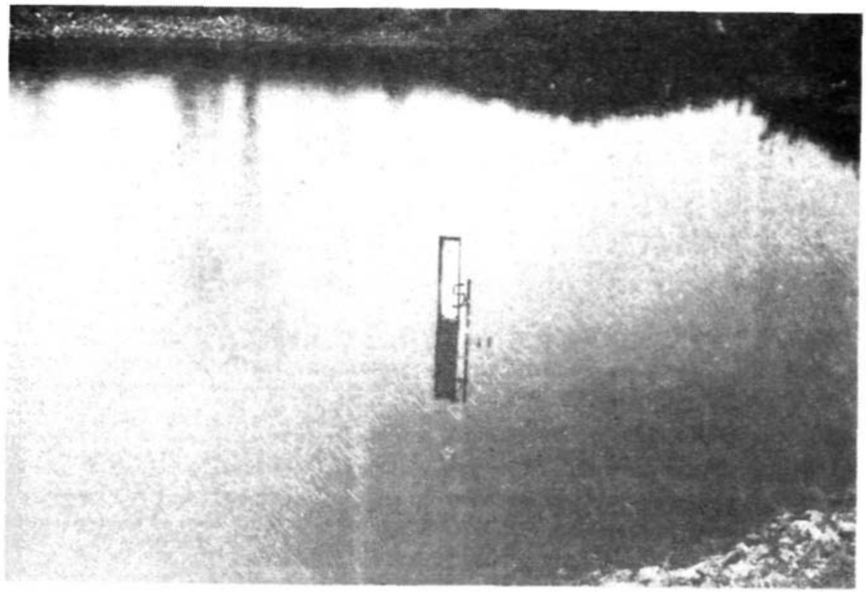

Figure 13. Lagoon bottom sand filter at Table Grove

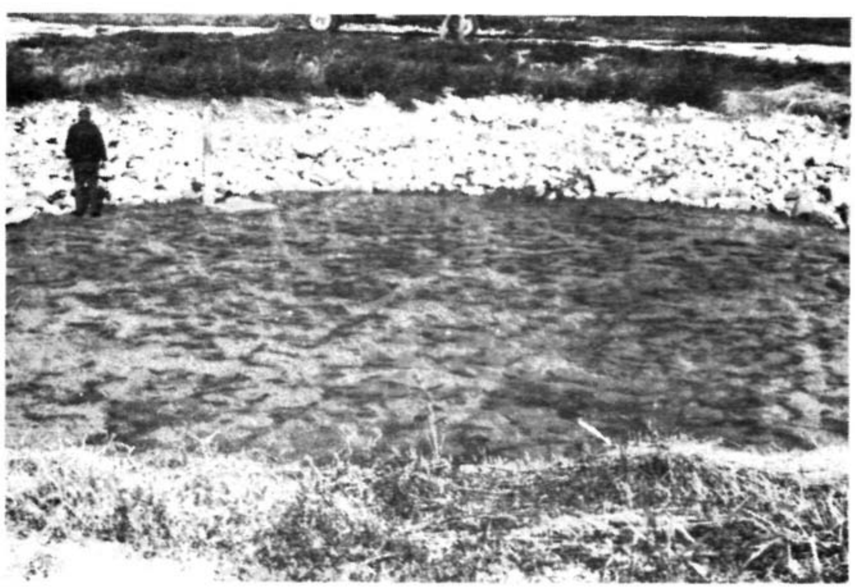

Figure 14. Lagoon bottom sand filter at Liberty

reliance was placed on the concept of probability whereby some judgment was used concerning likely variations in effluent quality. The data obtained for all plants are included in the appendix.

Lagoon Bottom Sand Filters

As mentioned earlier, the communities of Table Grove, Liberty, and Teutopolis are served by a LBSF preceded by a 3-cell lagoon arrangement. In each case the hydraulic loadings are substantially below design (see table 1). The facilities serving Table Grove and Liberty are identical in size and arrangement. Figure 13 shows the third cell lagoon in which a LBSF is located at Table Grove. The staff gage is useful for determining the rate of filter clogging and shows a water depth atop the filter approaching 5 feet. Figure 14 depicts the LBSF serving Liberty after its contents were drained. The light area is sand and the dark area is residual solids. The Teutopolis facility is shown in figure 15. A close examination reveals the growth of aquatic weeds rooted in the submerged berm between two 6-inch deep sand beds. The following discussion is a summary of the data and their evaluation for the input and output of the lagoon bottom sand filters.

Suspended Solids

Lagoon bottom sand filters are designed to limit average suspended solids concentrations in effluents to 30 mg/l and not to exceed 2.5 times that numerical limit more than 5 percent of the time. As shown in table 2, influent suspended solids averaged 59, 51, and 80 mg/l for Table Grove, Liberty, and Teutopolis, respectively. Effluent suspended solids averaged 21, 16, and 15 mg/l in the same order. For 80 percent of the time the suspended solids were 70 percent volatile.

Figure 15. Lagoon bottom sand filter at Teutopolis

Table 2. Summary of Average Values for Influents and Effluents

	Table-Grove	*Lib-erty LBSF*	*Teutop-olis*	*Blu-ford*	*Thompson-ville ISF*	*Cisne*
TSS						
In	59	51	80	16	79	62
Out	21	16	15	17	7	5
BOD_5						
In	44	38	36	30	218	148
Out	20	25	24	11	7	4
FC						
In	2,271	930	1,497	391,000	1,266,000	1 700,000
Out	14,114	46	250	37,872	52,370	35,213
NH_3-N						
In	1.8	2.4	1.3	8.6	27.9	22.4
Out	4.2	5.2	3.9	4.2	4.8	0.7
NO_3-N						
In	0.6	0.4	0.2	14.3	1.0	0.7
Out	0.5	0.2	0.2	17.4	27.0	24.4
T. COD						
In	160	152	187	104	347	291
Out	104	80	94	34	38	24
S. COD						
In	70	66	84	58	140	154
Out	68	55	60	33	33	25
VSS						
In	43	45	68	10	65	48
Out	19	11	10	5	4	3
DO						
In	3.7	7.7	10.9			
Out	1.4	2.4	0.9			
T. PO_4-P						
In	3.3	2.8	3.3	8.6	13.4	8.0
Out	3.7	3.3	3.1	7.9	8.9	7.2

	Fairview SRF	*Paw Paw*	*Freeburg E.*	*Smithton GMF*	*Freeburg W.*
TSS					
In	58	4	15	56	10
Out	54	4	4	17	3
BOD_5					
In	18	9	15	20	13
Out	18	6	9	9	3
FC					
In	202	20	2725	1948	223,400
Out	185	11	278	1585	101,610
NH_3-N					
In	2.9	1.3	0.8	0.1	1.0
Out	2.9	1.1	0.6	0.1	0.7

Table 2. Concluded

	Fairview	Paw Paw	Freeburg E.	Smithton	Freeburg W.
	SRF			GMF	
NO_3-N					
In	1.1	0.3	0.7	0.3	10.0
Out	1.0	0.5	0.8	0.3	10.9
T. COD					
In	88	36	62	103	29
Out	73	40	47	57	23
S. COD					
In	40	31	50	43	25
Out	37	37	39	39	25
VSS					
In	42	3	11	43	6
Out	37	3	2	12	2
DO					
In	12.9	6.4			
Out	4.9	7.2			
T. PO_4-P					
In	4.6	2.1	4.5	9.1	15.8
Out	4.9	2.9	4.6	8.0	16.8

Note: Values in mg/l except for FC

The variations experienced for influent and effluent suspended solids is shown in figure 16. About 50 percent of the time influents to the LBSF (lagoon effluents) will be 50 mg/l. The suspended solids concentrations will be equal to or less than 18 mg/l about 10 percent of the time, and equal to or less than 98 mg/l about 80 percent of the time. In fact the LBSF influent will be 30 mg/l or less (lagoon effluent standard) about 30 percent of the time. The LBSF effluent will be 12 mg/l about 50 percent of the time, and it will contain suspended solids concentrations equal to or greater than 75 mg/l no more than 3 percent of the time. Although the filters examined are operating at hydraulic loadings less than design, it appears that an LBSF will produce an effluent generally in compliance with the specified standard in terms of suspended solids.

5-Day Biochemical Oxygen Demand

Lagoon bottom sand filters are designed to limit average BOD_5 concentrations in effluents to 30 mg/l with a concentration of 75 mg/l not being exceeded 5 percent of the time. The BOD_5 in the influent of the tertiary units serving Table Grove, Liberty, and Teutopolis averaged 44, 38, and 36 mg/l, respectively. The BOD_5 in the effluent averaged 20, 25, and 24 mg/l in the same order. The probability of occurrence for different BOD_5 levels is also shown in figure 16. The slope of the effluent line of best fit in the figure suggests that effluent BOD_5s are more variable than influent BOD_5s. The influent line of best fit shows that the lagoon system, without the LBSF, will produce an effluent of 30 mg/l BOD_5 or less 45 percent of the time. At 50 percent of the time the BOD_5 will be 35 mg/l or less in the influent to the LBSF and about 15 mg/l or less in its effluent. BOD_5 equal to or in excess of 75 mg/l will occur about 5 percent of the time in LBSF effluent.

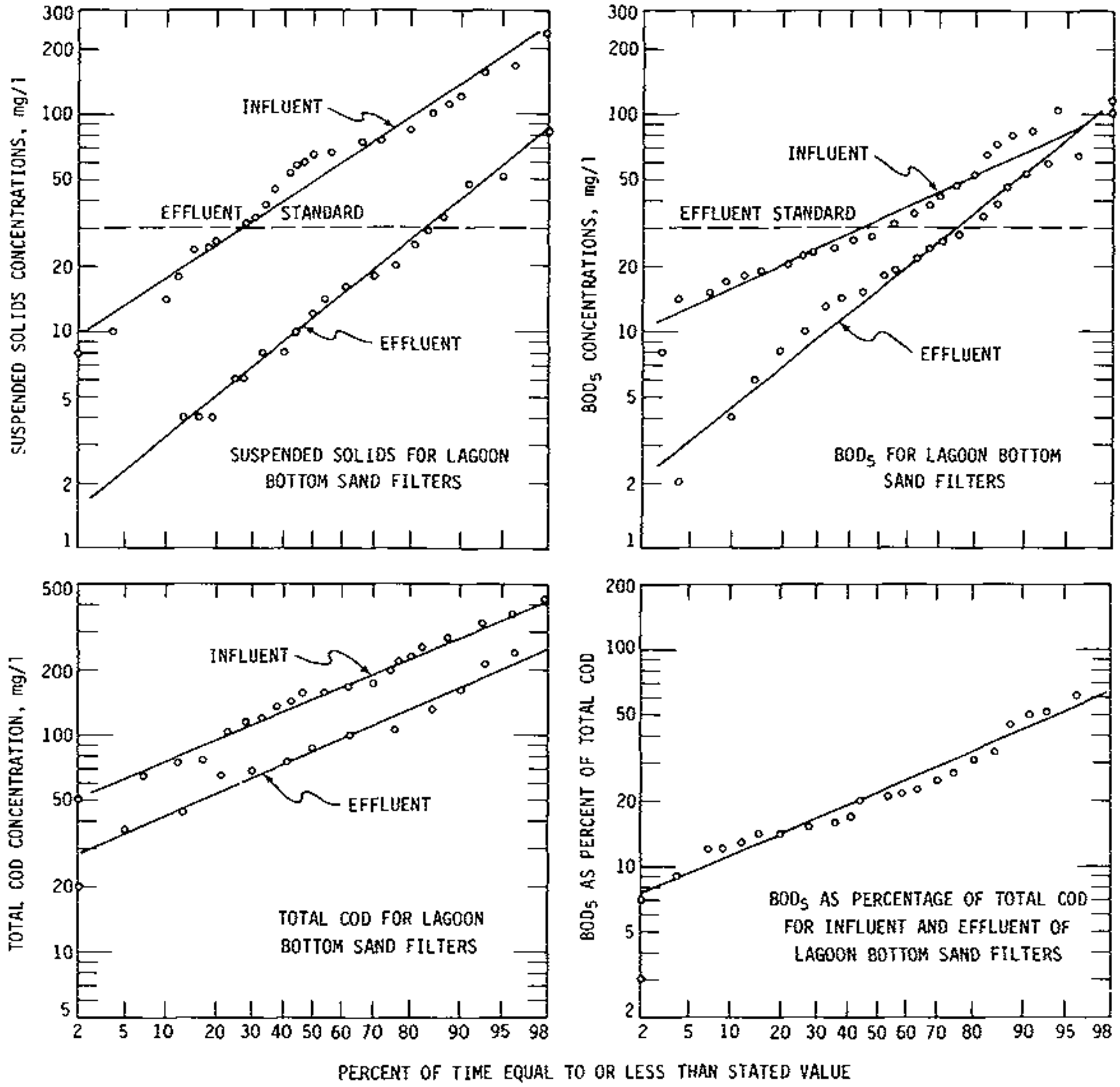

Figure 16. Evaluation of data for lagoon bottom sand filters

The variation in effluent BOD_5 is comparable to the effluent suspended solids as shown in figure 16, i.e., the lines of best fit are parallel. Interestingly, the concentrations of suspended solids will be *lower* than the BOD_5 in LBSF effluent, suggesting that the filter is performing best as a suspended solids remover. Nevertheless, the LBSF does produce an effluent substantially in compliance with the 30 mg/l standard.

Chemical Oxygen Demand

COD as defined by Standard Methods (American Public Health Association, 1975) is a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. That portion of organic matter oxidized includes cellulose (algae is about 75 percent cellulose) and carbonaceous compounds (BOD_5) but not ammonia. The COD test is most useful if, after many values, it can be correlated with the concentration of some other important constituent in wastewater.

There is no effluent standard for COD. At Table Grove, Liberty, and Teutopolis the total COD contained in the filter effluent averaged 160, 152, and 187 mg/l, respectively (table 2). The concentrations in the effluent averaged 104, 80, and 94 mg/l in the same order. The change in soluble COD as it passed through the filter was not significant. The probability of COD concentration occurrences is shown in figure 16 for the influent and effluent. The COD in the influent is 145 mg/l about 50 percent of the time; similarly the effluent will contain 84 mg/l.

Efforts to correlate concentrations of COD with BOD_5 or suspended solids were not rewarding. Nevertheless, the ratios of BOD_5 to corresponding COD in the influents and effluents combined were determined. The percent of total COD contributed by BOD_5 was plotted as shown in figure 16. The line of best fit indicates that about 22 percent of the total COD is contributed by BOD_5 about 50 percent of the time. This is not a major contribution.

Algae were also considered a source of COD. To determine the. magnitude of that source, the ratios of corresponding soluble and total COD values were arrayed and the percent insoluble COD was determined. The values are plotted in figure 17. In the influent algae contributed 52 percent or less of the total COD about 50 percent of the time. About 90 percent of the time algae were responsible for 36 percent or more of the total COD in the influent. This is a major contribution. The algae components of COD in filter effluents were substantially less, about 23 percent or less 50 percent of the time. On the basis of the relationships for algae and total COD, the compiling of COD values over a period of time will be useful as a measure of the filter's effectiveness for removing algae.

Ammonia-Nitrogen

There are no effluent limitations on ammonia-nitrogen (NH_3-N) in Illinois except for several large municipalities located on the Illinois waterway. There is a stream water quality standard of 1.5 mg/l. Where there is no stream water, any effluent discharged to the stream bed must comply with the 1.5 mg/l NH_3-N standard. The influent to the LBSFs of Table Grove, Liberty, and Teutopolis averaged 1.8, 2.4, and 1.3 mg/l, respectively. Filter effluents averaged 4.2, 5-2, and 3.9 mg/l in the same order. The LBSF is a generator of NH_3-N as a result of the development of anaerobic conditions within the filter sand beds. The dissolved oxygen was zero in 77 percent of the samples taken from LBSFs.

The variation in NH_3-N concentrations for LBSFs is shown in figure 17. About 50 percent of the time the NH_3-N in the influent is 0.54 mg/l and that in the effluent is 3.5 mg/l. The effluent of the filter will be equal to or greater than 1.5 mg/l about 83 percent of the time. The effluent from a 3-cell lagoon (shown in figure 17 as influent to the filter) will be equal to or greater than 1.5 mg/l NH_3-N about 27 percent of the time. If NH_3-N is a major consideration for effluent quality, the choice of an LBSF as a tertiary unit is questionable.

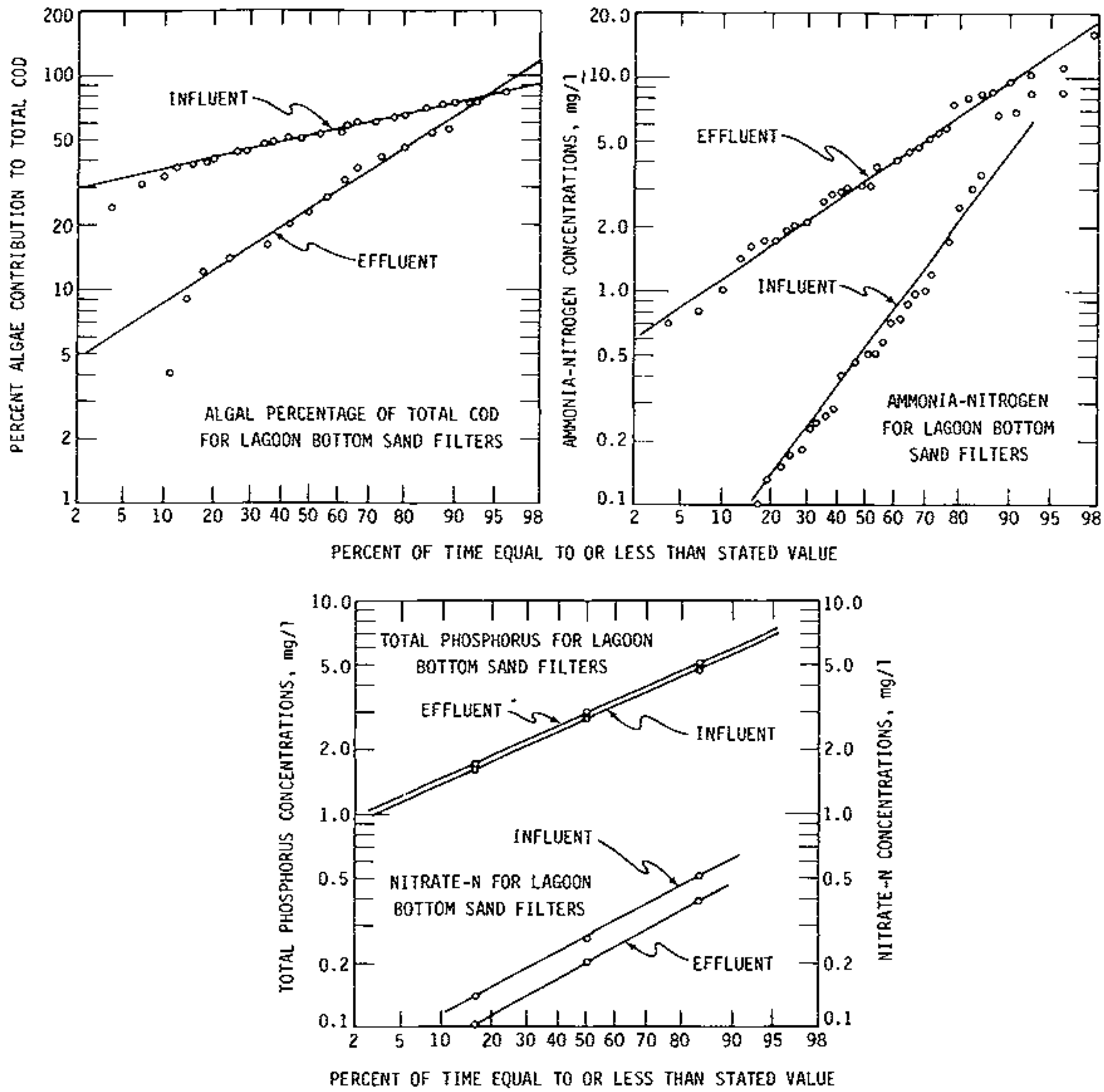

Figure 17. Evaluation of data for lagoon bottom sand filters

Nitrate and Phosphorus

Concentrations of nitrate-nitrogen (NO_3-N) and phosphorus (PO_4-P) are generally not limited in sewage effluents. There are certain limitations for PO_4-P for effluents discharging into the Fox River, the Lake Michigan basin, and locations where lakes and reservoirs may be adversely affected. There was very little difference, on the average, in the concentrations of NO -N and PO_4-P applied to a LBSF compared with the filter's output. The following are the averages observed:

	NO_3-N		PO_4-P	
	In	*Out*	*In*	*Out*
Table Grove	0.6	0.5	3.3	3.7
Liberty	0.4	0.2	2.8	3.3
Teutopolis	0.2	0.2	3.3	3.1

The lack of significant alterations of these constituents during passage through LBSF is further demonstrated in figure 17. About 50 percent of the time the influent NO -N is 0.3 mg/l or less; the effluent concentration similarly is 0.2 mg/l or less. For PO_4-P the concentration likely to occur 50 percent of the time in the influent is 2.8 mg/l or less; that for the effluent is 3.0 mg/l or less. As a point of conjecture it is quite probable that significant quantities of PO_4-P, as part of algal cells, may be trapped by the filter, but under anaerobic conditions that PO_4-P retained in the cell residue is likely resolubi1ized and flows through the bed.

Fecal Coliform

Fecal coliform concentrations are limited by an effluent requirement of 400/100 ml as the maximum density. The facilities serving Table Grove produced an effluent complying with the standard in only 5 of 11 samples. On the other hand, the effluent from the Teutopolis filter was in compliance for 12 samples of 14 collected. The effluent samples at Liberty were chlorinated and all samples collected (11) had fecal coliform densities less than 400/100 ml. The filter facilities serving Teutopolis are not a good example for assessing fecal coliform removal because 7 of the 11 samples collected from the filter influent were less than 400/100 ml and in 5 of those fecal coliform was not detected. The bacterial loadings for the Table Grove facilities ranged from 0 to 23,000/100 ml and are probably typical. Until more conclusive data are available it is prudent to disinfect LBSF effluents to insure compliance with the standard.

Intermittent Sand Filters

Intermittent sand filters, unlike lagoon bottom sand filters, are not constantly submerged; instead, they are dosed intermittently. The sand bed is usually divided and two doses of either primary or secondary effluent is applied to each one-half of the bed daily. Until the development of small package sewage treatment plants employing modifications of the activated sludge process, ISFs served many small communities, schools, and state parks in Illinois. Land and maintenance requirements are their unattractive features. However, with their history of producing a stable effluent coupled with minimal energy requirements for operation, the probability of their use has been enhanced. No units operating in Illinois treat municipal lagoon effluent. The ones evaluated were preceded by primary units (settling tanks) in the communities of Bluford, Thompsonvi1le, and Cisne.

The facilities at Bluford and Thompsonvi1le are relatively new and sewage flow has not reached design proportions. To compensate for this only one-half of the filters is being used thus permitting hydraulic loadings approaching the design of 3 gpd/ft^2 (see table 1). The facilities serving the two communities are identical in size and arrangement. The distribution box and system are shown in figure 18. A different view of the distribution system, consisting of wooden troughs, for spreading the primary treated effluent on the sand bed is shown in figure 19. Alternating pumps convey the primary effluent to the distribution box and thence to the beds. The sewage plant at Cisne, which has been operating for 25 years, uses alternating siphons to dose the sand beds. The dosing tank and siphons are shown in figure 20. The sand beds shown in figure 21 are operating at a hydraulic loading of 3 gpd/ft^2.

The following is a summary of the data developed from observations and sampling of intermittent sand filters.

Suspended Solids

Intermittent sand filters are designed to produce a 12 mg/l suspended solids when operating in conjunction with lagoons. In past years their use as a secondary sewage treatment unit was predicated on at least 20 mg/l suspended solids effluent. The influent to the Bluford filter is an extremely weak sewage averaging 16 mg/l suspended solids (see table 2). Suspended solids in the influent to the sand beds serving Thompsonville and Cisne average 79 and 62 mg/l, respectively. Effluent concentrations, in the same order, average 17, 7, and 5 mg/l. On the average, the ISFs are producing an effluent of considerably higher quality than anticipated. This is expecially the case for Thompsonvi1le and Cisne.

The variation of suspended solids concentrations in the influent and effluent of the ISFs is shown in figure 22. Fifty percent of the time the influent contains about 40 mg/l of suspended solids. Eighty-five percent of the time influent solids are equal to or less than 100 mg/l. Effluent solids are 4 mg/l about 50 percent of the time and are likely to exceed 10 mg/l only 17 percent of the time.

Although the nature of the suspended solids in effluents from primary units is different from that of lagoon effluents, the concentrations of suspended solids are remarkably similar in their variations and numerical values. This is quite apparent when comparing the influent data for suspended solids of figure 16 with that of figure 22.

5-Day Biochemical Oxygen Demand

When used in conjunction with lagoons, ISFs are designed to produce a 10 mg/l BOD_5 effluent. The BOD_5 concentrations in the influent to the sand beds serving Bluford, Thompsonvi1le, and Cisne average 30, 218, and 148 mg/l. In the same order the BOD_5 concentrations in their effluents average 11, 7, and 4 mg/l. The probability of occurrence of BOD_5 in the influent and effluent of the units is shown in figure 22. The concentration likely to occur 50 percent of the time in the influent is 100 mg/l BOD_5. The BOD_5 in the influent is quite variable, ranging at least 80 percent of the time from 28 to 370 mg/l.

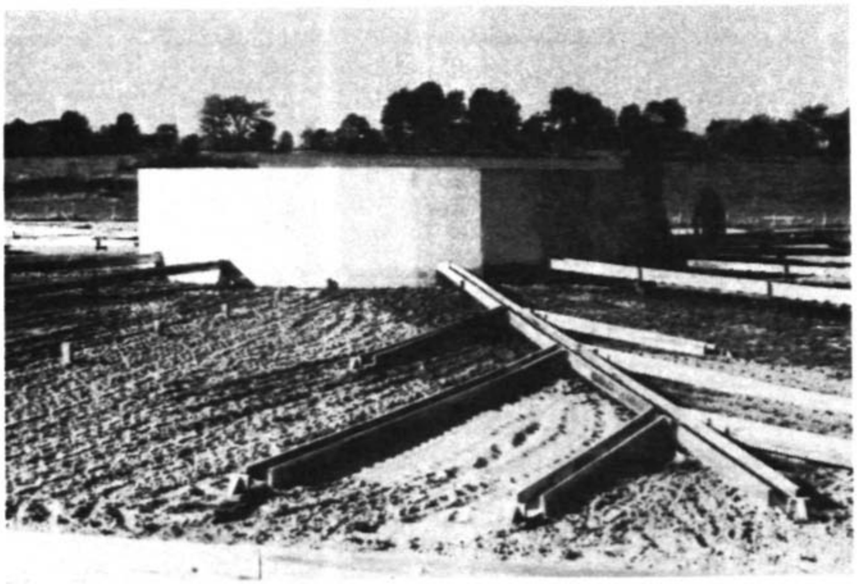

Figure 18. Dosing tank for intermittent sand filter

Figure 19. Distribution system for intermittent sand filter

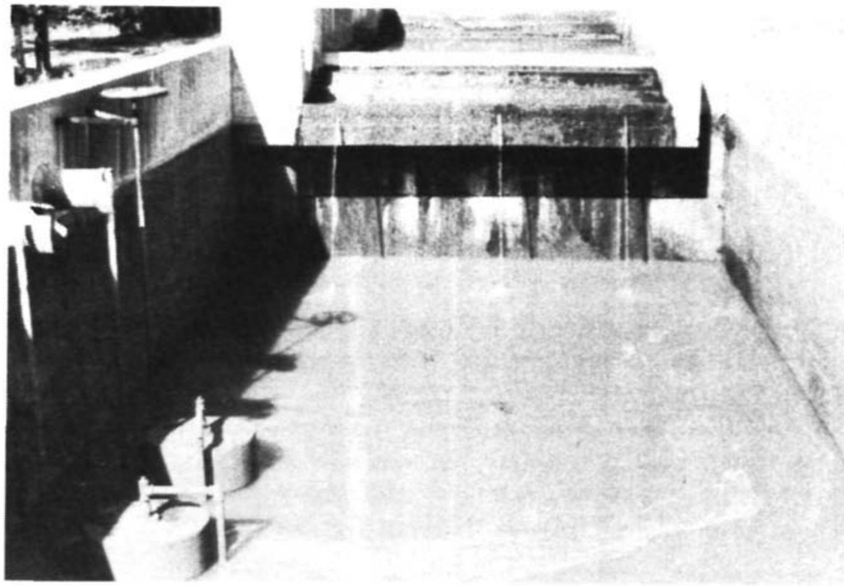

Figure 20. Dosing tank and siphons at Cisne

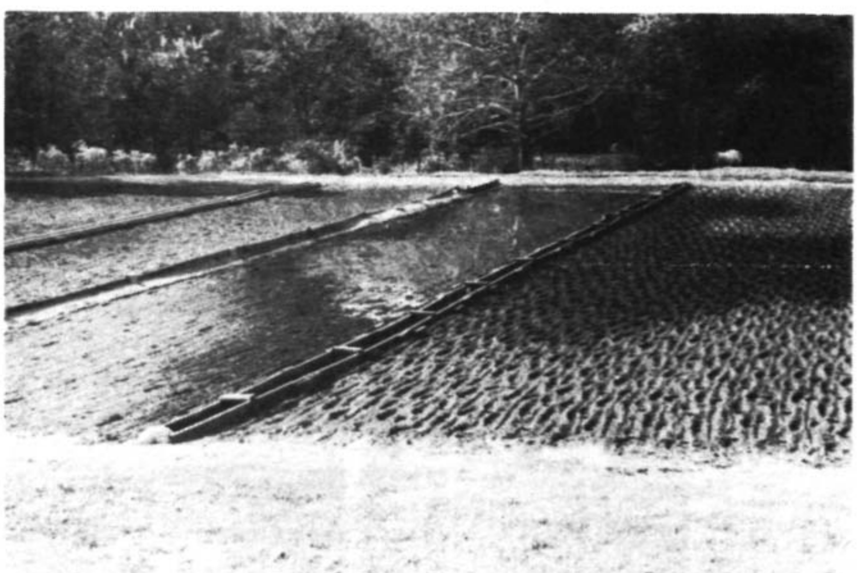

Figure 21. Intermittent sand filter at Cisne

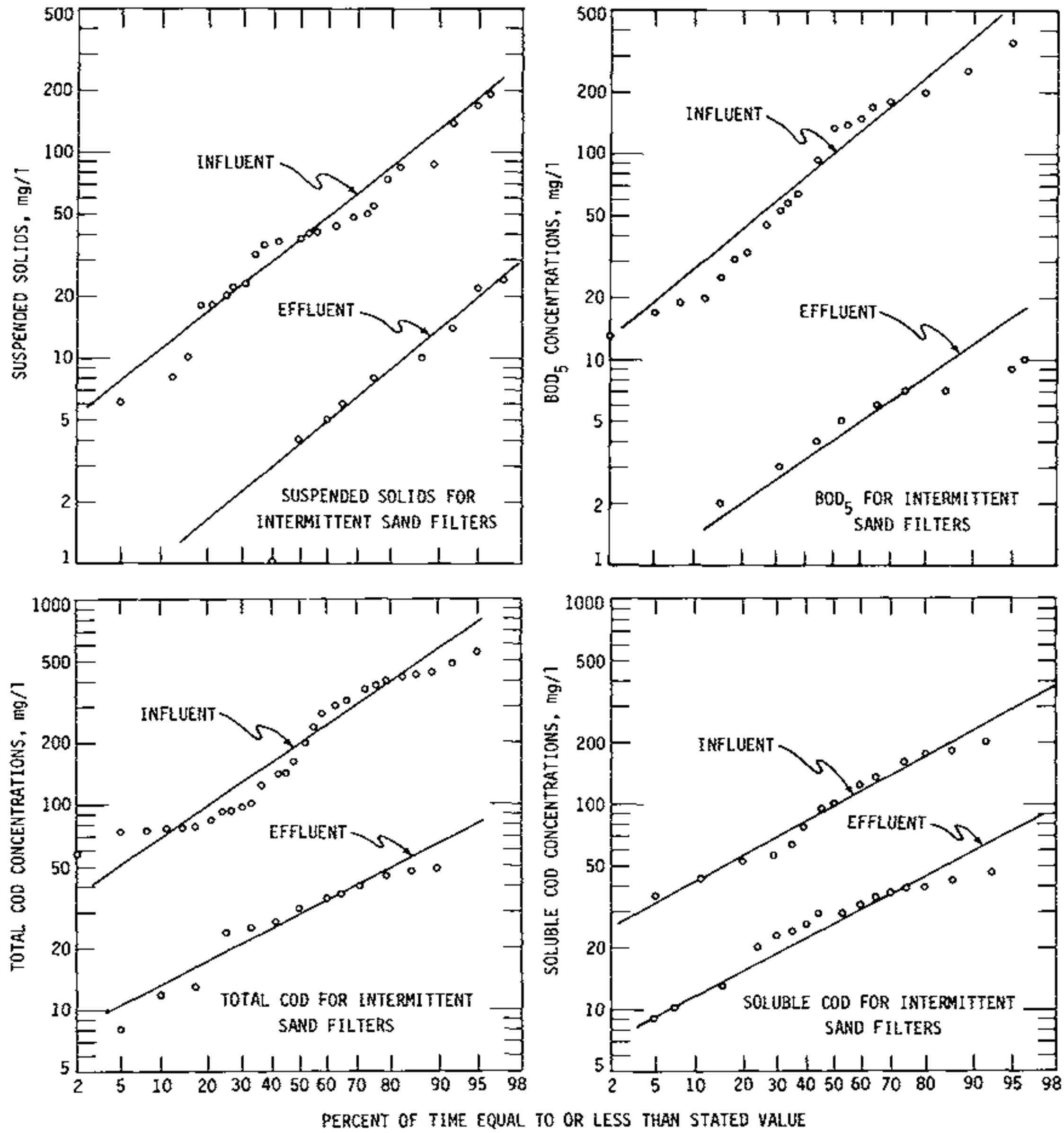

Figure 22. Evaluation of data for intermittent sand filters

Effluent BOD_5 is 4 mg/l or less 50 percent of the time and the variability of effluent BOD_5 concentrations is practically identical to that observed for effluent suspended solids. From figure 22 it appears that BOD_5 in excess of 12 mg/l will occur only about 10 percent of the time in the effluent. Whereas the LBSFs appear to function principally as solids removal units, the ISFs perform equally well as a solids removal and a biological reduction unit.

Chemical Oxygen Demand

As mentioned earlier, there is no effluent requirement for COD in Illinois. However, the comparison of COD concentrations of a wastewater with other constituents is often useful and comparisons between COD values of different wastes of like origin can reflect the relative oxidizability (chemical and biological) of the wastes. On the average the influent total COD concentrations for Bluford, Thompsonville, and Cisne are 104, 347, and 291 mg/l, respectively. Concentrations in the effluent averaged 34, 38, and 24 mg/l in the same order. The probability of occurrence for total COD concentrations is shown in figure 22. Unlike that experienced in LBSFs, a significant reduction in soluble COD occurred during the passage of wastewater through the filters. As shown in figure 22, the concentration of soluble COD likely to occur in the filter influent 50 percent of the time is 100 mg/l. This is comparable with the BOD_5 concentration in the influent. Effluent soluble BOD_5 anticipated 50 percent of the time is 26 mg/l.

The reduction of soluble COD by ISF units, compared with the LBSF where significant reduction did not occur, is probably a function of the characteristics of primary effluent compared with lagoon effluents as well as the respective reduction mechanisms supported in the filters. That environment in the LBSF is anaerobic, whereas an aerobic condition is maintained in the ISF.

Ammonia-Nitrogen

The influent concentrations of NH_3-N to the ISF units are relatively high averaging 8.6, 27.9, and 22.4 mg/l, respectively, for Bluford, Thompsonville, and Cisne. This is to be expected because the primary units are solely designed to remove suspended solids and the long detention times in the dosing tanks, up to 6 hours, without the benefit of aeration is conducive to the development of anaerobic conditions. In spite of the NH_3-N loading applied to the filters their effluent concentrations averaged 4.2, 4.8, and 0.7 mg/l for the three plants.

Figure 23 shows influent and effluent NH_3-N variations. Fifty percent of the time the influent concentration is 17 mg/l; 80 percent of the time it ranges from 6.4 to 45 mg/l. The reduction through the ISF is substantial. Fifty percent of the time the effluent NH_3-N concentration is 1.6 mg/l and ranges from 0.35 to 7.5 mg/l about 80 percent of the time.

The reduction of NH_3-N by nitrification requires nitrifying bacteria. During the early work in Florida on intermittent sand filters, the value of sand beds operating under aerobic conditions as substrates for nitrifying bacteria was documented. Therefore it is not surprising that the ISF units were found to be excellent NH_3-N reduction units.

Nitrate and Phosphorus

Because of the nitrifying capability of ISF units, the production of NO_3-N in their effluents is expected. The concentrations of NO_3-N in the influent of the filters average 14.3, 1.0, and 0.7 mg/l for Bluford, Thompsonville, and Cisne, respectively. The effluent NO_3-N averaged 17.4, 27.0, and 24.4 mg/l in the same order.

Phosphate-phosphorus concentrations are not significantly affected by ISF units. Average concentrations ranged from 8.0 to 13.4 mg/l in the filter influent. The average concentration in effluents ranged from 7.2 to 8.9 mg/l.

Fecal Coliform

The reduction of fecal coliforms by ISF units is not sufficient to permit the discharge of their effluents to streams without disinfection. The following is a summary of the bacterial densities detected in the influent and effluent of the units. Values are in densities per 100 ml.

	Range in influent	*Range in effluent*
Bluford	21,000-1,210,000	9,100-240,000
Thompsonville	900-2,800,000	900-210,000
Cisne	225,000-9,400,000	120-323,000

Submerged Rock Filters

The use of submerged rock filters (SRF) in Illinois is a recent innovation. Design requirements anticipate effluents that will meet the standards for 30 mg/l for both suspended solids and BOD_5. Two municipal installations were examined, one serving Fairview and the other Paw Paw. The filter serving Fairview is shown in figure 24. The filter is quite narrow at the top and free board is minimal. There are times when wind-generated waves crest the filter. The filter is located in the third cell of a lagoon system and has open water on its effluent side. A close-up of the contents of the third cell lagoon at Paw Paw is shown in figure 25. The lagoon supports luxurious growth of submerged pond weed and abounds in aquatic insects and some fishes. The filter serving Paw Paw is shown in figure 26. Within it is a drainage system which discharges to a sump located near the center of the filter. During the period of sampling the system was operating on a fill and draw schedule because of low incoming waste flows.

The characteristics of the inflows and outflows of the two SRF systems are so different that the data for them cannot be combined for evaluation purposes. Those characteristics for the Fairview installation are given in table 2.

In terms of probability of occurrence for influent and effluent concentrations at Fairview, there is little difference. The influent and effluent concentrations are likely to be the same at all times. On the average, the effluent does not meet effluent standards for suspended solids. Dissolved oxygen in the influent averaged 12.9 mg/l; that in the effluent averaged 4.9 mg/l. In 6 of 13 samples collected from the effluent the dissolved oxygen was zero. Fecal coliform densities ranged from 0 to 630/100 ml in the filter influent and 0 to 980/100 ml in the effluent.

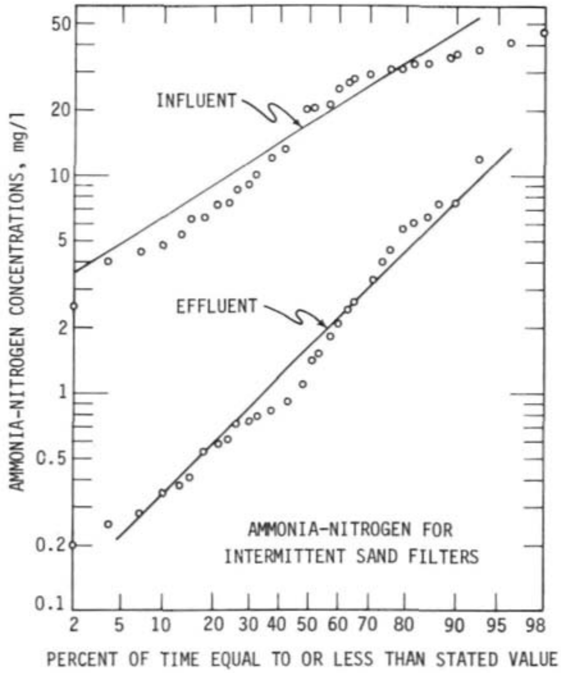

Figure 23. Ammonia-nitrogen for intermittent sand filters

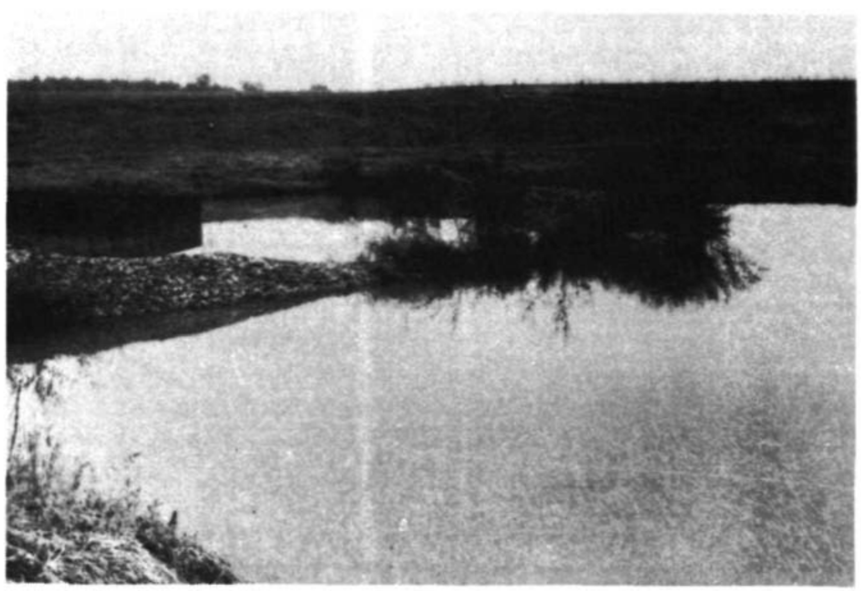

Figure 24. Submerged rook filter at Fairview

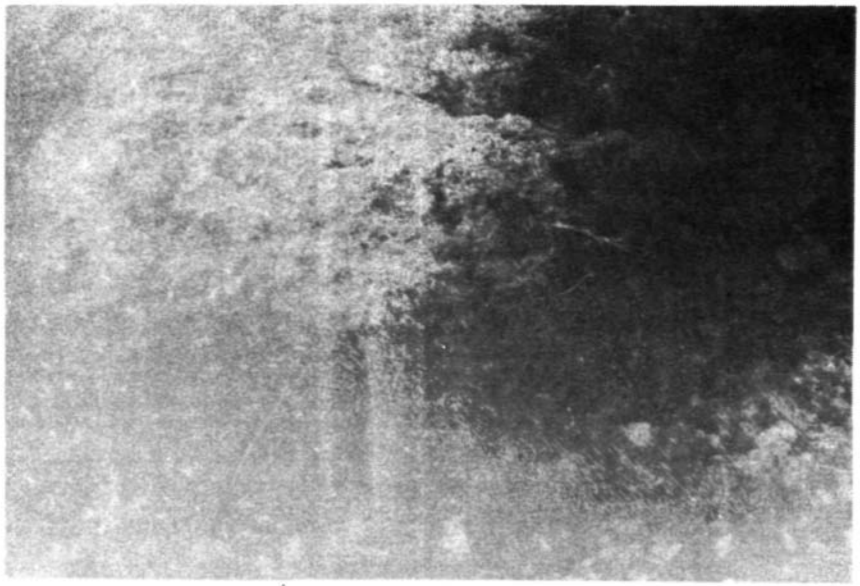

Figure 25. Third cell lagoon at Paw Paw

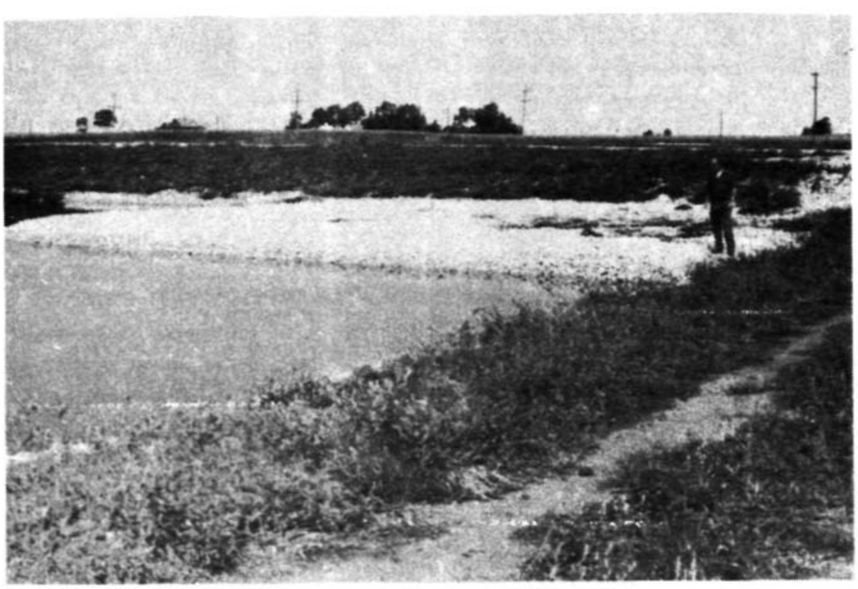

Figure 26. Submerged rook filter at Paw Paw

The characteristics for the Paw Paw installation also are given in table 2. Loadings on the filter are extremely low thus precluding a meaningful evaluation of the filter. The quality of the influent to the filter is satisfactory for discharge to stream waters. Under the current loadings the concentration applied to the filter is the same as that leaving the filter. Dissolved oxygen averaged 6.4 mg/l in the influent and 7.2 mg/l in the effluent. Fecal coliform densities ranged from 0 to 120/100 ml in the influent and 0 to 70/100 ml in the effluent.

The efficiency of the SRF serving Fairview is not impressive, and the capability of the SRF serving Paw Paw is not proven.

Granular Media Filters

The granular media filters (GMF) evaluated serve the communities of Freeburg and Smithton. As described earlier Freeburg is served by two plants, i.e., East plant and West plant. The filter facilities at Smithton and the Freeburg East plant treat the effluent from a 2-cell aerated lagoon system. The Freeburg West plant filters handle effluent from an activated sludge process (contact stabilization). Although the types of filters used are different at Smithton and Freeburg East their influent and effluent data can be combined for evaluative purposes. The West plant data will be treated separately.

There are basic differences in the treatment chain at Freeburg East and Smithton compared with the other lagoon-filter arrangements previously described. At these two plants, a settling unit is imposed between the lagoon effluent stream and the filter units, which is not the case for the lagoon bottom sand filters. A basic difference in the operation between the two facilities is that the filters at Freeburg East are dosed intermittently by pumps, whereas the filters at Smithton are subjected to continuous effluent flow except during periods of backwash. Also the filter media at the East plant is about 36 inches deep, whereas 12 inches is provided for the Smithton units. Figure 27 shows the second cell at the East plant with a substantial growth of duckweed in the foreground. Figure 28 shows one of the five enclosed filters at the Freeburg East plant. The following discussion summarizes the treatment capabilities of the two treatment units at current waste flows.

Suspended Solids

A lagoon system followed by GMF units is expected to produce an effluent meeting the standards of 12 mg/l suspended solids. The suspended solids in the effluent to the filters serving the Freeburg East plant and Smithton average 15 and 56 mg/l, respectively. The Smithton influent is not unlike that observed for the lagoon systems serving Table Grove, Liberty, Teutopolis, and Fairview where settling tanks are not provided. This would suggest the settling facilities at Smithton are not effective — certainly not as efficient as those serving the East plant. Filtered effluent concentrations average 4 and 17 mg/l, respectively, for the East plant and Smithton.

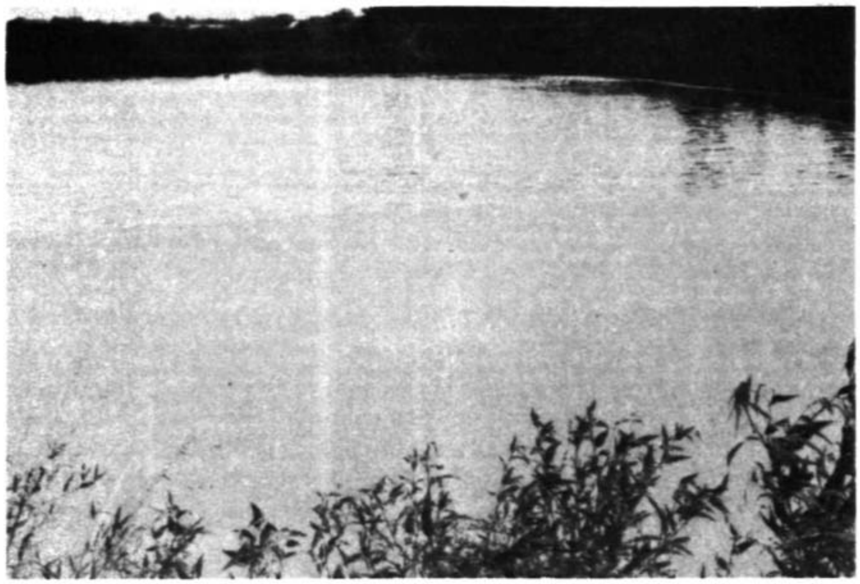

Figure 27. Aerated second cell at Freeburg (East)

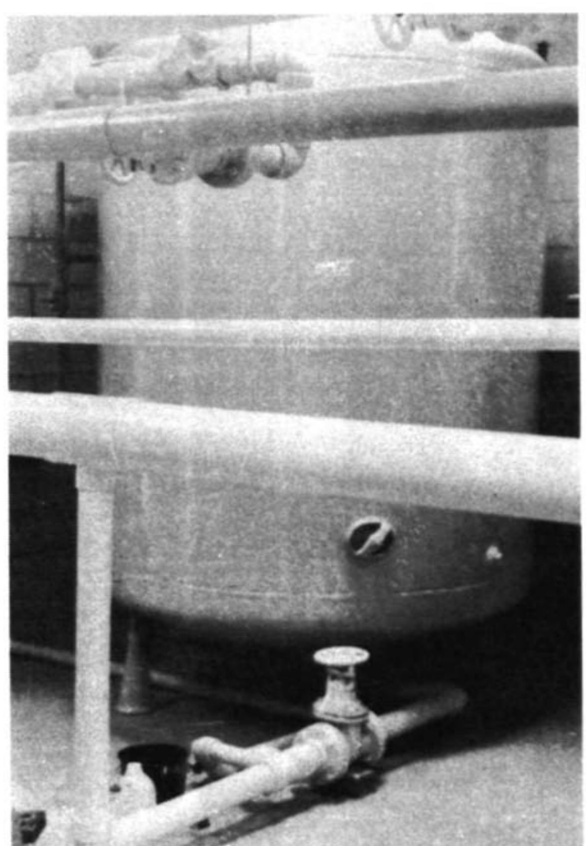

Figure 28. Granular media filter at Freeburg (East)

The variation of suspended solids concentrations in the influent and effluent of the GMFs is shown in figure 29. Fifty percent of the time the influent and effluent concentrations are about 26 and 10 mg/l, respectively. The effluent will exceed 30 mg/l only about 10 percent of the time.

5-Day Biochemical Oxygen Demand

When used with lagoons, GMFs are expected to produce a 10 mg/l BOD_5 effluent. The BOD_5 in the influent serving the Freeburg East plant and Smithton average 15 and 20 mg/l, respectively. The BOD_5 in their effluents average the same, 9 mg/l. The probability of occurrence for BOD_5 concentrations for influent and effluent flows is shown in figure 29. That BOD_5 likely to occur 50 percent of the time in the influent is 16 mg/l; that for the effluent is 6 mg/l. The effluent BOD_5 will vary from about 2 to 17 mg/l about 80 percent of the time and will exceed 12 mg/l about 25 percent of the time. The degree of variation in the effluent BOD_5 is about the same as that for effluent suspended solids.

Chemical Oxygen Demand

There is no correlation in terms of BOD_5 and volatile solids concentrations with total or soluble COD. The average concentrations of COD in the influents are 62 and 103 mg/l, respectively, for the East plant and Smithton. In the same order effluent concentrations averaged 50 and 43 mg/l. There is not a significant reduction of soluble COD during passage through the filter units.

The variations in COD concentrations are shown in figure 29. COD concentrations of 75 mg/l *are* likely to occur in the influent 50 percent of the time. Similarly, the concentration in the effluent is about 50 mg/l. The significance of COD reductions without reasonable correlation with other parameters is indeterminate. However, as shown in figure 29, BOD_5 is about 16 percent of total COD, and algae accounts for 28 percent of the total COD about 50 percent of the time. There is no significant difference in these values when considering the influent and effluent separately. Therefore these data were combined in this instance.

Nitrogen and Phosphorus

Nitrogen loadings to the units are extremely low. On the average NH_3-N concentrations of 0.8 and 0.1 mg/l occur in the influent and 0.6 and 0.1 mg/l occur in the effluent, respectively, at the East plant and Smithton. Nitrate-nitrogen concentrations are 0.7 and 0.3 mg/l in the influent and 0.8 and 0.3 mg/l in the effluent. There is a perceptible nitrification process occurring within the units as shown in figure 29 suggesting that aerobic conditions are being maintained within the filter beds.

The average total phosphorus concentrations in the influent varied from 4.5 mg/l for the East plant to 9.1 mg/l for Smithton. Average effluent concentrations are 4.6 and 8.0 mg/l, respectively. The filter units do not function in a manner that affects their phosphorus input.

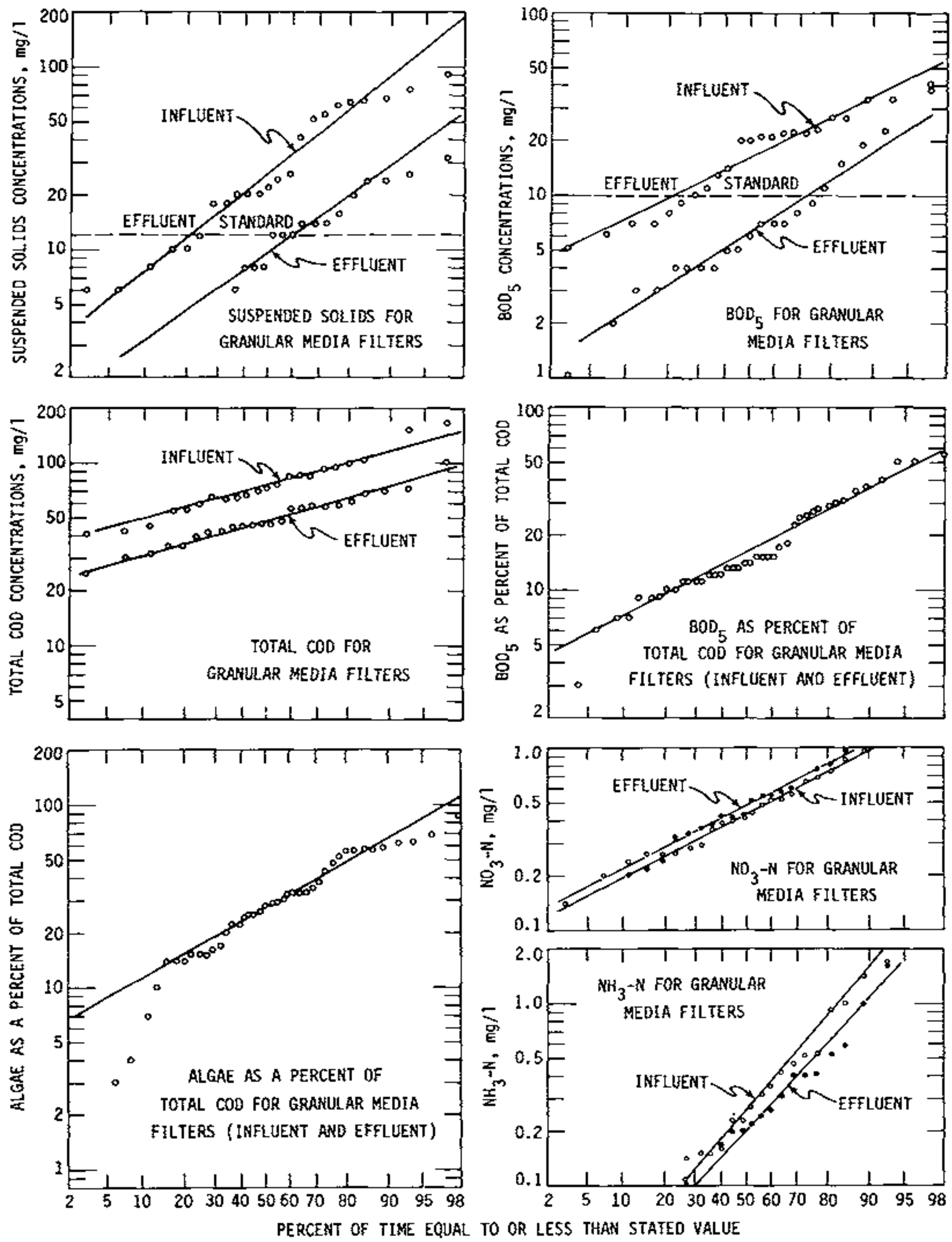

Figure 29. Evaluation of data for granular media filters

Fecal Coliform

Fecal coliform reduction through the filter units is substantial. In the treated effluent the density of fecal coliforms is equal to or less than 400/100 ml in 10 of 12 samples taken at each plant. Fecal coliforms were not detected in 5 of the 12 samples at the East plant nor in 7 of the 12 samples at Smithton. The maximum density in the East plant effluent was 1700/100 ml; at the Smithton plant the maximum was 16,700/100 ml.

Freeburg West Plant

The activated sludge process is producing an effluent that is probably satisfactory for discharge without using the granular media filter. The average concentrations for the influent and effluent of the filter unit are given in table 2.

For 12 samples examined from the filter effluent, BOD_5 was equal to or less than 5 mg/l and suspended solids concentrations were generally non-detectable. It appears that sufficient time is being provided in the activated sludge process to establish a nitrification system as evidenced by low NH_3-N levels and relatively high NO_3-N levels. The arithmetic means for fecal coliform densities varied from 223,400/100 ml in the influent to 101,610/100 ml in the effluent.

DISCUSSION

Although the principal objective of the study was to evaluate tertiary filter units, some opportunity was afforded to examine the effluent quality of facultative lagoons, the most common type of lagoon in Illinois. Before proceeding with a discussion of the tertiary units a brief summary will be presented regarding effluents from lagoons.

On a year-round basis it is likely, as reported by Pierce (1974), that a 3-cell lagoon system will produce effluents meeting the 30 mg/l BOD_5 standard. However, the data assembled In this study during the warmer months suggest that suspended solids concentrations equal to or greater than 30 mg/l will be exceeded about 70 percent of the time. BOD_5 equal to or greater than 30 mg/l will be exceeded about 55 percent of the time. It is quite apparent that if a 30/30 effluent or less is required for lagoon installations tertiary facilities must be provided. A summary of expectations for concentrations of suspended solids, BOD_5, and NH_3-N for facultative lagoon effluents is as follows.

Percent of time	*(In milligrams per liter)* SS	BOD_5	NH_3-N
50	50	32	0.6
30	≥ 75	≥ 40	≥ 1.3
10	≥ 140	≥ 68	≥ 4.5

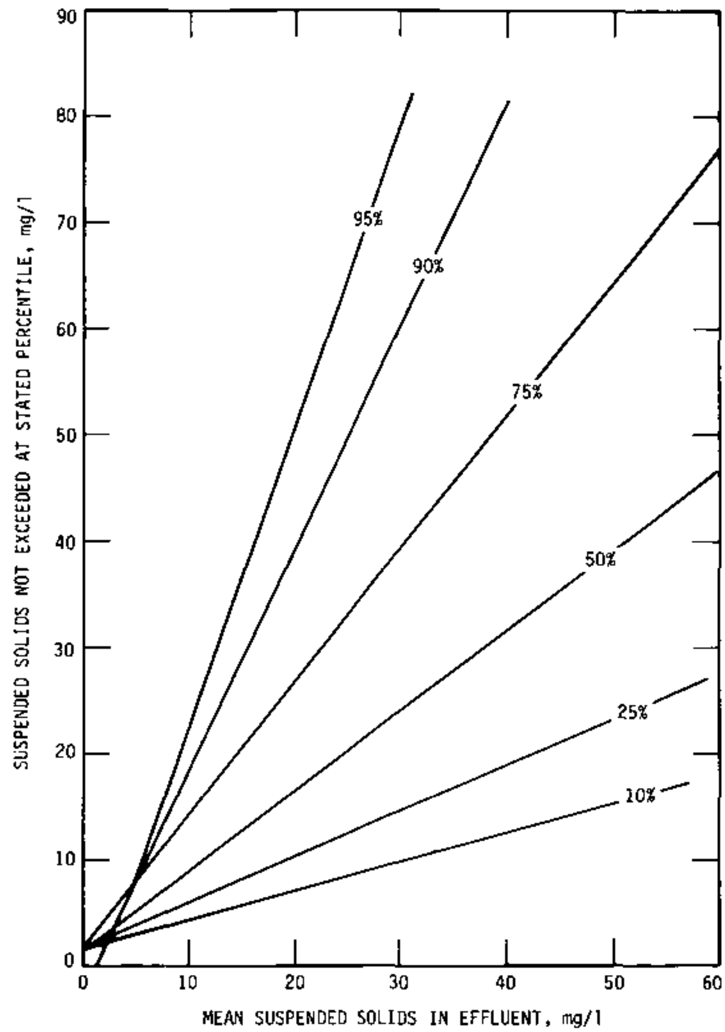

Figure 30. Suspended solids for lagoons

The data for lagoon effluents also offered an opportunity to develop some relationships between probable concentrations of suspended solids versus mean concentrations. The relationships are depicted in figure 30. The chart can be used thusly:

a) Assume conditions require that the suspended solids in an effluent shall not exceed 30 mg/l at least 90 percent of the time. What average value for suspended solids is required? From the 30 mg/l noted on the ordinate, trace to the right to the 90 percentile line and thence downward to the abscissa to find the mean value required is 16 mg/l.

b) Assume a mean value of 30 mg/l is to be achieved in the lagoon effluent. What concentration is not likely to be exceeded 90 percent of the time? Trace from the mean value on the abscissa upward to the 90 percentile line and thence to the left to the ordinate and find the value is 60 mg/l.

The average values determined for the influent and effluent of 11 tertiary units evaluated are given in table 2.

Suspended Solids

Contrary to the findings of Foess and Borchardt (1969) and Parker (1976) algal cells in lagoon effluents can be effectively removed by sand beds. The removal process is not likely one involving repulsive forces as suggested by Williams (1976). When dealing with the high density of algal cells present in lagoon effluent, a mat of algae is formed on the sand surface during the filtering process. This mat enhances the filterability of the bed. Under these circumstances the effectiveness of suspended solids removal is not a function of sand bed depth. This is borne out by observations of the beds receiving lagoon effluent during the course of this study. The 6-inch deep bed serving Teutopolis and the 12-inch deep bed serving Smithton are as effective in removing suspended solids as the 24-inch beds serving Table Grove and Liberty and the 36-inch 'perilite' bed serving the Freeburg East plant (see table 2).

Any of the sand beds, be they constantly submerged, intermittently dosed, or housed in fabricated metal, are capable of reducing substantially the suspended solids concentrations applied to them. Although the intermittent sand filters described previously were not dosed with lagoon effluent, it is believed fair to include them for comparative purposes, as follows:

Percent of time	Effluent suspended solids, mg/l		
	LBSF	*ISF*	*GMF*
50	12	4	10
70	≤20	7	15
90	≤40	14	30

In terms of suspended solids in effluents there is little difference between the LBSF and the GMF. The ISF is the most effective. It is possible that the suspended solids in lagoon effluents, because of size and shape, may be more difficult to remove than the suspended solids from settling tanks applied to the ISFs. However, as shown in table 2, the suspended solids concentrations applied to the ISF units were generally higher (except Bluford) than that applied to other tertiary units, yet the resultant effluent concentrations were generally lower (except Bluford) than that in other types of filter units. On that basis the comparison is appropriate.

The likelihood of equaling or exceeding 30 mg/l suspended solids in the effluents of LBSFs, ISFs, and GMFs is 15, 0, and 10 percent of the time, respectively.

The SRF serving Fairview is not an effective suspended solids remover and the SRF serving Paw Paw cannot be fairly assessed.

5-Day Biochemical Oxygen Demand

The removal of BOD_5 may be a function of bed depth. This was not clear in this study because the 6- and 12-inch beds seem to be as effective as the deeper beds. Nevertheless, it is reasonable to expect that a substrate, in this case sand or other fine grain material, must be ample to harbor the organisms and provide the time of passage for biological reduction of the soluble organic material in the wastewaters. Furman et al. (1955) did find that 89 percent of the applied BOD_5 is removed in the top 12 inches of sand in an intermittent sand filter. Whether nitrification occurs within the same depth or requires more depth has not been documented. Under the circumstances it seems prudent to require media depths of 24 to 30 inches unless the only consideration is suspended solids removal.

As shown in table 2 the LBSF BOD_5 effluent is generally higher than the ISF or GMF. The following shows the variation to be expected.

Percent of time	*Effluent BOD_5, mg/l*		
	LBSF	*ISF*	*GMF*
50	16	4	6
70	≤25	≤16	≤19
90	≤52	≤12	≤17

There appears to be little to choose from between the ISF and GMF units in terms of BOD_5 effluent. This is not to say that the LBSF effluent quality is not satisfactory. The probability of equaling or exceeding 30 mg/l BOD_5 in the effluents of LBSFs, ISFs, and GMFs is 25, 0, and 2 percent, respectively. The SRF at Fairview, as shown in table 2, did not effectively reduce BOD_5.

Chemical Oxygen Demand

All of the sand-type filters reduce the concentration of total COD applied to them. With the exception of the lagoon system at the Freeburg East plant, all lagoon wastes, on the average, contain suspended solids concentrations in excess of 50 mg/l. At these loadings the removal of COD, on the average, varied from 35 to 50 percent. As mentioned earlier, BOD_5 and algae account for 45 to 48 percent of the total COD about 50 percent of the time. This indicates that the COD removed by the filters is principally the *particulate* fraction of the total COD, and this is confirmed by the data for soluble COD which is not reduced significantly during the passage of lagoon waste through the filters.

Those filters serving primary treated sewage (settled) behave differently. This is due more to the characteristics of the waste load than to the operation or design of the filters. On the average the total COD removal ranges from 70 to 90 percent and soluble COD removal ranges from 45 to 85 percent. This suggests that settled sewage is more amenable to being chemically and biologically oxidized than effluents of lagoons.

Because of the lack of correlation between total COD and other parameters, the use of COD as a measure of tertiary treatment effectiveness for domestic waste is questionable.

Nitrogen and Phosphorus

The presence of nitrogen and phosphorus in a wastewater may interfere with the uses of the waters of a receiving stream or lake. The tertiary units at the 11 plants are not designed to reduce nitrogen and phosphorus. Their influence on incoming concentrations of NH_3-N, NO_3-N, and total PO_4-P were nevertheless evaluated because of the lack of effluent quality data for such units.

The average NH_3-N concentrations in lagoon effluents are low ranging from 0.1 mg/l at Smithton to 2.9 mg/l at Fairview. Nitrate-N concentrations are also low ranging, on the average, from 0.2 mg/l at Teutopolis to 1.1 mg/l at Fairview. With the exception of the Bluford facility, NO_3-N concentrations are also low in the settled sewage ranging from 0.7 mg/l at Cisne to 1.0 mg/l at Thompsonville. The NO_3-N concentrations at Bluford average 14.3 mg/l. An examination of the NH_3-N concentrations at that plant compared with the other two settled sewage locations may explain the difference. At Bluford the settled sewage averages 8.6 mg/l NH_3-N, whereas at Thompsonville and Cisne the concentrations average 27.9 and 22.4 mg/l. The sewage at Bluford is very weak with an average BOD_5 of 30 mg/l after settling. With the time provided in the dosing tank, nitrification is in progress thereby reducing NH_3-N levels and increasing NO_3-N levels in the settled sewage.

The effluent concentrations of NH_3-N and NO_3-N vary considerably for each type of filter, i.e., LBSF, ISF, and GMF. For this reason they are treated separately here.

The LBSF is an anaerobic unit and consequently a producer of NH_3-N. The average concentration of NH_3-N applied is 1.8 mg/l and the average in the effluent is 5.1 mg/l. It seems reasonable to expect that any sewage treatment unit constantly submerged for an extended period of time will develop anaerobic conditions. Harris et al. (1975) observed such conditions when an intermittent sand filter was constantly flooded.

As expected, NO_3-N concentrations in the effluent are not significantly different from those in the influent. Nitrate-N on the average ranges from 0.2 to 0.5 mg/l.

At the three LBSFs, NH_3-N concentrations in the effluents will exceed 1.5 mg/l about 83 percent of the time. The dissolved oxygen in the effluent will be zero at about the same frequency.

The phosphorus content did not change significantly within the filter units. On the average it varies from 2.8 to 3.3 mg/l in the influent and 3.1 to 3.7 mg/l in the effluent. This is somewhat surprising if it is assumed that the algal cells, while in the lagoons, are in a state of 'luxury phosphorus uptake.' If the algal cells are in that state and they are subsequently removed in the filter, which they are, a reduction of phosphorus would seem inevitable. It would not appear that the content of phosphorus in algal cells is a major fraction of the total phosphorus in lagoon waste. One can speculate that the phosphorus within the cells becomes solubilized under anaerobic conditions and therefore distorts the picture regarding phosphorus removal. However, the observations made on other filters in which anaerobic conditions were not detected (Freeburg East and Smithton) do not show significant phosphorus removal either. A reasonable assumption is that most of the phosphorus applied to the LBSFs is in soluble form and flows through the filters unaffected.

The ISF is an aerobic unit. It is a reducer of NH_3-N. The average concentration of NH_3-N applied is 19.6 mg/l; the average concentration in the effluent is 3.2 mg/l. That nitrification is in progress is evident by the NO_3-N concentrations in the effluent which on the average vary from 17.4 to 27.0 mg/l at the three ISF units. Although the units are operating at a hydraulic loading of 3 gpd/ft^2 settled sewage, the work of others (Harris et al., 1975; Middlebrooks et al., 1977) indicates that 10 gpd/ft^2 of applied. lagoon effluent will provide equal treatment effectiveness.

On the basis of the rather high concentration of NH_3-N applied to the ISF units (19.6 mg/l average), effluent concentrations will not exceed 1.5 mg/l 50 percent of the time.

The removal of phosphorus within ISF units cannot be depended upon. The average input to the filters is 10 mg/l; the average output is 8 mg/l.

The GMF units do not have significant quantities of NH_3-N applied to them. The average inflow concentrations at the Freeburg East plant and Smithton varies from 0.1 to 0.8 mg/l. Nevertheless, as shown in figure 29, some nitrification did occur within the filters suggesting that the filters do remain aerobic. However, because of the design hydraulic loading rates of 1 to 2 gpm/ft^2, the time required for the nitrification process is less likely to be available during design flows. Significant NH_3-N reductions cannot be relied upon for GMF. Nor can phosphorus removal be accomplished within these units.

The SRF units, as near as can be determined, do not affect nitrogen or phosphorus concentrations applied to them during the warm weather periods. O'Brien (1975) reported that SRFs do become anaerobic during summer and fall months and that NH_3-N concentrations in the effluent will exceed Influent concentrations. The arrangement of the Fairview filter did not permit an examination of the effluent stream prior to its mixing with the pond of substantial volume on the effluent side of the filter.

Fecal Coliform

The effluents from lagoons are relatively low In fecal coliform densities compared with other treated sewage. This is probably a function of the time of retention provided by lagoon systems. The range of fecal coliform densities

Table 3. Range of Fecal Coliform Densities, per 100 ml

Community	*Influent*	*Source*	*Effluent*	*Source*
Table Grove	0-23,000	lagoon	0-117,000	LBSF
Liberty*	0-5,400	lagoon	0-30	LBSF
Teutopolis	0-10,700	lagoon	0-2,800	LBSF
Bluford	21 ,000-1,210,000	settled sewage	3,400-240,000	ISF
Thompsonville	900-4,000,000	settled sewage	900-210,000	ISF
Cisne	225,000-9,400,000	settled sewage	120-12,6000	ISF
Freeburg East	0-15,000	lagoon	0-1,700	GMF
Smithton	180-4,300	lagoon	0-16,700	GMF
Freeburg West	34,000-580,000	treated sewage	30-270,000	GMF

**Chlorinated effluent at LBSF*

for the influent and effluent of the various types of filter units are shown in table 3. Although the tertiary units in general provide a reduction in fecal coliform densities, they do not produce an effluent that will meet the 400/100 ml standard. Disinfection will have to be provided to achieve the standard.

COMMENTARY AND CONCLUSIONS

The hydraulic and organic loadings applied to the filter units examined during this study were substantially below design except for the intermittent sand filter units. Yet there are sufficient data to characterize the units as they respond to concentrations of suspended solids, BOD_5, ammonia-nitrogen, phosphorus, and fecal coliforms during warm weather operations.

Because the nature of the influent to the filter units is an important consideration, a brief review of lagoon operations is presented. The lagoons in the central and northern regions of Illinois are ice covered most of the winter. In the southern part of the state, ice cover for 30 to 45 days during the winter months is not unusual. At these times the contents of the lagoons are anaerobic. There are no supplemental treatment methods recommended for treating anaerobic waste in Illinois. It therefore makes sense to discourage the discharge of lagoon effluents during periods of ice cover, and *it would not be unreasonable to require provision of at least 3 months storage in excess of design periods of retention in all lagoons.*

The facultative lagoon (non-aerated) is solely dependent on air-to-water transfer of oxygen and the production of oxygen by algal photosynthesis to stabilize the waste discharged into it. As algal masses develop, with corresponding oxygen production, the algae buoy toward the water surface and the cells tend to flocculate. This phenomenon is referred to as autoflocculation. The condition provides an advantage for lessening the suspended solids loading on a filter unit. Withdrawal of the lagoon contents below the water surface will produce an effluent with minimum suspended solids thus prolonging filter runs. *Interconnecting piping and discharge structures should be arranged to permit drawoffs 24 inches below the water surface but not closer than 12 inches from the lagoon bottom.* The observation of expanses of duckweed on the 'aerated' lagoons at the Freeburg East plant suggest this requirement should be applied to all lagoon installations.

The effluents from staged lagoons are not capable of meeting the 30/30 effluent standard. Supplemental treatment is required. The observations of lagoon bottom sand filters, intermittent sand filters, and granular media filters that handle lagoon effluents may be capsulized as follows.

Lagoon bottom sand filters and granular media filters are equally effective in producing satisfactory suspended solids concentrations. Intermittent sand filters are the most effective in suspended solids removal.

Intermittent sand filters and granular media filters are equally effective in producing satisfactory BOD_5 concentrations. The lagoon bottom sand filter is the least effective.

Lagoon bottom sand filters become anaerobic and produce ammonia-nitrogen. At design loadings the granular media filters do not affect the ammonia-nitrogen concentrations applied to them. Intermittent sand filters support the nitrification process and reduce ammonia-nitrogen.

Phosphorus is not significantly affected by any of the units, and though all units reduce fecal coliform densities, a standard of 400/100 ml cannot be reliably achieved.

Low dissolved oxygen concentrations are produced in the effluent of lagoon bottom sand filters.

The submerged rock filter serving Fairview was not effective by any criteria used, and the Paw Paw installation could not be evaluated.

From these observations, the following conclusions are made:

1) The moratorium on submerged rock filters should remain in effect.

2) If ammonia-nitrogen concentrations in sewage effluents continue to be a consideration, the approval of lagoon bottom sand filters should be discontinued and their consideration as a recommended sewage works in Illinois should be dismissed.

3) The supplemental treatment of lagoon effluents should be limited to intermittent sand filters and granular media filters.

4) The hydraulic loading for lagoon effluent treatment should not exceed 10 gpd/ft^2 for intermittent sand filters and 2 gpm/ft^2 for granular media filters.

5) Because of the very small cell size of algae in lagoon systems, the filter media for lagoon effluent treatment should be fine grain only, thus excluding the concept of dual media, with effective size ranging from 0.3 to 0.6 mm at a minimum depth of 30 inches atop an adequate coarse aggregate base.

6) All existing lagoon bottom sand filters should be operated on an intermittent dosage basis with water depths applied to the beds not exceeding 9 to 12 inches.

7) Staged lagoon systems with single pass filter operation and dosage control will produce tertiary quality effluents.

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APPENDIX

TABLE GROVE (LBSF)

INFLUENT

Date	Temp.	D.O.	PH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5.	F.C.
3/8/77	7.80	0	8.00	64	60	115	68	6.69	0.34	6.77	29	23,000
3/16/77	12.80	7.30	7.73	72	64	105	62	6.82	0.23	5.02	31	4,500
3/29/77	11.10	—	8.96	64	64	175	67	1.74	2.26	3.14	23	350
4/29/77	19.10	2.30	9.43	68	—	286	49	.43	0.68	2.30	41	160
5/17/77	22.50	—	9.43	40	36	157	63	.71	0.09	2.50	80	130
5/31/77	23.9	0	8.80	32	29	177	83	.88	0.15	2.48	38	10
6/14/77	21.1	0	8.65	162	74	358	180	1.23	0.40	4.16	116	0
6/28/77	24.1	0	8.91	58	56	120	56	.26	0.34	2.46	37	80
7/12/77	26.6	4.60	8.40	14	12	152	48	.46	0.28	2.39	14	10
7/26/77	25.70	5.20	8.70	24	24	133	80	.24	0.28	2.22	27	0
9/13/77	22.40	0	7.00	74	62	169	67	3.53	1.91	3.39	105	86
10/4/77	15.00	5.10	9.11	8	8	77	51	.15	0.14	5.80	20	130
10725/77	12.80	15.86	7.08	84	24	56	39	.23	0.16	.71	15	1,070

EFFLUENT

Date	Temp.	D.O.	PH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5.	F.C.
3/8/77	5.10	0	7.96	29	26	76	73	8.28	0.80	7.22	34	21,000
3/16/77	8.50	0	7.69	34	29	73	72	5.45	0.16	5.02	21	117,000
3/29/77	10.90	-	8.65	51	51	117	101	3.87	0.14	2.91	14	1,100
4/29/77	12.00	0	8.23	6	—	245	38	14.42	0.18	8.25	46	3
5/17/77	21.50	-	8.47	16	16	128	94	.78	0.11	4.55	28	160
5/31/77	18.6	0	8.59	7	7	162	106	7.60	0.15	4.04	15	0
6/14/77	NO SAMPLE - DRAINING LAGOONS											
6/28/77	NO SAMPLE - DRAINING LAGOONS											
7/12/77	24.6	0	8.20	0	0	126	83	2.13	0.24	3.10	24	0
7/26/77	24.7	-	7.95	48	38	92	74	.71	0.25	2.74	13	510
9/13/77	20.10	0	7.01	0	0	66	50	1.70	1.34	1.13	9	9,800
10/4/77	15.00	3.30	7.23	18	18	—	20	1.11	0.49	1.08	6	450
10/25/77	12.20	7.70	7.15	24	8	—	37	0.49	1.20	.50	6	5,700

LIBERTY (LBSF)

INFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/23/77	8.60	8.80	7.59	11	11	75	46	16.15	0.72	5.26	17	970
3/29/77	12.20	12.40	8.25	26	26	76	48	.50	1.83	4.64	18	360
4/29/77	21.3	8.50	9.50	82	—	228	39	.58	0.30	2.25	47	0
5/17/77	21.00	—	8.39	156	156	118	88	.75	0.10	1.80	106	1,600
5/31/77	20.8	12.8	8.95	—	—	278	84	2.47	0.16	3.02	43	310
6/14/77	21.0	0	9.03	52	52	159	66	.98	0.31	1.47	24	980
6/28/77	22.0	0	8.42	74	74	168	68	3.00	0.27	2.66	50	100
7/12/77	28.70	16.10	9.20	26	18	166	76	.47	0.26	1.58	35	0
7/26/77	26.40	12.70	9.55	34	32	157	84	.17	0.21	1.55	31	10
9/13/77	20.40	0	8.68	28	20	103	52	.50	0.15	2.45	19	5,400
10/4/77	SHUTDOWN FOR CLEANING											
11/7/77	14.50	6.00	7.45	24	16	141	72	1.00	0.30	4.59	26	500

EFFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/23/77	7.80	2.20	7.59	5.00	4.8	41	35	4.11	0.11	3.53	2	20
3/29/77	8.50	2.00	8.55	6.00	4.5	44	35	2.73	0.15	3.41	2	1
4/29/77	12.50	0	8.08	4	—	64	28	5.15	0.12	3.20	24	0
5/17/77	18.70	—	7.57	0	0	107	85	2.02	0.08	6.35	60	80
5/31/77	19.3	0.4	8.18	—	—	140	87	11.44	0.23	4.62	53	10
6/14/77	18.7	9.7	8.62	4	4	53	48	9.60	0.22	2.99	20	0
6/28/77	19.0	0	7.76	20	20	101	47	10.22	0.20	2.74	65	230
7/12/77	18.0	8.20	7.75	4	4	38	45	5.74	0.32	2.42	1	0
7/26/77	26.40	1.20	7.60	16	16	89	44	2.76	0.23	3.80	28	90
10/4/77	SHUTDOWN FOR CLEANING											
11/7/77	13.80	0	6.32	84	42	103	20	1.96	0.12	1.76	13	20

TEUTOPOLIS (LBSF)

INFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/9/77	10.60	0.60	7.70	10.00	8.50	68	33	8.16	0.18	5.87	23	8,000
3/16/77	12.00	0.30	7.54	18.00	11	65	33	8.22	0.15	4.39	8	10,700
4/27/77	18.20	19.15	9.69	60	—	138	48	0	0.25	1.59	22	(1,700 TC)
5/10/77	20.60	11.20	9.41	52	32	51	50	0	0.11	5.00	25	500
5/24/77	NO SAMPLE - SHUT DOWN											
6/7/77	NO SAMPLE - FILLING LAGOONS											
6/21/77	NO SAMPLE - SHUT DOWN											
7/5/77	NO SAMPLE - SHUT DOWN											
7/20/77	NO SAMPLE - FILLING LAGOONS											
8/24/77	25.80	2.90	8.90	36	22	115	71	0.10	0.29	1.80	24	10
8/31/77	30.10	12.60	7.30	100	88	254	67	.13	0.26	2.37	53	0
9/6/77	29.00	10.80	9.30	66	52	141	75	.05	0.13	1.67	20	0
9/7/77	25.20	10.30	9.40	86	74	167	78	.18	0.15	1.01	84	200
9/21/77	23.70	19.80	9.72	240	180	332	91	0	0.18	5.16	73	0
9/27/77	22.20	10.60	9.01	120	104	219	87	0	0.21	3.03	27	0
9/28/77	21.20	11.90	9.59	112	108	199	—	0	0.23	3.07	34	0
10/12/77	12.60	10.90	8.77	66	58	157	82	0.27	.21	3.34	24	0
10/18/77	11.80	10.20	8.91	80	80	430	108	1.22	0.26	3.86	65	50
10/19/77	15.20	22.00	9.12	72	64	284	158	0.40	0.14	3.77	19	0

EFFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/9/77	7.40	0	7.83	8.00	6.90	64	36	8.40	0.17	5.42	26	2,000(TC)
3/16/77	11.20	0	8.09	14	10	65	35	7.98	0.12	4.29	8	2,800
4/27/77	16.20	0	8.94	48	—	104	13	1.70	0.09	1.52	18	(300 TC)
5/10/77	19.60	2.00	9.08	26	16	76	43	2.18	0.10	3.85	22	0
5/24/77	NO SAMPLE - SHUT DOWN											
6/7/77	NO SAMPLE - FILLING LAGOONS											
6/24/77	NO SAMPLE - SHUT DOWN											
7/5/77	NO SAMPLE - SHUT DOWN											
7/20/77	NO SAMPLE - FILLING LAGOONS											
8/24/77	22.60	0	7.25	10	8	73	53	1.38	0.28	3.49	18	10
8/31/77	22.50	0	7.20	8	4	71	50	2.90	0.27	2.98	15	20
9/6/77	29.00	10.80	8.00	16	16	69	58	3.00	0.13	2.59	13	0
9/7/77	22.70	0	7.90	14	14	75	66	3.83	0.09	2.86	106	0
9/21/77	20.40	0	8.41	12	12	86	74	4.73	0.18	2.59	17	0
9/27/77	21.50	0	7.96	18	14	97	87	4.45	0.19	2.89	39	0
9/28/77	19.80	0	8.02	18	18	—	100	4.33	0.18	2.76	15	0
10/12/77	13.60	0	8.02	8	8	88	74	3.17	.23	2.84	10	70
10/18/77	11.60	0	7.91	0	0	241	63	3.10	.13	2.91	15	0
10/19/77	11.80	0	8.15	8	8	105	88	3.07	.15	2.93	8	100

BLUFORD (ISF)

INFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/9/77	8.00	5.0	7.40	23	21	92	58	12.93	0.55	8.48	734	500,,000
3/15/77	11.40	—	7.2	6.00	4.50	59	35	12.67	2.46	4.48	19	250,,000
4/28/77	16.30	—	7.30	—	—	77	33	9.05	12.18	6.19	311	,210,,000
5/11/77	16.50	—	7.31	6	0	73	50	6.44	21.47	7.65	17	250,,000
5/24/77	22.60	—	6.95	36	14	94	44	6.30	14.47	10.00	13	--
6/7/77	21.00	—	7.10	6	6	97	55	10.08	12.10	10.36	33	300,,000
6/21/77	22.4	—	6.73	8	8	76	52	4.72	22.13	9.48	25	410,,000
7/5/77	25.2	—	6.80	22	10	84	52	5.30	19.41	1.57	20	340,,000
7/19/77	27.30	—	6.70	10	10	73	49	4.37	15.21	11.84	5	21,,000
9/7/77	24.40	—	6.80	20	14	138	56	2.51	21.56	10.15	L.A.	600,,000
9/27/77	21.80	—	6.74	18	18	100	100	3.62	17.32	11.00	65	420,000
10/19/77	14.00	—	6.82	18	12	284	110	20.10	12.44	12.19	64	500,000

EFFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/9/77	8.10	5.00	7.20	107	17	34	23	12.34	0.56	5.87	7	47,500
3/15/77	12.60	—	7.24	31	5	31	26	12.37	2.01	4.23	5	13,000
4/28/77	16.00	—	6.95	0	0	35	28	2.61	15.09	5.38	7	50,000
5/11/77	15.40	—	7.43	4	0	44	32	.59	26.07	8.05	7	9,100
5/24/77	23.00	—	7.39	28	8	45	42	3.35	15.26	6.74	7	13,000
6/7/77	21.10	—	7.00	0	0	45	37	5.73	14.42	9.27	6	18,000
6/21/77	22.70	—	6.97	10	8	—	44	0.73	24.71	2.00	>27	25,000
7/5/77	25.30	—	6.65	8	4	—	28	0.28	20.38	9.98	2	—
7/19/77	27.80	—	6.80	4	4	—	28	0.79	18.99	12.05	50	240,000
9/7/77	24.40	—	6.90	4	4	28	28	0.19	27.23	10.56	11	5,100
9/27/77	21.80	—	6.81	10	8	38	38	4.00	23.36	10.62	4	40,000
10/19/77	13.30	—	6.74	0	0	39	39	7.74	20.92	10.46	3	3,400

THOMPSONVILLE (ISF)

INFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/15/77	10.00	7.0	35	28	78	37	7.33	6.32	6.75	45	420,000
3/23/77	9.90	7.0	—	--	—	96	7.74	0.13	11.69	360	1,200,000
4/28/77	14.10	6.72	40	—	151	90	24.73	0.25	9.73	136	700,000
5/10/77	15.50	7.28	86	38	321	180	35.71	0.98	2.65	250	900
5/24/77	18.80	7.56	86	50	414	239	42.45	0.39	16.60	94	830,000
6/8/77	20.9	6.80	37	33	439	193	46.13	0.50	15.97	257	900,000
6/21/77	20.6	6.74	—	—	—	—	23.19	0.66	25.75	—	4,000,000
7/5/77	23.50	6.50	—	—	—	—	30.34	1.28	23.16	—	—
7/19/77	22.80	6.55	170	150	555	136	37.18	0.39	17.35	320	2,300,000
9/6/77	24.68	6.65	144	124	439	165	29.02	0.24	13.85	200	2,800,000
9/27/77	21.10	6.35	—	—	—	—	12.88	0.60	—	—	1,000,000
10/18/77	15.80	6.59	32	30	380	113	29.42	0.31	13.89	200	1,100,000

EFFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/15/77	10.60	6.7	5.00	4.00	31	20	4.52	11.24	5.73	5	150,000
3/23/77	9.10	7.1	8.00	5.50	25	10	7.54	19.10	6.91	10	8,200
4/28/77	14.60	6.50	0	0	32	24	0.80	23.76	7.23	2	5,400
5/10/77	17.20	6.85	2	0	37	32	20.74	32.82	8.70	6	900
5/24/77	21.00	6.67	24	8	46	35	6.48	25.09	14.60	5	70,000
6/8/77	19.3	6.70	0	0	27	26	2.75	37.42	14.99	30	4,900
6/21/77	23.2	6.86	4	4	95	86	5.93	39.35	2.27	7	210,000
7/5/77	24.70	6.25	6	0	—	37	2.39	34.40	12.56	3	13,000
7/19/77	26.80	6.65	8	6	12	27	2.12	36.73	12.94	2	13,000
9/6/77	24.90	6.60	14	13	—	13	.62	30.19	8.03	4	40,000
9/27/77	20.80	6.51	8	6	76	47	1.50	8.69	4.97	6	100,000
10/18/77	14.50	6.61	0	0	48	38	1.77	25.06	7.76	2	13,000

CISNE (ISF)

INFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/9/77	9.60	7.02	55	40	129	64	12.04	1.81	6.90	>54	450,000
3/16/77	10.40	7.32	50	38	160	81	11.86	1.58	4.82	59	670,000
4/27/77	16.50	7.7	48	—	151	95	20.60	0.12	6.41	140	15,000,000
5/11/77	16.50	7.49	40	28	324	135	20.60	0.18	7.95	170	225,000
5/25/77	20.50	7.82	88	56	306	128	34.89	0.27	12.7	149	—
6/8/77	18.90	7.48	40	30	423	196	33.55	3.22	8.57	185	1,430,000
6/22/77	19.70	7.11	74	58	208	166	4.15	—	7.76	140	1,100,000
7/6/77	23.20	7.25	44	44	364	145	29.35	0.20	3.41	180	—
7/20/77	23.80	7.10	36	36	245	123	20.51	0.21	8.43	136	580,000
9/7/77	24.50	7.35	44	40	304	160	26.33	0.15	8.26	200	1,100,000
9/28/77	21.20	7.10	192	132	482	383	30.06	0.20	11.22	202	9,400,000
10/19/77	19.20	7.07	38	30	401	175	25.87	0.18	10.35	158	800,000

EFFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/9/77	8.20	7.75	1.00	.9	6	4	.35	19.39	5.46	2	4,800
3/16/77	11.10	7.51	1.00	.6	24	19	.25	15.83	4.73	3	1,800
4/27/77	16.20	7.0	0	0	27	15	.54	21.91	6.13	2	87,000
5/11/77	17.00	7.13	0	0	46	22	.91	19.94	8.50	6	120
5/25/77	22.80	7.08	22	8	27	24	1.17	30.41	7.18	3	2,700
6/8/77	21.50	7.15	0	0	23	11	.90	35.30	8.33	1	510
6/22/77	23.40	6.79	6	6	44	35	.41	33.48	9.41	1	2,200
7/6/77	25.10	6.90	0	0	13	76	1.42	27.00	8.41	7	3,200
7/20/77	27.30	7.35	8	8	—	28	.89	24.23	7.35	3	12,600
9/7/77	25.30	7.36	0	0	—	9	.38	22.87	5.99	9	1,900
9/28/77	21.60	6.93	26	16	48	45	.71	23.93	S.04	6	323,000
10/19/77	14.50	7.04	0	0	—	12	0.82	16.61	6.67	4	4,100

FAIRVIEW (SRF)

INFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.,	NH_3-N	NO_3-N	PO_4-P	BOD,	F.C.
3/23/77	6.70	13.80	7.49	41	40	97	54	16.09	1.85	9.95	19	330
3/29/77	12.50	11.80	8.98	88	68	110	51	13.08	2.32	8.54	25	630
4/14/77	16.50	—	9.10	143	130	135	28	2.25	4.08	5.37	26	520
4/29/77	13.40	16.00	10.17	150	—	112	22	.07	2.46	2.20	18	30
5/17/77	22.10	20.10	10.11	8	4	64	38	.09	0.12	1.70	13	0
5/31/77	23.6	12.50	9.38	—	—	109	52	2.24	0.12	1.56	16	0
6/14/77	18.6	10.7	9.22	66	50	84	40	.42	0.24	1.86	17	40
6/28/77	25.2	13.00	9.15	56	50	76	43	.40	0.16	1.95	18	80
7/12/77	24.8	6.00	9.00	24	22	85	56	.51	0.22	2.51	11	290
7/26/77	24.80	6.60	8.55	38	38	92	38	.08	0.15	3.06	22	0
9/13/77	19.40	0.30	8.70	26	16	65	40	2.48	0.15	3.85	30	340
10/4/77	14.50	10.10	8.91	30	28	56	28	0.01	1.05	13.48	12	280
10/25/77	11.40	9.00	8.50	24	20	55	37	0.33	0.78	4.30	11	90

EFFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD	F.C.
3/23/77	6.70	9.30	7.27	68	62	83	39	13.97	1.95	9.57	14	70
3/29/77	10.50	9.20	8.89	86	68	112	45	11.52	2.62	8.66	24	580
4/14/77	16.50	18.60	9.45	128	106	68	36	.25	4.70	4.43	24	20
4/29/77	12.30	13.00	10.11	110	—	71	24	.66	1.67	2.30	20	2
5/17/77	21.50	4.30	8.82	—	—	58	38	.18	0.11	2.50	8	
5/31/77	23.70	0	8.88	—	—	103	53	1.70	0.08	2.15	14	20
6/14/77	18.4	0	9.07	34	34	77	42	2.10	0.15	2.30	22	190
6/28/77	25.70	0	8.97	38	36	63	35	.34	0.18	1.42	19	20
7/12/77	24.60	0	8.95	26	16	72	25	.88	0.19	2.75	15	70
7/26/77	23.80	0	7.85	38	38	101	43	1.41	0.21	3.41	22	980
9/13/77	19.20	0	8.57	18	12	62	37	4.11	0.11	7.44	30	400
10/4/77	14.50	2.00	8.61	22	18	—	28	0.29	0.76	12.39	17	40
10/25/77	11.60	7.30	8.35	22	22	—	43	0.24	0.66	3.95	0	10

PAW PAW (SRF)

INFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/24/77	5.00	12.0	8.01	7.00	3.6	34	19	4.95	0.22	2.80	10	120
4/14/77	14.60	4.20	8.08	5.00	3.4	12	12	6.00	0.42	3.56	5	0
5/18/77	24.20	12.60	9.64	9	6	38	33	.19	0.64	2.75	6	0
6/1/77	NO SAMPLE - SHUT DOWN BECAUSE OF LOW FLOW											
6/15/77	19.6	7.50	9.71	0	0	48	40	.24	0.34	.73	3	0
6/29/77	21.40	4.60	10.05	18	18	33	28	.10	0.21	.66	2	0
7/13/77	23.80	0	9.50	0	0	51	40	.44	0.21	.64	4	20
7/27/77	21.20	2.80	9.30	2	2	35	35	0	0.20	.86	4	40
9/14/77	17.30	2.30	8.57	0	0	43	40	.58	0.18	1.88	–	20
10/5/77	13.10	9.00	8.76	0	0	15	15	.08	0.20	5.26	2	0
10/26/77	9.70	9.10	8.78	0	0	52	52	.23	0.25	1.87	8	0

EFFLUENT

Date	Temp.	D.O.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
3/24/77	3.80	9.30	8.00	4.00	2.80	29	26	2.74	0.28	2.38	7	70
4/14/77	14.60	8.70	8.05	5.00	3.4	12	12	5.50	1.59	9.91	3	0
5/18/77	21.30	8.70	7.94	16	12	—	18	0.0	1.13	4.15	3	0
6/1/77	NO SAMPLE - SHUT DOWN BECAUSE OF LOW FLOW											
6/15/77	18.50	6.30	9.33	0	0	51	37	.07	0.64	.64	1	0
6/29/77	21.30	3.90	9.28	16	16	98	92	1.84	0.29	.91	3	0
7/13/77	21.70	3.70	8.80	0	0	—	58	.47	0.19	.76	5	0
7/27/77	20.80	4.40	9.00	2	2	54	41	.16	0.21	.80	2	10
9/14/77	16.90	5.86	8.58	0	0	—	31	.49	0.13	1.88	29	10
10/5/77	13.60	11.80	8.54	0	0	—	30	0	0.24	5.42	2	20
10/26/77	10.10	9.10	9.03	1	0	—	25	0	0.23	1.76	2	0

FREEBURG (E) (GMF)

INFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
8/2/77	25.50	7.05	24	12	45	43	0.32	.44	3.65	8	0
8/10/77	24.70	6.80	10	8	65	40	1.41	.51	4.45	11	5,200
8/16/77	26.60	7.05	6	0	56	42	1.73	.55	4.25	6	100
8/17/77	25.40	7.40	6	4	68	48	1.72	.51	4.54	7	800
8/23/77	23.40	7.00	18	10	64	55	0.47	0.66	3.74	7	1,700
8/24/77	22.90	6.80	20	14	64	55	0.52	0.48	4.34	20	2,600
8/30/77	24.20	7.30	12	12	54	41	0.93	0.72	4.62	5	1,100
8/31/77	24.50	7.00	18	18	42	36	1.07	0.68	4.96	21	700
9/20/77	20.90	7.92	8	6	40	35	0.27	1.14	4.46	9	0
9/21/77	21.70	7.87	10	10	86	63	0.53	1.15	4.57	42	1,000
10/11/77	13.40	7.30	26	18	83	83	0.14	1.01	5.43	22	4,500
10/12/77	13.40	7.68	22	14	73	55	0.42	.88	5.27	22	15,000

EFFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
8/2/77	25.20	7.05	14	6	46	43	6.40	0.20	4.93	6	0
8/10/88	25.00	7.20	0	0	57	38	1.07	0.55	3.96	1	30
8/16/77	26.10	7.00	0	0	42	38	1.70	0.52	4.33	5	100
8/17/77	25.70	7.20	0	0	35	26	1.78	0.58	4.47	4	0
8/23/77	23.50	7.30	6	6	45	35	0.40	0.82	4.29	3	0
8/24/77	23.10	7.15	14	10	45	35	0.41	0.65	4.09	–	0
8/30/77	24.40	7.20	12	6	43	31	0.10	1.86	4.47	4	400
8/31/77	24.70	6.80	0	0	47	33	0.59	0.55	4.32	19	1,700
9/20/77	21.50	7.52	0	0	46	40	0.01	1.12	4.78	3	1,000
9/21/77	21.00	7.44	0	0	40	40	0.24	1.09	4.80	38	30
10/11/77	13.50	7.27	0	0	56	56	0.22	1.08	5.54	4	0
10/12/77	13.00	7.24	0	0	58	58	0.52	0.77	5.68	8	80

FREEBURG (W) (GMF)

INFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
8/2/77	23.70	6.95	24	10	35	35	1.22	11.38	14.79	7	350,000
8/10/77	22.00	6.80	4	2	31	6.8	1.57	6.16	6.98	10	220,000
8/16/77	24.50	6.70	4	2	53	18	3.07	5.56	18.05	9	580,000
8/17/77	23.10	6.65	8	6	—	—	0.09	10.03	16.25	1	34,000
8/23/77	23.20	7.00	18	18	16	33	1.15	16.50	16.18	12	460,000
8/24/77	22.30	6.90	10	8	37	24	0.03	0.94	15.40	3	250,000
8/30/77	22.80	6.95	—	—	19	16	1.52	9.09	13.27	6	220,000
8/31/77	23.40	7.60	10	4	28	22	0.07	9.65	16.38	3	42,000
9/20/77	22.60	7.11	8	8	34	31	1.70	12.19	10.52	8	230,000
9/21/77	21.80	7.11	8	0	25	25	.05	14.94	11.53	23	70,000
10/11/77	18.20	7.01	6	2	22	22	1.59	12.06	10.07	6	160,000
10/12/77	17.30	6.61	8	6	22	22	.18	11.90	40.00	67	65,000

EFFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
8/2/77	23.60	7.00	14	2	—	38	0.95	12.25	18.28	5	270,000
8/10/77	22.20	6.80	0	0	14	30	1.23	6.81	9.94	4	100,000
8/16/77	24.30	6.70	0	0	—	43	2.08	5.75	20.03	3	180,000
8/17/77	23.60	6.80	0	0	38	26	0.09	10.19	17.86	1	4,600
8/23/77	23.20	7.30	10	8	58	34	0.85	12.24	16.71	4	260,000
8/24/77	22.30	7.00	10	10	—	36	0.02	18.20	17.82	1	178,000
8/30/77	22.70	6.90	0	0	6	5	0.46	8.85	11.89	3	14,000
8/31/77	23.30	8.00	0	0	28	22	0	9.41	19.01	5	30
9/20/77	22.30	6.94	0	0	12	12	0.99	12.62	10.73	2	140,000
9/21/77	20.90	6.96	0	0	19	19	0.55	10.97	11.93	-	43,200
10/11/77	18.40	7.09	0	0	12	12	0.75	11.80	9.29	3	27,000
10/12/77	17.30	7.04	0	0	25	25	0.11	11.72	38.57	2	2,500

SMITHTON (GMF)

INFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
8/3/77	26.30	7.90	66	42	87	38	.03	0.29	12.63	13	180
8/10/77	26.20	7.60	20	6	70	30	0.15	0.14	12.16	10	300
8/16/77	27.80	8.90	62	38	156	34	0.15	0.20	9.69	23	2,100
8/17/77	26.60	8.50	56	24	78	31	0.23	0.26	10.15	20	4,300
8/23/77	25.80	7.90	20	18	60	61	0.06	0.26	6.62	22	1,200
8/24/77	24.80	7.55	90	74	107	46	0.03	0.28	7.57	27	3,300
8/30/77	25.90	8.10	76	72	101	38	0.03	0.26	7.66	13	1,500
8/31/77	25.70	8.70	—	—	—	49	.07	0.24	7.58	34	900
9/20/77	22.20	9.20	52	50	93	45	0	0.36	7.56	27	1,800
9/21/77	21.50	9.06	64	60	99	42	.35	0.39	8.44	—	2,200
10/11/77	14.60	9.13	66	54	108	47	.23	0.41	8.54	14	4,200
10/12/77	12.40	8.76	42	40	169	54	.16	0.39	9.43	21	1,400

EFFLUENT

Date	Temp.	pH	TSS	VSS	COD Total	COD Sol.	NH_3-N	NO_3-N	PO_4-P	BOD_5	F.C.
8/3/77	25.60	7.40	24	10	43	32	0	0.20	9.09	4	0
8/10/77	25.80	7.50	16	8	70	39	0.15	0.25	11.27	2	127
8/16/77	27.80	7.50	12	4	45	36	0.15	0.43	9.48	5	0
8/17/77	26.80	7.60	12	8	25	21	0.20	0.42	8.08	7	16,700
8/23/77	25.80	7.98	32	20	101	52	0.00	0.34	5.91	15	0
8/24/77	25.10	7.60	26	22	58	40	0.00	0.21	6.41	—	0
8/30/77	25.60	7.30	14	12	—	30	0.20	0.33	6.41	11	0
8/31/77	25.60	7.80	8	8	42	35	0.17	0.22	6.71	23	100
9/20/77	22.40	8.26	8	8	62	42	0	0.38	8.14	9	0
9/21/77	21.50	8.33	8	8	69	45	0.10	0.59	7.72	—	0
10/11/77	13.90	8.23	20	20	59	50	.26	0.37	8.55	7	2,100
10/12/77	12.20	8.43	24	20	73	51	.31	0.38	8.70	7	0