



Assessment Of Single-Stage Trickling Filter Nitrification



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Washington, D.C.

ASSESSMENT OF SINGLE-STAGE
TRICKLING FILTER NITRIFICATION

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SECTION 1.

INTRODUCTION

As part of its program of providing technical assistance to local governments in the area of municipal wastewater treatment, the Office of Municipal Pollution Control (OMPC) evaluates specific technologies and reports on their capabilities and limitations. This report is part of a larger effort to compare different wastewater technologies that can achieve nitrification. OMPC plans to look at oxidation ditches and sequencing batch reactors to compare their ammonia-removal efficiencies and costs with those of trickling filters and conventional activated sludge processes.

Many municipalities may have ammonia limits added to their permits in the near future. For the large number of facilities that include trickling filters in their treatment train, modifications to the filters would frequently be the most cost-effective solution to this additional treatment need.

This report evaluates the use of trickling filters for nitrification of municipal wastewater. This study originally focused on single-stage trickling filters, a biological process application wherein carbon oxidation and nitrification are accomplished within the same unit without separation of the biomass used to accomplish these operations. Multiple-stage systems were added to the study due to the limited number of single-stage facilities. The multiple-stage systems evaluated in this report all had performance data that were measured after the first stage so they could be compared to single-stage systems.

Information was compiled from the EPA, Regional and State offices, literature, and wastewater treatment plant personnel. The data were collected from full-scale treatment facilities and used to evaluate process performance and aid in understanding the effect of various operating parameters.

SECTION 2.

CONCLUSIONS

The extent to which single-stage trickling filter nitrification is practiced is very limited. Ten single-stage plants were identified, with six of these utilizing the solids-contact process in conjunction with the trickling filter. Several other plants use separate two-stage processes for carbonaceous/nitrogenous BOD removal. They have either two-stage trickling filters with intermediate clarifiers or a trickling filter in series with an activated sludge process.

The evaluated plants were generally meeting their permit requirements, including ammonia-nitrogen limits when applied. Several plants exhibit some increase in effluent ammonia and BOD levels during cold weather months, although the differences are relatively small and there is no direct correlation apparent with temperature. Both plastic media and rock filters are represented by the plants. There are no apparent differences in performance related to the medium; the reactor sizings are different because of the various specific area characteristics of the media.

Nitrification requires relatively low organic loadings. These can be expressed on a volumetric or medium surface area loadings basis, and are generally set to yield effluent BOD₅ levels less than 10 to 15 mg/L. Operating at these levels will assure an environment in which the autotrophic nitrifying bacteria can compete with the faster growing heterotrophic bacteria responsible for carbonaceous BOD removal. Loadings that are less than 10 lbs BOD/1,000 ft³-d or 0.3 lbs BOD/1,000 ft²-d will allow for nitrification and yield effluent ammonia-nitrogen levels less than 4 mg/L. These loadings, based on a review of combined data from 10 selected plants, compare favorably with the organic loading guidelines suggested by the USEPA for proper design and operation of single-stage trickling filters (1975 Process Design Manual for Nitrogen Control).

Recirculation is beneficial to the process performance of trickling filters. There was no clear indication of optimum rates from the selected plant data. Ratios of recycle to raw wastewater flow in the order of one to three would appear to be adequate operational criteria to achieve this performance.

SECTION 3.

RECOMMENDATIONS

Several process configurations are available to accomplish nitrification with trickling filters. The predominant application utilizes a two-stage arrangement with intermediate clarification. This offers greater stability and will likely yield a more highly polished effluent than a single-stage process. The single-stage operation, however, can offer a more cost-effective approach, requiring less tankage and unit operations. This presumes that loadings would be similar to those required for two-stage operation.

This report indicates that the application of the single-stage trickling filter nitrification process is very limited, and, as such, there are limited data from which to evaluate performance and process design. It is recommended that further study be made of the process in direct comparison to a two-stage configuration. This would best be accomplished in the field, preferably at an existing full scale facility, with side by side treatment trains. It should focus on organic loadings (surface and volumetric), hydraulic loadings and recirculation rates. Encompassing two seasons would allow for an assessment of temperature effects. The resulting data would enhance OMPC's planned report on the nitrification costs and capabilities of different technologies.

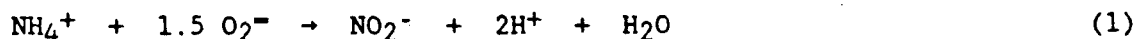
SECTION 4.

NITRIFICATION IN TRICKLING FILTERS

INTRODUCTION

Today, ammonia-nitrogen removal is a major concern for many wastewater treatment facilities because of the U.S. Environmental Protection Agency's approach to implementing more stringent water quality based ammonia limits. This has resulted in an increased interest to find cost effective technologies for ammonia removal.

Ammonia is biologically converted to nitrite and nitrate in a two-step nitrification process. It is first oxidized to nitrite (NO_2^-) by nitrosomonas bacteria and then to nitrate (NO_3^-) by nitrobacter bacteria, both of which are autotrophic:



Nitrification can be accomplished by both suspended and fixed growth processes as long as a sufficient amount of oxygen is available to nitrifiers and enough alkalinity is present in the wastewater. Oxidation of high soluble BOD concentrations in the liquid phase by heterotrophic bacteria deplete oxygen availability, and the nitrifiers are unable to compete with the relatively faster growing heterotrophs. Nitrification begins only when soluble BOD concentrations in the liquid phase are low enough for nitrifiers to compete with heterotrophs.

A number of wastewater treatment plants in the United States are practicing nitrification with trickling filters because of the stability, ease of operation and cost effectiveness of the treatment process. The trickling filter is an aerobic fixed film reactor which uses a solid surface medium to

support biological film growth. Media traditionally consist of rocks, slag, or synthetic materials. Rock and slag trickling filters generally have four to ten feet of media depth. Plastic media trickling filters are normally constructed much deeper (15 to 25 feet) because of the lighter weight and better ventilation capabilities of the packing. Recent advances in the development of plastic media with different structural configurations have made this technology more efficient and cost effective. Various types of trickling filter configurations in use for achieving nitrification are discussed in this section.

SINGLE-STAGE NITRIFICATION

Little information is available for the process in which carbon oxidation and nitrification are accomplished in a single trickling filter unit. Stenquist et al., (1974) studied the process in a plastic media trickling filter, the results of which suggested that organic loading is the limiting factor. Organic loadings less than 25 lbs BOD₅/day/1,000 cubic feet (0.40 kg/day/m³) were found to favor a high degree of nitrification in plastic media filters.

The EPA Process Design Manual for Nitrogen Control (1975) recommends an organic loading of 10 to 12 lb BOD₅/day/1,000 cubic feet (0.16 to 0.19 kg/m³/day) to attain 75 percent nitrification in single-stage rock media filters. Higher allowable organic loadings for plastic media filters, as reported by Stenquist (1974), is attributed to the greater specific surface area of plastic media and better oxygen supply. Rock filters generally have poor ventilation when water and air temperatures are close.

The minimum hydraulic loading rate for plastic media trickling filters is in the range of 0.5 to 1.0 gpm/ft² (0.020 to 0.041 m³/m²-minute) to ensure uniform wetting of the medium. A recirculation ratio of 1:1 was consistently found to improve ammonia removals in a rock media trickling filter at Salford, England (USEPA, 1975). The data from this study are presented in Table 4-1. As shown, lower effluent ammonia levels were achieved with recirculation over a range of loadings between 22.5 and 3.2 lbs BOD₅/1,000 ft³-d; the greater effect

EFFECT OF RECIRCULATION ON NITRIFICATION IN ROCK TRICKLING FILTERS AT SALFORD, ENGLAND

BOD ₅ load lb/1000 cu ft/day (kg/m ² /day)	Influent BOD ₅ , mg/l	Influent NH ₄ ⁺ -N mg/l	Effluent NH ₄ ⁺ -N, mg/l		Percent nitrification	
			without recirculation	with recirculation	without recirculation	with recirculation
22.6 (0.36)	266	33.9	19.7	13.6	82	60
16.3 (0.26)	235	31.3	16.9	11.8	46	62
11.8 (0.19)	191	32.0	9.7	4.8	70	85
9.2 (0.15)	239	43.9	12.5 ⁽¹⁾	2.2	72	95
7.7 (0.12)	165	40.5	11.4	4.9	72	86
5.9 (0.095)	192	40.7	5.7	2.8	86	93
4.6 (0.074)	199	38.3	2.8	0.9	93	96
3.2 (0.051)	206	36.6	0.7	0.4	93	99

^aMedia was blast slag, 8 ft (2.4 m) deep. With recirculation a 1:1 ratio was employed.

(1) original table had 125 mg/L; this was assumed to be a typo and changed to 12.5.

TABLE 4-1. PERFORMANCE DATA SHOWING THE EFFECT OF RECIRCULATION ON
NH₄⁺-N REMOVAL IN A ROCK FILTER
(FROM USEPA NITROGEN CONTROL MANUAL, 1975).

on removals was apparent at higher loadings. The EPA Design Manual recommends provision for recirculation for better ammonia removals.

Parker and Richards (1986) investigated single-stage nitrification in trickling filters by comparing the data from two pilot studies. Results show that nitrification begins only when soluble BOD₅ concentrations are less than 20 mg/L. Hence, nitrifiers become established in the biofilm only in the lower portion of the tower, where the soluble BOD₅ concentrations are low enough for nitrifiers to compete against heterotrophs. Parker and Richards also reported that cross-flow plastic media were the most efficient for achieving nitrification in a single-stage system. Process interactions, like the return of untreated digester supernatant to the headworks, increase the soluble BOD₅ concentrations and will affect the single-stage nitrification process. Such return streams must be considered in design and operation. According to Parker and Richards (1986), favorable operating conditions required to achieve carbonaceous BOD removal and nitrification in a single-stage trickling filter are low organic loadings, high residence times, sufficient oxygen availability and consistency in hydraulic, organic and ammonia loadings.

SEPARATE STAGE NITRIFICATION

Most of the wastewater treatment facilities using trickling filters for nitrification are configured as two-stage systems, with intermediate clarification. In the first stage, the removal of carbonaceous BOD₅ is accomplished, followed by the second stage where nitrification is achieved.

An early study of nitrification in trickling filters was conducted by Duddles et al., (1974), which indicated the feasibility of using a plastic medium trickling filter for nitrification. In separate stage nitrification, the rate of nitrification was found to be directly related to the surface area of the media, rather than the media volume. Plastic media have high specific surface areas (27 to 68 square feet/cubic ft.), as compared to rock or slag media (13 to 20 square feet/cubic ft.) resulting in smaller volume requirements, and reducing the cost for space, structure, and distributor arms.

The USEPA's Process Design Manual for Nitrogen Control (1975) gives design curves for nitrification in plastic media trickling filters (Figures 4-1 and 4-2), showing that the efficiency of nitrification is directly related to the surface loading. Figures 4-1 and 4-2 present an empirical relationship between the desired effluent $\text{NH}_3\text{-N}$ concentration and the required surface area of media. The curves also demonstrate the temperature dependency of the nitrification process, indicating lower surface area requirements at higher temperatures. These curves are based on data collected in pilot scale studies in Midland, Michigan (Figure 4-1) and Lima, Ohio (Figure 4-2), where primary treatment and secondary treatment for carbonaceous BOD removal was followed by plastic media (corrugated vertical type) trickling filtration. Figure 4-2 shows surface reaction rates for Lima, Ohio data compared with the trend lines developed from the Midland, Michigan data.

Gullicks and Cleasby (1986) suggested that there were deficiencies in the EPA trickling filter nitrification design procedure, and that the design curves are applicable only to municipal wastewater and the conditions under which the data were generated. The accuracy of the EPA design curves was questioned and they suggested that the effects of the hydraulic loading rate and influent $\text{NH}_3\text{-N}$ concentration to the tower are not adequately addressed.

Gullicks and Cleasby (1986) proposed new design curves (Figures 4-3 and 4-4) which incorporate the effects of four critical design parameters: the hydraulic loading rate, the influent $\text{NH}_4^+\text{-N}$ concentration, the recycle rate, and the wastewater temperature. Their empirical approach is based on a flux-limited fixed film process theory, which suggests that: (1) when wastewater temperature increases, the mass transfer rate should increase due to the increase in the film diffusivities and biomass activity, and (2) when the hydraulic loading rate or the influent ammonia-nitrogen concentration increases, the mass transfer rate should increase because the concentration gradient from the liquid phase to the biofilm is increased. The proposed design curves (Figures 4-3 and 4-4) apply only to nitrification of municipal secondary effluent that has been settled before application to the trickling filter towers. The curves are based on 6.55 m of vertical-type plastic media with a specific surface area of $88.6 \text{ m}^2/\text{m}^3$. Gullicks and Cleasby recommended

SURFACE AREA REQUIREMENTS FOR NITRIFICATION - MIDLAND MICHIGAN

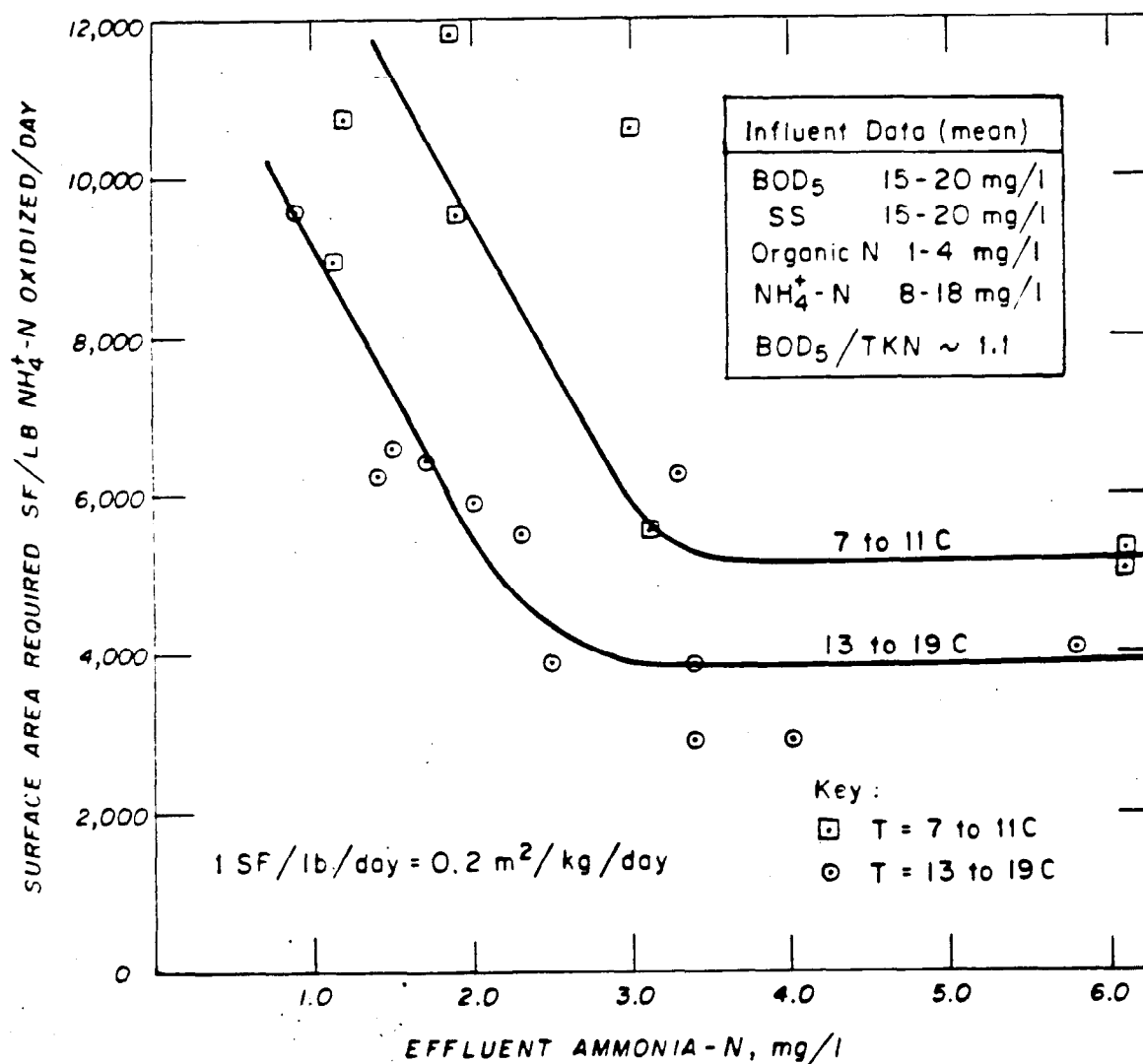


FIGURE 4-1. EPA PROCESS DESIGN CURVES, BASED ON MIDLAND, MI STUDY
(FROM USEPA NITROGEN CONTROL MANUAL, 1975).

SURFACE AREA REQUIREMENTS FOR NITRIFICATION -
LIMA, OHIO

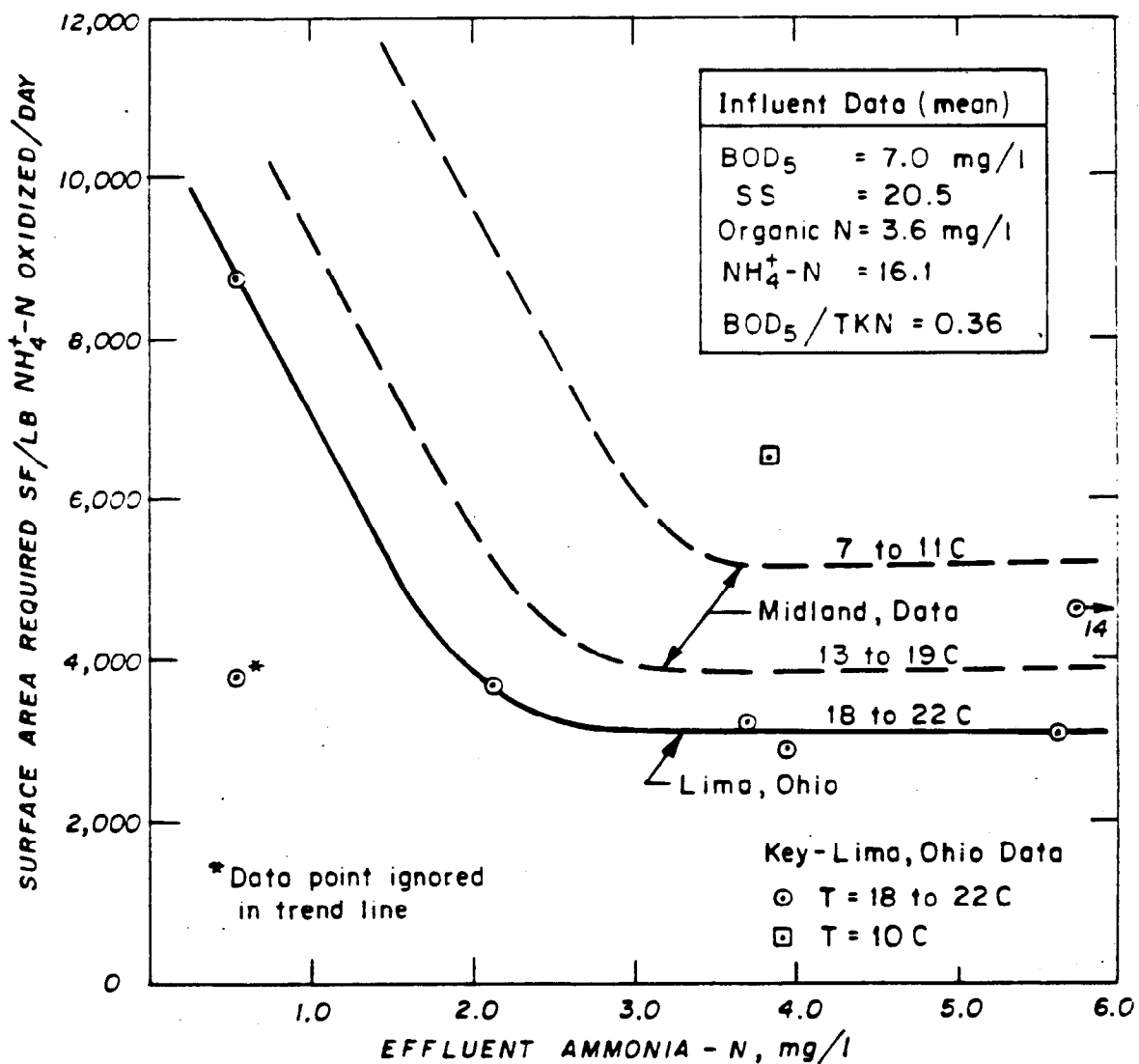
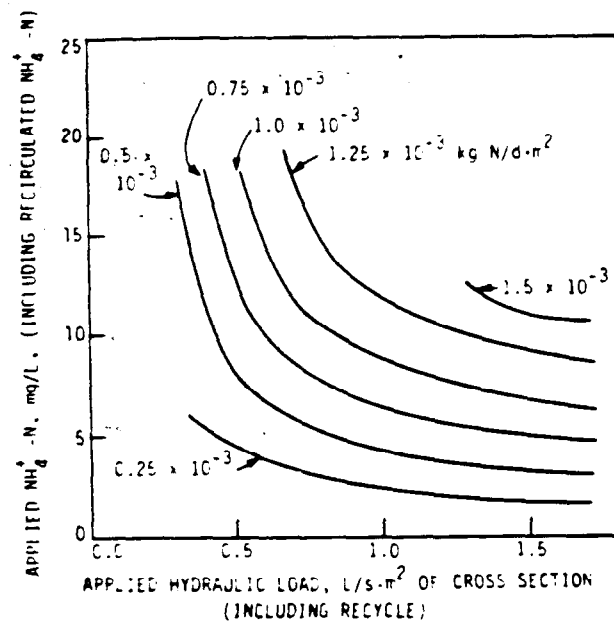
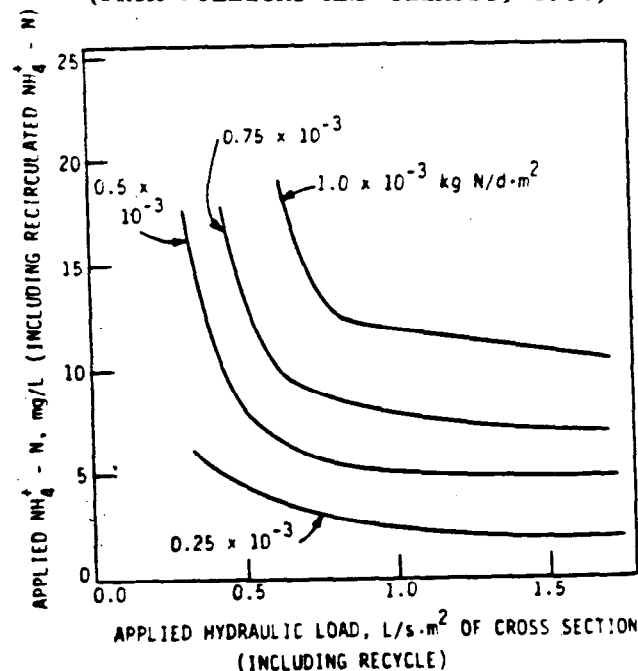


FIGURE 4-2. EPA PROCESS DESIGN CURVES, BASED ON LIMA, OH STUDY
(FROM USEPA NITROGEN CONTROL MANUAL, 1975).



Predicted NH_4^+-N removal, $\text{kg/d} \cdot \text{m}^2$ of media surface, versus applied hydraulic load and applied NH_4^+-N for nitrification of municipal secondary clarifier effluent ($\text{BOD}_5 < 30 \text{ mg/L}$ and $\text{SS} < 30 \text{ mg/L}$), wastewater temperatures $> 14^\circ\text{C}$, and 6.55 m of vertical plastic media (specific surface = $88.6 \text{ m}^2/\text{m}^3$).

FIGURE 4-3. DESIGN CURVES INCORPORATING APPLIED HYDRAULIC AND AMMONIA LOADS AT TEMPERATURES GREATER THAN 14°C (FROM GULLICKS AND CLEASBY, 1986)



Predicted NH_4^+-N removal, $\text{kg/d} \cdot \text{m}^2$ of media surface, versus applied hydraulic load and applied NH_4^+-N for nitrification of municipal secondary clarifier effluent ($\text{BOD}_5 < 30 \text{ mg/L}$ and $\text{SS} < 30 \text{ mg/L}$), wastewater temperatures $10-14^\circ\text{C}$, and 6.55 m of vertical plastic media (specific surface = $88.6 \text{ m}^2/\text{m}^3$).

FIGURE 4-4. DESIGN CURVES INCORPORATING APPLIED HYDRAULIC AND AMMONIA LOADS AT TEMPERATURES BETWEEN 10 AND 14°C (FROM GULLICKS AND CLEASBY, 1986).

that these curves should be used with caution at wastewater temperatures less than 10°C and hydraulic loading rates greater than 1.36 L/s-m² (7 gpm/ft²) of tower cross-section.

The principal difference between the design curves proposed by Gullicks and Cleasby and the EPA design curves is that the required media surface area is dictated by the loading criteria (concentration and hydraulic load) in Figures 4-3 and 4-4, whereas in the EPA curves (Figures 4-1 and 4-2) it is dictated by the effluent quality.

Table 4-2 presents ammonia removal data for rock media separate stage trickling filters (USEPA, 1975). These data show that the nitrification rates are 15 to 50 percent of those found with plastic media filters, when expressed on a volumetric loading basis. These lower rates are attributed to the lower specific surface area and shallower depths of rock media filters when compared to those using plastic media.

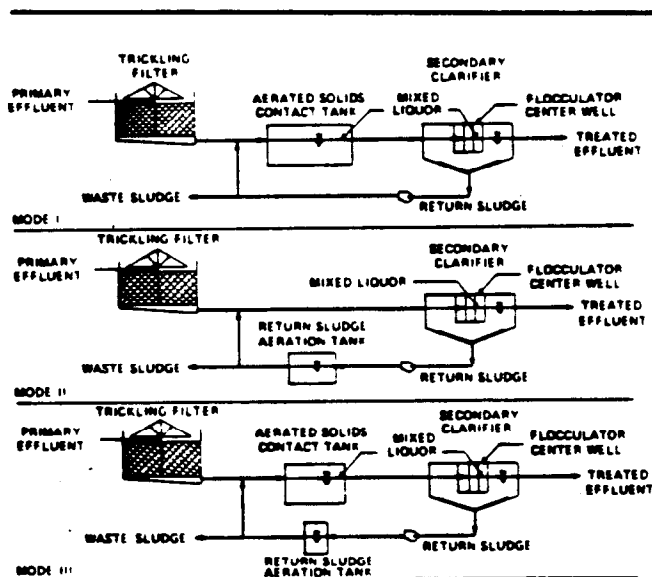
Gujer and Boller (1986) proposed a theoretical nitrification model for tertiary trickling filtration. This model emphasizes residual ammonia concentration, recirculation rates, arrangement of filters in series, alkalinity, residual nitrite concentration and temperature. Basic design information was collected during a 20 month long pilot study. Sampling was conducted with depth, allowing an estimate of actual nitrification rates at various levels within the trickling filters as a function of the respective ammonia concentration. The peak nitrification rate declined significantly with depth, apparently due to the patchy development of the biofilm at lower depths. This was caused by the absence of a continuous supply of ammonia to these lower regions of the filter. The study also showed significant temperature dependency.

Boller and Gujer (1986) reported that plastic media trickling filters following conventional mechanical-biological wastewater treatment were suited for nitrification when ammonia load fluctuations were not too high. Low solids production enabled direct discharge without the need for additional clarification. Specific media surface areas in the range of 150 to 200 m²/m³,

NITRIFICATION IN SEPARATE STAGE ROCK TRICKLING FILTERS

Facility location	Depth, ft (m)	Media	Influent		Effluent			Ammonia - N oxidized lb/1000 cu ft/day (kg/m ³ /day)
			BOD ₅ mg/l	NH ₄ -N, mg/l	BOD ₅ mg/l	NH ₄ -N, mg/l	Percent removed	
Johannesburg, S.A. (full-scale)	12 (3.7)	2-3 in. (5.1 to 7.6 cm) rock	28	23.9	14	8.3	65	3.5 (0.055)
	12 (3.7)	1.5 in. (3.8 cm) rock	32	25.2	13	4.4	83	2.2 (0.035)
	9 (2.7)	1 in. (2.5 cm) rock	23	22	10	9.1	59	2.4 (0.038)
Northampton, England (pilot-scale)	6 (1.8)	1.5 in. (3.8 cm) rock	80	33	10	11.2	66	1.0 (0.016)

TABLE 4-2. AMMONIA REMOVAL DATA ON SEPARATE STAGE ROCK TRICKLING FILTERS (FROM USEPA NITROGEN CONTROL MANUAL, 1975).



Variations of the TF/SC process.

FIGURE 4-5. ALTERNATIVE CONFIGURATIONS OF THE TRICKLING FILTER/SOLIDS CONTACT PROCESS (FROM MATASCI, et. al., 1986)

hydraulic loads higher than $2 \text{ m}^3/\text{m}^2/\text{h}$, and ammonia loads of approximately $0.4 \text{ g}/\text{m}^2/\text{d}$ were favorable conditions for full nitrification ($< 2 \text{ mg}/\text{L} \text{ NH}_3\text{-N}$) under winter conditions (water temperature, 10°C).

Parker et al., (1989), investigated the use of biofilm-control mechanisms to enhance reaction rates in separate stage nitrifying trickling filters. These included use of cross flow plastic media with higher oxygen transfer characteristics and provisions for flooding and backwashing to control predator organisms. The backwashing was also used to control the biofilm inventory, eliminating excessive sloughing and the need for subsequent clarification. The study showed a significant improvement in the reaction rates in tertiary nitrifying trickling filters; regular flooding and backwashing were successful in preventing the suppression of nitrification typically caused by filter fly larvae and other predators. Parker (1989) also concluded that properly designed and operated nitrifying trickling filters are reliable, and yield significant cost savings when compared to competitive nitrification technologies.

Okey and Albertson (1989) analyzed data from five pilot tertiary treatment facilities to study the kinetics of ammonia nitrogen oxidation under varying operating conditions. The study concluded that more than one kinetic regime existed in the nitrifying tower, corresponding to ammonia concentration. A zero order region existed when the ammonia nitrogen concentration was high and the system was oxygen limited. A first order regime for ammonia nitrogen oxidation occurred at low ammonia nitrogen concentrations. At loading rates greater than $1.2 \text{ gNH}_3\text{-N}/\text{m}^2\text{-d}$ the units periodically exhibited an oxygen deficient condition. The study recommended the use of forced ventilation for plants that are required to produce an effluent with less than $3 \text{ mg}/\text{L}$ ammonia nitrogen.

Okey and Albertson (1989) also studied temperature effects on ammonia nitrogen oxidation in nitrifying trickling filters. They indicate that changes in the nitrification reaction rates with temperature are controlled by diffusivity and external concentration and not by basic changes in the rate at

which the cell processes the substrates; this suggests that using Arrhenius-type temperature corrections for reaction rates may not be appropriate.

TRICKLING FILTER/SOLIDS CONTACT (TF/SC) PROCESS

The TF/SC process was first developed in the late 1970s to enhance the BOD₅ and suspended solids removal efficiency of an existing trickling filter facility at the City of Corvallis (Norris et al., 1982). It has since been widely applied, particularly for upgrading existing trickling filters.

The TF/SC process is biological/physical in nature and typically includes a trickling filter, an aerobic solids contact tank, flocculation and secondary clarification. Biological solids are continuously extracted from the secondary clarifier and returned to the aerated solids contact tank for contact with trickling filter effluent. Matasci et al., (1986) listed three different modes of operation for the TF/SC process (Figure 4-5).

Mode 1: The secondary clarifier sludge is returned to an aerated contact tank to mix with the trickling filter effluent. This mode is favored to enhance removal of soluble BOD and particulates.

Mode 2: The return sludge is first aerated before mixing with the TF effluent. Settling is improved, yielding lower effluent solids.

Mode 3: Both procedures are implemented. This mode is normally required when improved soluble BOD and particulate removals are required.

In a typical TF/SC process, most of the soluble BOD removal takes place in the trickling filter. The trickling filter effluent is mixed with the return sludge from the secondary clarifier in order to improve particulate BOD removal and SS reduction via enhanced flocculation. The solids contact tank is normally designed for less than one hour contact time; typical design values for solids retention time in the solids contact tank are less than two days.

Field investigations were conducted by USEPA in 1984 at Oconto Falls, Wisconsin; Tolleson, Arizona; Medford, Oregon; Chilton, Wisconsin and Morro Bay, California (USEPA, 1988). Tables 4-3 and 4-4 give information about design parameters and monthly performance data, respectively, for the Tolleson, Oconto Falls, Corvallis and Medford facilities. Tolleson had two stage trickling filtration with intermediary clarification. Corvallis and Oconto Falls had single stage filtration. Medford was originally an activated sludge plant that was converted to a TF/AS plant, with the flexibility to operate in the TF/SC mode. The performance of the Medford facility is difficult to compare with the other TF/SC plants as it has plastic media (compared to rock media at Corvallis, Oconto Falls and Tolleson), high organic loadings (115 lb/1,000 ft³ - d) and the longest solids contact time (39 minutes). Within the narrow range of organic loadings studied at the different TF/SC plants, organic loading was not found to affect final effluent quality significantly. Matasci et al., (1986) emphasized the need for reliable primary treatment; an increase in the primary effluent suspended solids was found to correlate well with an increase in final effluent suspended solids.

Keeping the secondary solids and return sludge in an aerobic condition appears to be an important factor in the successful operation of the TF/SC process. A minimum solids contact time of 12 minutes is required for reliable performance. Although the solids contact tank is primarily designed to increase solids flocculation and capture, it is also found to remove additional soluble BOD from the trickling filter effluent if longer aeration contact time is provided. At the Medford facility, a 75 percent reduction in the trickling filter effluent soluble BOD was accomplished at a solids contact time of 39 minutes.

The TF/SC process can operate over a broad range of MLSS concentration without affecting effluent quality. Other major advantages noted for the TF/SC process are relatively low capital costs, an ability to withstand high organic loadings, production of a very dense sludge, and high quality effluent. Solids retention time in the solids contact tank is less than 2 days. Although the minimum required solids retention time for nitrifying bacteria is a function of temperature, dissolved oxygen and pH (USEPA, 1975), typical minimum SRTs

Design data for operating TF/SC facilities.

	Tollason	Oconto Falls	Corvallis	Medford
Design flow, m ³ /s (mgd)				
Average dry weather flow	0.36 (8.3)	0.017 (0.38)	0.43 (9.7)	0.79 (18.0)
Peak wet weather flow	0.78 (17.7)	0.033 (0.75)	1.23 (28.0)	2.63 (60.0)
Design loading, 1000 kg/d (1000 lb/day)				
BOD	10.9 (24.0)	0.30 (0.67)	4.94 (10.9)	15.9 (35.0)
SS	9.80 (21.6)	0.36 (0.79)	5.22 (11.5)	12.7 (28.0)
Primary overflow rate, m ³ /m ² · d (gpd/sq ft)	40 (970)	15 (370)	40 (980)	42 (1030)
Trickling filter				
Media type	Plastic/rock	Rock	Rock	Plastic
BOD loading, g/m ³ · d (lb/day/1000 cu ft)	880/150 (55/9.1)	560 (35)	380 (24)	1840 (115)
TF/SC mode	1	1	3	1
Return sludge aeration time (33% return rate), minutes	—	—	9	—
Aerated solids contact time (total flow including recycle), minutes	9	8	2	— ^a
Flocculator center well				
Percent of clarifier area	13	16	12	5
Detention time (total flow including recycle), minutes	25	38	25	5
Secondary clarifier				
Overflow rate based on total clarifier area, m ³ /m ² · d (gpd/sq ft)	18 (440)	12 (300)	19 (470)	20 (480)
Sidewater depth, m (ft)	4.9 (16)	4.6 (15)	5.5 (18)	4.6 (15)
Sludge removal system	Suction header	Suction tube	Suction tube	Suction header-1 Suction tube-3
Weir location	Inboard	Inboard	Inboard	Inboard

^a Contact time at existing flow of 0.39 m³/s (8.8 mgd) plus 33% return rate is 39 minutes.

TABLE 4-3. DESIGN DATA FOR FULL-SCALE TF/SC FACILITIES
(FROM MATASCI, et. al., 1988)

Monthly average performance at operating TF/SC facilities.

Parameter	Tollason			Oconto Falls			Corvallis			Medford		
	April 1983-March 1984			April 1983-March 1984			April 1983-March 1984			April 1984-July 1984		
	High	Low	Average	High	Low	Average	High	Low	Average	High	Low	Average
Influent flow												
Average m ³ /s (mgd)	0.29 (6.7)	0.22 (5.0)	0.27 (6.1)	0.020 (0.46)	0.012 (0.28)	0.016 (0.36)	0.78 (17.9)	0.25 (5.6)	0.46 (10.5)	0.43 (9.9)	0.36 (8.2)	0.39 (8.9)
Influent characteristics												
BOD, mg/L	350	222	277	179	119	146	188	48	108	173	142	157
SS, mg/L	300	192	224	151	100	118	191	112	154	159	119	138
Temperature, °C	—	—	—	19	8	13	22	13	17	22	16	19
Primary effluent												
BOD, mg/L	373	107	173	—	—	—	114	35	70	90	76	81
SS, mg/L	400	57	121	—	—	—	82	56	66	38	29	34
TF effluent												
BOD, mg/L	42.5 ^a	10.4 ^a	22.8 ^a	—	—	—	39	22	30	81	51	66
SS, mg/L	45.9 ^a	9.9 ^a	23.6 ^a	—	—	—	72	54	59	89	39	71
Return sludge SS, g/L	—	—	—	—	—	—	17.2	5.4	11.3	—	—	—
MLSS, mg/L	1620	551	1040	—	—	—	4980	1560	3130	1870	1480	1620
Secondary effluent												
BOD, mg/L	15	4	7	32	14	21	9	5	7	23	14	19
Carbonaceous BOD, mg/L	—	—	—	—	—	—	7	4	5	11	6	8
SS, mg/L	20	4	9	23	6	13	13	7	9	9	6	8

^a Intermediate clarifier effluent

TABLE 4-4. PERFORMANCE DATA FROM FOUR FULL-SCALE TF/SC FACILITIES.
(FROM MATASCI, et. al., 1988)

reported in the literature for nitrifying bacteria are over two days. Hence, it is likely that minimal nitrification enhancement is being accomplished in the solids contact tank. Matasci et al., (1986) have also mentioned in their study that solids contact tanks are not designed for nitrification. Thus the trickling filters themselves, even if operating in a TF/SC system will still accomplish the major fraction of soluble BOD₅ reduction and nitrification.

SECTION 5.

STATUS OF TRICKLING FILTER NITRIFICATION APPLICATIONS

INTRODUCTION

A survey was conducted to identify the extent to which trickling filters are used at municipal facilities in the United States to accomplish nitrification. This was not meant to be an exhaustive search, but of sufficient coverage to assess the state-of the-art, and to determine the availability of performance data.

Information was obtained from several sources. This included a computer search, using the USEPA Permit Compliance System (PCS); however, only two trickling filter plants were identified that were required to practice nitrification. Other sources included USEPA regional and/or State offices; consultants/engineering firms having expertise in this area; and treatment plants cited in the literature. The design and performance data for the plants were obtained directly from the facility operators.

SUMMARY OF TRICKLING FILTER PLANTS

Twenty-seven trickling filter plants that are accomplishing some degree of nitrification were identified. Each is described in Appendix A. Seven are located in Ohio; four in Indiana; three each in California, Pennsylvania and Texas, and one each in Alabama, Colorado, Illinois, Iowa, Nevada, New Jersey and New York.

The types of plants are summarized in Table 5-1. A total of ten plants are practicing single-stage nitrification. Of these, six have the solids contact modification to enhance particulate BOD removal. Seventeen plants have separate stage nitrification, six of which use an activated sludge or stabilization pond in conjunction with the trickling filter.

TABLE 5-1. SUMMARY OF PLANT OPERATIONS

<u>Mode of Operation</u>	<u>Number of Plants</u>	<u>Plant Location</u>
Single-stage nitrifying trickling filter	4	Palm Springs, California; Amherst, Ohio; Chemung County, New York; New Providence, New Jersey
Single-stage trickling filter with solids contact modification	6	Wauconda, Illinois; Ashland, Ohio; Buckeye Lake, Ohio; Wauseon, Ohio; East Montgomery County, Ohio; Pickerington, Ohio
Separate-stage trickling filter (with intermediate clarification)	11	Bremen, Indiana; Kendallville, Indiana; Rochester, Indiana; Allentown, Pennsylvania; Reading, Pennsylvania; Cibolo Creek, Texas (three plants); Ozark, Alabama; Boulder, Colorado; Laport, Indiana
Trickling filter in series with activated sludge process (two-stage)	6	Cedar Rapids, Iowa; Stockton, California; Sunnyvale, California; Reno, Nevada; Youngstown, Ohio; Landsdale, Pennsylvania

Relevant information regarding the plant configuration, wastewater characteristics and current performance are summarized in Table 5-2. Design flows range as high as 42.0 mgd with most plants between 50 and 100 percent of their design capacity. The majority of plants use plastic media. Twelve are exclusively plastic, while there is one slag media plant (Palm Springs) and two rock media plants. The rest have combinations of rock and plastic media filters. Depths of the rock filters range between 4 and 10 feet. The plastic media filters are generally deep, typically between 20 and 40 feet. Shallower filters with plastic media are typically retrofits of old rock filters.

Trickling filters are generally designed with effluent recycle capabilities to maintain stable hydraulic loadings during normal diurnal variations. The Wauconda and Amherst plants do not practice recirculation, while a recirculation ratio of 1:1 is maintained at Palm Springs, Bremen and New Providence. A high ratio of 6:1 is used at Ozark to control solids buildup.

TABLE 5-2. SUMMARY OF DESCRIPTION OF TRICKLING FILTERS PRACTICING NITRIFICATION

Plant Location	Flow (mgd)		Treatment Process	Arrangement	Trickling Filter					Permit Requirement		Current Effluent	
	Design	Present			Number of Units	Media Type	Media Depth (feet)	Diameter (feet)	Recir- culation Ratio	BOD	NH ₃	BOD	NH ₃
										SS (mg/l)	(mg/l)	SS (mg/l)	(mg/l)
Palm Springs, California	10.9	7.53	Single stage trickling filter	4 filters in parallel	4	Slag	9.5	140	1:1	30 30	-	7 9	0.5
Stockton, California	42.0	28.0	Single stage trickling filter followed by oxidation pond.	3 trickling filter and 3 biotowers in parallel	3 3	Rock Plastic	4 22	150 150	*	30 10	-	25 10	17
Wauconda, Illinois	1.4	0.7	Single stage trickling filter followed by solids contact process.	2 trickling filters in parallel	2	Plastic	28	50	None	10 12	1.4(summer) 4(winter)	<10 <5	<0.1
Bremen, Indiana	1.3	1.1	Two stage trickling filter and biotower combination.	1st stage: 2 biotowers in parallel 2nd stage: 1 trickling filter	2 1	Plastic Rock	32 6	35.5 60	0.8:1 None	10 10	6(summer) 9(winter)	<10 <10	<2.7
Kendallville, Indiana	2.68	1.4	Two stage trickling filter and biotower combination.	1st stage: 3 trickling filters in parallel 2nd stage: 1 biotower	2 1	Rock Plastic	5.5 6.5	80 80	* *	15 15	2	10 5	<1
Laporte, Indiana	7.0	3.0	Two stage trickling filter and biotower combination.	1st stage: 2 trickling filters in parallel 2nd stage: 2 biotowers in parallel	1 1 2	Limestone Synthetic Pack Synthetic Pack	6 6 20	178x125 116 70	* * *	30 30	2(summer) 4(winter)	8 12	2.5
Rochester, Indiana	1.65	0.8	Three stage trickling filter and biotower combination.	1st stage: 1 trickling filter 2nd stage: 1 trickling filter 3rd stage: 1 biotower	1 1 1	Rock Rock Plastic	6 6 18	80 80 80	* * *	25 30	6(summer) 12(winter)	12 21	0.6
Cedar Rapids, Iowa	42.0	35.0	Single stage trickling filter followed by activated sludge process.	4 trickling filters in parallel.	4	Plastic	24	140	*	30 30	7.5	5 17	0.5
Chemung County, New York	*	3.8	Two trickling filters without intermediate clarifier	2 trickling filters in series.	2	Rock	6	135	3:1	25 30	-	10	5.4

TABLE 5-2. SUMMARY DESCRIPTION OF TRICKLING FILTER PLANTS PRACTICING NITRIFICATION
(Continued)

Plant Location	Flow (mgd)		Treatment Process	Trickling Filter						Permit Requirement		Current Effluent	
	Design	Present		Arrangement	Number of Units	Media Type	Media Depth (feet)	Diameter (feet)	Recirculation Ratio	BOD	NH ₃	BOD	NH ₃
										SS (mg/l)	(mg/l)	SS (mg/l)	(mg/l)
Amherst, Ohio	2.0	2.03	Two trickling filters without intermediate clarifier	2 trickling filters in series.	2	Plastic	17	40x90	None	10 12	3(summer) 6(winter)	<10 <10	1.7(summer) 3 (winter)
Youngstown, Ohio	35.0	30.0	Single stage trickling filter followed by activated sludge.	4 trickling filters in parallel.	4	Plastic	16	100	*	12 20	3(summer) 15(winter)	5 10	0.31
Ashland, Ohio	5.0	2.96	Single stage biotowers with solids contact process.	2 biotowers in parallel	2	Plastic	30	80	not measured	10 10	2 (summer) 11(winter)	6 7	1.5
Pickerington, Ohio	0.58	0.5	Single stage trickling filter with solids contact process.	1 trickling filter	1	Plastic	27	50	*	10 12	1.5(summer) 4.0(winter)	<2 <6	0.11
Buckeye Lake, Ohio	1.1	0.85	Single stage trickling filter with solids contact process.	2 trickling filters in parallel.	2	Plastic	42	45	*	15 20	3(summer only)	2 5	0.3
Wauseon, Ohio	1.5	0.9	Single stage trickling filter with solids contact process.	2 trickling filters in parallel.	2	Plastic	14	75	*	15 17	1.5(summer) 4.0(winter)	<10 <15	5
Allentown, Pennsylvania	40.0	32.87	Two stage trickling filter	1st stage: 4 trickling filters in parallel	4	Plastic	32	100	None	30 30	3(summer) 9(winter)	12 11	4.7 (summer) 5.9 (winter)
				2nd stage: 1 trickling filter	1	Rock	8	8 acres	0.2:1				
Landsdale, Pennsylvania	2.5	2.4	Activated sludge process followed by single stage trickling filter.	2 trickling filters in parallel	2	Plastic	20	65	*	22 30	1.9(summer) 5.7(winter)	<5 <5	0
Reading, Pennsylvania	*	20.0	3 stage trickling filter	1st stage: 2 trickling filters in series	2	Rock		212	*	30 30	5(summer) 15(winter)	30 20	3.5
				2nd stage: 2 trickling filters in parallel	2	Rock		212	*				
				3rd stage: 1 trickling filter	1	Rock		154	*				

TABLE 5-2. SUMMARY DESCRIPTION OF TRICKLING FILTER PLANTS PRACTICING NITRIFICATION
(Continued)

[illegible]

Plant Location	Flow (mgd)		Treatment Process	Trickling Filter						Permit Requirement		Current Effluent	
	Design	Present		Arrangement	Number of Units	Media Type	Media Depth (feet)	Diameter (feet)	Recirculation Ratio	BOD	NH ₃	BOD	NH ₃
										SS (mg/l)	(mg/l)	SS (mg/l)	(mg/l)
Reno, Nevada	*		Single stage trickling filter with solid contact										

*Design information and/or operating data were not available

Recirculation rates at the Cibolo Creek plants range between 2.4 and 6.0. At several plants, although recirculation is practiced, measurements are not taken of the recycle rate, and estimates of the recirculation ratio cannot be made.

None of the plants are experiencing problems with meeting permit requirements for BOD₅, suspended solids, and ammonia removal (if required), particularly during warmer temperature seasons. Problems have been noted at LaPorte, Bremen, and Ashland with ammonia removal during cold temperature periods.

Performance data availability was limited. Several plants practicing separate stage nitrification had no intermediate data, while others were only recently started and had a small data base. Ten plants were identified that had sufficient data to evaluate their performance. These included five plants with separate stage nitrification, for which the first stage performance data were available. As assessment of the facilities' performance data is presented in the next section.

SECTION 6.

EVALUATION OF SELECTED PLANT PERFORMANCE DATA

INTRODUCTION

Of the twenty-seven facilities that were identified as trickling filter plants accomplishing nitrification, ten were selected for further evaluation. These had sufficient data for analysis, which were made available by the individual plant operators:

1. Palm Springs, California
2. Amherst, Ohio
3. Chemung County, New York
4. Wauconda, Illinois
5. Ashland, Ohio
6. Bremen, Indiana
7. Allentown, Pennsylvania
- 8-10. Cibolo Creek, Texas (three parallel plants)

Each is described in Appendix A. Summaries of the performance data are provided in Appendix B. These data have been further reduced and summarized in Table 6-1. Please note that the figures presented in Table 6-1 and Appendix B may not always match with the figures presented in Table 5-2 and Appendix A because different sampling locations and different sets of data may have been used. The following discussions present an assessment of the plants, and then evaluate in general the use of trickling filters for nitrification.

ASSESSMENT OF SELECTED TRICKLING FILTER PLANTS

Palm Springs, California

The Palm Springs, California wastewater treatment plant utilizes a single-stage slag media trickling filter system. The facility is comprised of bar

TABLE 6-1. SUMMARY OF PERFORMANCE DATA FOR SELECTED TRICKLING FILTER PLANTS

<u>Facility:</u>	Palm Springs, California	Amherst, Ohio	Chemung County, New York	Ashland, Ohio		
<u>Description:</u>		Two Plastic Media Filters in Series (No Inter. Clar.) (Single Stage)	Two Rock Filters in Series (No intermediate Clarifier) (Single Stage)	Single stage, Plastic media filters (with Solids Contact)		
	Single Stage, Slag Media					
<u>Influent</u>	<u>T >17°C</u>	<u>T >17°C</u>	<u>T <16°C</u>	<u>T <16°C</u>	<u>T >17°C</u>	<u>T <16°C</u>
BOD (mg/L)	101	62.0	67.1	55.6	104.	85.7
NH ₃ -N (mg/L)	20	14.7	13.0	11.3	15.5	13.0
Temperature (°C)	23-28	17-20	8-15	11-16	17-22	13.16
Flow (mgd)	7.73	1.86	2.12	5.82	2.7	3.3
<u>Permit^a</u>						
NH ₃ -N	None	3	6	None	2	11
BOD (mg/L)	30	10	10	25	10	10
<u>Effluent</u>						
NH ₃ -N (mg/L)	2.61	1.7	3.0	5.4	3.5	3.6
BOD (mg/L)	7.43	7.5	7.6	10.8	6.	5.8
<u>BOD Loading</u>						
(lbs BOD/1,000 ft ³ -d)	11.11	7.3	9.0	15.69	7.6	8.6
(lbs/BOD/1,000 ft ² -d) ^b	0.55	0.24	0.3	0.78	0.253	0.285
<u>NH₃-N Loading</u>						
(lbs NH ₃ -N/1,000 ft ³ -d)	2.15	1.8	1.8	3.2	1.14	1.17
(lbs NH ₃ -N/1,000 ft ² -d) ^b	0.107	0.057	0.058	0.16	0.038	0.039
<u>Hydraulic Loading</u>						
(gpd/ft ²) ^c	125.	517	589	407	267.	327

TABLE 6-1. SUMMARY OF PERFORMANCE DATA FOR SELECTED TRICKLING FILTER PLANTS
(Continued)

<u>Facility:</u> <u>Description:</u>	Wauconda, Illinois		Bremen, Indiana				Allentown, Pennsylvania			
	Single stage plastic media filter (with solids contact)		Two stage system				Two stage system			
			First Stage		Second Stage		First Stage		Second Stage	
			Plastic Media		Rock Media		Plastic Media		Rock Media	
<u>Influent</u>	<u>T >17°C</u>	<u>T <16°C</u>	<u>T >17°C</u>	<u>T <16°C</u>	<u>T >17°C</u>	<u>T <16°C</u>	<u>T >17°C</u>	<u>T <16°C</u>	<u>T >17°C</u>	<u>T <16°C</u>
BOD (mg/L)	127.	107.	40.4	43.6	10.6	15.2	122	118	50	73
NH ₃ -N (mg/L)	17.4	13.6	8.8	10.7	1.1	2.7	13.1	14.2	10.0	11.4
Temperature (°C)	17-21	11-16	17-18	10-14	17-18	10-14	17-19	11-16	17-19	11-16
Flow (mgd)	0.61	0.76	1.1	1.1	-	-	34.5	32.1	-	-
<u>Permit^a</u>										
NH ₃ -N	1.4	4.	-	-	6	9	-	-	3	9
BOD (mg/L)	10	10	-	-	10	10	-	-	30	30
<u>Effluent</u>										
NH ₃ -N (mg/L)	0.67	1.26	1.12	2.72	0.8	2.1	10.0	11.4	4.7	5.9
BOD (mg/L)	10	13	10.6	15.2	3.1	5.2	50	73.1	12.	12.4
<u>BOD Loading</u>										
(lbs BOD/1,000 ft ³ -d)	11.73	12.28	5.7	6.33	5.7	8.2	74.3	71.8	6.9	10.0
(lbs/BOD/1,000 ft ² -d) ^b	0.391	0.409	0.16	0.18	0.28	0.41	2.5	2.4	0.343	0.5
<u>NH₃-N Loading</u>										
(lbs NH ₃ -N/1,000 ft ³ -d)	1.6	1.56	1.24	1.53	0.65	1.5	8.0	8.6	1.4	1.5
(lbs NH ₃ -N/1,000 ft ² -d) ^b	0.048	0.046	0.036	0.044	0.033	0.074	0.266	0.288	0.07	0.075
<u>Hydraulic Loading</u>										
(gpd/ft ²) ^c	312	386	548	555	384	389	2193	2043	132	123

TABLE 6-1. SUMMARY OF PERFORMANCE DATA FOR SELECTED TRICKLING FILTER PLANTS
(Continued)

<u>Facility:</u> <u>Description:</u>	Cibolo Creek, Texas (Three Parallel Two-Stage Systems)					
	Plant A		Plant B		Plant C	
	First Stage Plastic Media	Second Stage Plastic Media	First Stage Plastic Media	Second Stage Plastic Media	First Stage Plastic Media	Second Stage Plastic Media
<u>Influent</u>	<u>T >17°C</u>	<u>T >17°C</u>	<u>T >17°C</u>	<u>T >17°C</u>	<u>T >17°C</u>	<u>T >17°C</u>
BOD (mg/L)	78.9	25.6	67.1	18.6	85.8	16.9
NH ₃ -N (mg/L)	20.5	10.5	17.6	5.7	21.0	5.6
Temperature (°C)	20-27	20-27	20-27	20-27	20-27	20-27
Flow (mgd)	0.64	-	0.35	-	1.23	-
<u>Permit^a</u>						
NH ₃ -N	-	4-6	-	4-6	-	4-6
BOD (mg/L)	-	10	-	10	-	10
<u>Effluent</u>						
NH ₃ -N (mg/L)	10.5	2.8	5.7	0.52	5.6	0.5
BOD (mg/L)	25.6	6.6	18.6	5.8	16.9	3.6
<u>BOD Loading</u>						
(lbs BOD/1,000 ft ³ -d)	22.4	8.2	11.8	3.3	10.5	2.7
(lbs/BOD/1,000 ft ² -d) ^a	0.7	0.14	0.37	0.154	0.28	0.07
<u>NH₃-N Loading</u>						
(lbs NH ₃ -N/1,000 ft ³ -d)	5.8	3.4	3.1	1.0	2.5	0.6
(lbs NH ₃ -N/1,000 ft ² -d) ^b	0.18	0.053	0.097	0.015	0.068	0.016
<u>Hydraulic Loading</u>						
(gpd/ft ²) ^c	271	271	147	147	233	233

^a30 day average
^bmedia surface area
^cfilter cross-sectional area

screening, an aerated grit chamber, primary clarification, four 140 foot diameter, 9.5 feet deep trickling filters, secondary clarification, sludge thickening and anaerobic digestion. The secondary effluent is disposed either to percolation ponds for groundwater recharge or to tertiary treatment for irrigation use.

The BOD to the trickling filters was estimated to average 101 mg/L in 1989 (see Table B-1 for summary of monthly performance data), with an average ammonia concentration of 20 mg/L. Note that these reflect an assumed 35 percent BOD₅ removal through the primary clarifiers. The flow was 7.73 mgd, approximately 70 percent of its design capacity. Temperatures are moderate year-round, ranging between 23 to 28°C in 1989.

The secondary plant is required to meet an effluent BOD of 30 mg/L or less (30-day mean), but does not have an ammonia limit. The monthly average effluent BOD₅ ranged between 3.4 and 15 mg/L, with a mean of 7.4 mg/L. Ammonia nitrogen ranged between 0.27 and 10.6 mg/L, with an annual mean of 2.61 mg/L. The loadings to the plant are consistent with nitrification design; the BOD and ammonia loadings are 11.1 and 2.15 lbs/1,000 ft³-d, respectively, on a volumetric basis, and 0.55 and 0.107 lbs/1,000 ft²-d, respectively, on a media surface area basis. The hydraulic loading rate is relatively low at 125 gpd/ft² of filter surface area. The plant maintains a recirculation ratio of 1:1.

Overall the Palm Springs secondary filter generates a consistent quality effluent, accomplishing high levels of ammonia removal. Although not required to nitrify, the loadings imposed on the system are consistent with those generally imposed for ammonia removal.

Amherst, Ohio

The Amherst, Ohio treatment plant is comprised of screening, grit removal, primary clarification, trickling filtration, secondary clarification and chlorine disinfection. There are two trickling filters placed in series without intermediate clarification. As such, the units are considered

equivalent to a single-stage system. The filters are each 40 feet wide, 90 feet long and 17 feet deep, with plastic cross-flow media

Currently, the plant is operating at an average flow of approximately 2 mgd (1.856 mgd winter, 2.12 mgd summer), equivalent to its design capacity. The plant is required to meet an effluent ammonia-nitrogen limit of 6 mg/L in the winter and 3 mg/L during the summer months. The BOD limit year-round is 10 mg/L. The BOD and $\text{NH}_3\text{-N}$ levels to the trickling filters are estimated for 1989 to have averaged approximately 65 and 14 mg/L, respectively. (See Table B-3; note that a 35 percent removal was assumed for BOD_5 through the primary clarifiers.) Temperatures for October through May ranged between 8 and 15°C, while the summer month temperatures ranged between 17 and 20°C.

The Amherst plant has consistently met ammonia removal requirements at loadings generally associated with nitrification design practices. Lower temperatures will cause lower removal rates. The average effluent ammonia concentration at temperatures greater than 17°C was 1.7 mg $\text{NH}_3\text{-N/L}$, while this increased to 3.0 mg/L at temperatures between 8 and 15°C. BOD_5 in the effluent averaged approximately 7.5 mg/L. Loadings were relatively low. The BOD and ammonia loadings were 7.29 to 8.96 lbs $\text{BOD}/1,000 \text{ ft}^3\text{-d}$ and 1.7 lbs $\text{NH}_3\text{-N}/1,000 \text{ ft}^3\text{-d}$, respectively. When expressed on a media surface area basis, these were 0.242 to 0.3 lbs $\text{BOD}_5/1,000 \text{ ft}^2\text{-d}$ and 0.05 lbs $\text{NH}_3\text{-N}/1,000 \text{ ft}^2\text{-d}$, respectively. Hydraulic loadings were 517 to 589 gpd per ft^2 of filter area.

Chemung County, New York

The Chemung County wastewater treatment plant is in its first year of operation. Operating data (See Table B-2) are for the months November 1989 through April 1990, with a temperature range of 11 to 16°C. The treatment works include comminution, screening, grit removal, primary clarification, trickling filtration, secondary clarification, post aeration and disinfection. There are two trickling filters in series without intermediate clarification (as such, they are considered a single-stage system). They have rock media, are 135 feet in diameter, and are 6 feet deep.

The average flow to the plant was 5.8 mgd. The monthly average BOD₅ to the trickling filters ranged between 42 and 88 mg/L and the ammonia-nitrogen ranged between 6.5 and 13.0 mg/L. The plant is required to meet an effluent BOD₅ for 25 mg/L; there is no ammonia requirement. Loadings to the plant's trickling filters are somewhat higher than the preceding plants. The BOD₅ loading was 13.7 lbs/1,000 ft³-d and 0.676 lbs/1,000 ft²-d; the ammonia loading was 3.17 lbs/1,000 ft³-d and 0.159 lbs/1,000 ft²-d. The average hydraulic loading was approximately 407 gpd/ft² of filter area. The plant is meeting its BOD limit, with monthly averages ranging between 8 and 14 mg/L (mean of 10.8 mg/L). The equivalent effluent ammonia levels ranged between 3.0 and 7.3 mg/L, with a mean of 5.4 mg/L.

Wauconda, Illinois

The Wauconda wastewater treatment plant consists of aerated grit removal, comminution, primary clarification, trickling filtration, aerated solids contact/flocculation, sand filters and chlorine disinfection. The single-stage trickling filter plant has two plastic media, 50 feet diameter, 28 feet deep, filters in parallel. The media surface area is 30 ft²/ft³.

The average flow to the plant (See Tables B-4A and B-4B for 1987 and 1988 performance data) has been approximately 0.7 mgd, or 50 percent of its design capacity. Cold month temperatures ranged between 11 and 16°C, with a range of 17 to 21°C during the warmer months. The BOD₅ in the primary effluent (monthly averages) ranged between 76 and 188 mg/L, with a mean of approximately 115 mg/L. The ammonia-nitrogen levels ranged between 12.4 and 17.6 mg/L. The plant is required to meet an effluent ammonia-nitrogen limit of 4 mg/L in the winter and 1.4 mg/L in the summer. The BOD₅ limit is 10 mg/L year-round.

BOD₅ loadings were approximately 12 lbs/1,000 ft³-d and 0.4 lbs/1,000 ft²-d; equivalent ammonia-nitrogen loadings were 1.6 N/1,000 ft³-d and 0.04 lbs N/1,000 ft²-d. The hydraulic loading had a mean level of approximately 355 gpd/ft². Overall the plant is generating a high quality effluent, consistent with the relatively low loadings to the plant. The mean effluent ammonia was

0.67 mg/L at temperatures greater than 17°C, and 1.26 mg/L at temperatures less than 16°C.

Ashland, Ohio

The Ashland, Ohio facility has an average design flow of 5.0 mgd, and is currently averaging approximately 3.0 mgd. It is a single-stage trickling filter plant with a solids-contact modification. Unit operations consist of screening, preaeration, grit removal, primary clarification, two biotowers in parallel, a solids contact tank, final clarification and UV disinfection. The plant is required to meet an ammonia-nitrogen limit of 2 mg/L in the summer and 11 mg/L in the winter. A BOD limit of 10 mg/L is imposed year-round. Both biotowers have plastic cross-flow media. Each is 80 feet in diameter and 30 feet deep. The media surface area is 30 ft²/ft³. Recirculation is practiced, but the rates are not measured.

The BOD₅ of the trickling filter influent (See Table B-5; the BOD₅ levels reflect a 35 percent removal through the primary system) ranged between 70 and 123 mg/L, with the higher levels during the warmer temperature months (17 to 22°C). The mean flow for the colder months (13 to 16°C) was higher (3.3 mgd) than that of the warmer months (2.7 mgd). Ammonia levels were similar in variability, ranging between 8.5 and 20 mg N/L on a monthly average basis.

Loadings were very consistent for the one year period. The BOD and ammonia loadings were 7.6 and 1.1 lbs/1,000 ft³-d, respectively, on a volumetric basis and 0.253 and 0.285 lbs/1,000 ft²-d on a surface area basis. The hydraulic loadings averaged 267 gpd/ft² during the warmer months and 327 gpd/ft² during the colder months.

The plant is meeting its effluent requirements. The BOD₅ in the effluent (including the solids-contact process) was less than 10 mg/L. The effluent ammonia-nitrogen levels are somewhat anomolous (See Table B-5) with high levels in the October through December period (average 8.6 mg N/L), and 4.6 mg/L in January. Levels were consistently lower in the April through September period preceding this and February and March afterward. Overall, one would expect

lower levels of ammonia throughout the year, given the lower loading to the system.

Bremen, Indiana

The Bremen, Indiana wastewater treatment plant is a two-stage trickling filter process. Unit operations consist of screening and comminution, grit removal, primary clarification, two parallel biotowers, intermediate clarification, a second-stage rock media filter, secondary clarification, sand filtration and chlorine disinfection. The first-stage biotowers are each 35.3 feet in diameter, and 32 feet deep, with plastic media ($34 \text{ ft}^2/\text{ft}^3$). The second-stage rock filter is 60 feet in diameter and 6 feet deep. Recirculation is practiced in the first stage (0.8:1). There is no recirculation in the second stage.

Data are available for all of 1989; these can be found (monthly averages) in Table B-6. A temperature range of 10 to 14°C was observed November through May, while it ranged from 17 to 19°C during the remaining months. Primary effluent BOD₅ was low, ranging between 24 and 60 mg/L, with a mean of approximately 42 mg/L. The ammonia-nitrogen averaged approximately 9.8 mg/L for the year. The plant effluent permit includes limits of 10 mg/L BOD₅, and 6 and 9 mg/L NH₃-N for summer and winter conditions, respectively. The design flow is 1.3 mgd; the current flow is averaging 1.1 mgd.

Loadings to the first-stage are relatively low, because of the lower incoming concentrations. The BOD load is approximately 6 lbs/1,000 ft³-d and 0.17 lbs/1,000 ft²-d; equivalent ammonia-nitrogen loadings are 1.4 lbs/1,000 ft³-d and 0.04 lbs/1,000 ft²-d. The hydraulic loading is approximately 552 gpd/ft² of reactor area. The effluent BOD₅ and NH₃-N levels were 10.6 and 1.12 mg/L, respectively, during the warmer months. These increase to 2.72 and 15.2 mg/L during the colder months.

Loadings to the second-stage rock filter were not greatly different than the first stage loading due to differences in volume and media surface area (See Table 6-1). Further reductions were accomplished during the summer months

when the BOD₅ and NH₃-N averaged 3.1 and 0.8 mg/L; these increased to 5.2 and 2.1 mg/L during the colder months. In all, the plant was consistently in compliance with its discharge permit requirements for BOD₅ and ammonia.

Allentown, Pennsylvania

The Allentown plant is a two-stage trickling filter plant designed for an average flow of 40 mgd. The facility is required to meet effluent ammonia-nitrogen limits of 3 and 9 mg/L during warm and cold temperature periods, respectively. The effluent BOD₅ limit is 30 mg/L. Data are available for 1989 (Table B-7) including intermediate ammonia-nitrogen and BOD₅ concentrations.

The unit operations include screening, grit removal, primary clarification, trickling filters (first stage), intermediate clarification, trickling filters (second stage), clarification and chlorine disinfection. The first stage has four plastic media trickling filters in parallel, each 100 feet in diameter and 32 feet deep. The second stage is a single large rock filter, 8 feet deep and covering an area of approximately 8 acres. Normally 2 of the first-stage filters and 75 of the second stage filter are in service. Recycle is practiced only on the second stage, with a target ratio of 0.2:1.

The current average flow to the plant is approximately 32.87 mgd. The warmer months temperature ranged between 17 and 19°C; the cold temperature averaged 11 to 16°C. The first-stage influent (primary effluent) averages monthly BOD₅ and NH₃-N levels between 100 and 137 mg/L, and 8.5 to 16.1 mg/L, respectively.

First-stage loadings are high, more typical of roughing filters. The BOD₅ loading averaged 66.36 lbs/1,000 ft³-d and 2.21 lbs/1,000 ft²-d for the year. Equivalent ammonia-nitrogen loadings were 6.7 lbs/1,000 ft³-d and 0.22 lbs/1,000 ft²-d. The hydraulic loading averaged 2,093 gpd/ft² of reactor area. The effluent BOD₅ averaged 50 mg/L at the warmer temperatures and 73.1 mg/L during the colder period. Ammonia-nitrogen levels in the first stage effluent were 10.0 and 11.4 mg/L for these periods, respectively.

The second-stage loadings at Allentown were more in line with those shown for the preceding plants, consistent with design loadings for nitrifying plants. The BOD₅ loading averaged 8.5 lbs/1,000 ft³-d and 0.44 lbs/1,000 ft²-d for the year. The average ammonia-nitrogen loads for the year were 1.4 lbs/1,000 ft³-d and 0.07 lbs/1,000 ft²-d. The hydraulic loading averaged 126 gpd/ft² of reactor area. The average monthly effluent BOD₅ was consistent through the year, ranging between 6 and 18, with an average 12.3 mg/L. The ammonia-nitrogen averaged 4.7 during the higher temperature months and 5.9 during the colder temperature months.

Cibolo Creek, Texas

Cibolo Creek operates three parallel treatment plants. All are two-stage trickling filter systems required to meet a BOD₅ limit of 10 mg/L. Ammonia limits are 6 mg N/L if the flow (total of three plants) is less than 4 mgd, and 4 mg N/L at flows greater than 4 mgd. The design flow is 6.2 mgd, which is split to the three plants (A, 29 percent; B, 16 percent; C, 55 percent). The current average total flow is approximately 2.2 mgd (0.64 mgd to A; 0.35 mgd to B; 1.23 mgd to C). Temperatures are moderate year-round, ranging between 20 and 27°C.

Unit operations at the three plants consist of primary clarification, first stage trickling filter, intermediate clarification, second stage trickling filter, secondary clarification, sand filter and chlorine disinfection.

The data available from the plants are summarized in Tables B-8, B-9 and B-10. These are from 12 sampling events encompassing a total period of 18 months (May 1988 through November 1989). The average BOD₅ levels in the primary clarifier effluent ranged between 67 and 86 mg/L; average ammonia-nitrogen levels ranged between 17 and 21 mg/L.

All of the trickling filters reactors utilize plastic media. The first-stage filters for Plants A and B are 8 feet and 7 feet deep, respectively, and 55 feet in diameter. The medium surface area for both is 32 ft²/ft³. The

second stages are each 7 feet deep, 55 feet in diameter and use media with a surface area of $64 \text{ ft}^2/\text{ft}^3$. The first-stage of Plant C is 82 feet in diameter and 16 feet deep, while the second-stage has a diameter of 82 feet and a depth of 12 feet. The packing in both units is comprised of alternative layers of vertical ($27 \text{ ft}^2/\text{ft}^3$) and cross-flow ($48 \text{ ft}^2/\text{ft}^3$) plastic media.

Loadings to each plant differ to a degree. First-stage average BOD_5 loadings ranged from $10.5 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$ on Plant C to $22.4 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$ for Plant A. Similarly the average ammonia-nitrogen loadings ranged from $2.5 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$ for Plant C to $5.8 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$ for Plant A. The ranges were similar when expressed on a surface loading basis (See Table 6-1). Average hydraulic loadings were from $147 \text{ gpd}/\text{ft}^2$ to $271 \text{ gpd}/\text{ft}^2$ of reactor area. Effluent BOD_5 and $\text{NH}_3\text{-N}$ level were consistent with the loadings. The BOD_5 was 16.9 and 18.6 mgd for Plants C and B, respectively, and 25.6 mg/L for the higher loaded Plant A. Similarly the first stage effluent $\text{NH}_3\text{-N}$ was 5.6 and 5.7 mg/L for Plants C and B, respectively, and 10.5 for Plant A.

Second-stage loadings for BOD_5 and $\text{NH}_3\text{-N}$ to the three plants showed the same variation as discussed for the first stage; ranging from low to Plant C and highest to Plant A. On a volumetric basis, the average BOD loading to C was $2.7 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$, increasing in B and A to $4.2 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$ and $8.2 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$, respectively. Comparable ammonia-nitrogen loadings were 0.93, 1.3 and $3.4 \text{ lbs}/1,000 \text{ ft}^3\text{-d}$ to Plants C, B and A, respectively. Again the average effluent BOD_5 and $\text{NH}_3\text{-N}$ levels reflect these loadings. The average effluent BOD was 3.6, 5.8 and 6.6 mg/L for Plants C, B and A, respectively. The average effluent $\text{NH}_3\text{-N}$ levels were 0.5, 0.52 and 2.8 mg/L, respectively.

ASSESSMENT OF SYSTEM PERFORMANCE CHARACTERISTICS

The data that were received from various plants, as presented in Table 6-1 and Appendix B, were reviewed as a whole, assessing the general operational characteristics for accomplishing nitrification. These analyses must necessarily be of a general nature, given the limits of the data and the narrow range of operating conditions experienced by the individual plants.

Figure 6-1 presents the ratio of the ammonia-nitrogen removal to the BOD₅ removal as a function of the BOD removal rate. These are averages for the same periods delineated in Table 6-1. As would be expected, the ratio decreases with increasing BOD removal rates, shifting to a process dominated by carbonaceous BOD removal with ammonia-nitrogen removal limited to that required for cell growth. If a nitrogen requirement for active systems is assumed to be 0.8 to 0.12, then the Allentown first stage, Bremen first stage and Ashland plants are considered carbonaceous removal processes with marginal ammonia removal activity outside that needed for cell growth,. The remaining units show higher ratios (in particular the second-stage units for Bremen, Cibolo Creek and Amherst), indicating nitrification activity. The transitional BOD removal rate appears to be in the range of 0.2 to 0.4 lbs BOD₅/d-1,000 ft².

The effluent ammonia-nitrogen concentrations are compared to the equivalent period effluent BOD₅ levels accomplished by the systems on Figure 6-2. This suggests that ammonia levels less than 2 to 4 mg/L NH₃-N will be reached when the effluent BOD₅ concentration is at levels less than 15 mg/L and preferably less than 10 mg/L

Figures 6-3 and 6-4 present the average effluent BOD concentration as a function of the BOD loadings to the trickling filters. These loadings are expressed on the basis of the media surface area (Figure 6-3) and the reactor volume (Figure 6-4). In both cases there is considerable scatter. Additionally, there is no apparent significant difference due to temperature effects. The data on Figure 6-3 suggest that surface area loadings should be less than approximately 0.3 lbs BOD/1,000 ft²-d for effective BOD removal. Equivalent BOD volumetric loadings are less than 10 lbs/1,000 ft³-d to accomplish effluent BOD₅ levels less than 10 to 15 mg/L.

A similar analysis is shown on Figures 6-5 and 6-6. Figure 6-5 presents the effluent ammonia-nitrogen concentration as a function of the media surface area BOD loadings. The variability is somewhat high, but the data indicate a surface area loading less than 0.25 to 0.30 lbs/1,000 ft²-d is needed in order to yield effluent ammonia levels less than 2 to 4 mg/L. When the BOD loading is expressed on a volumetric basis (Figure 6-6), the variability is reduced.

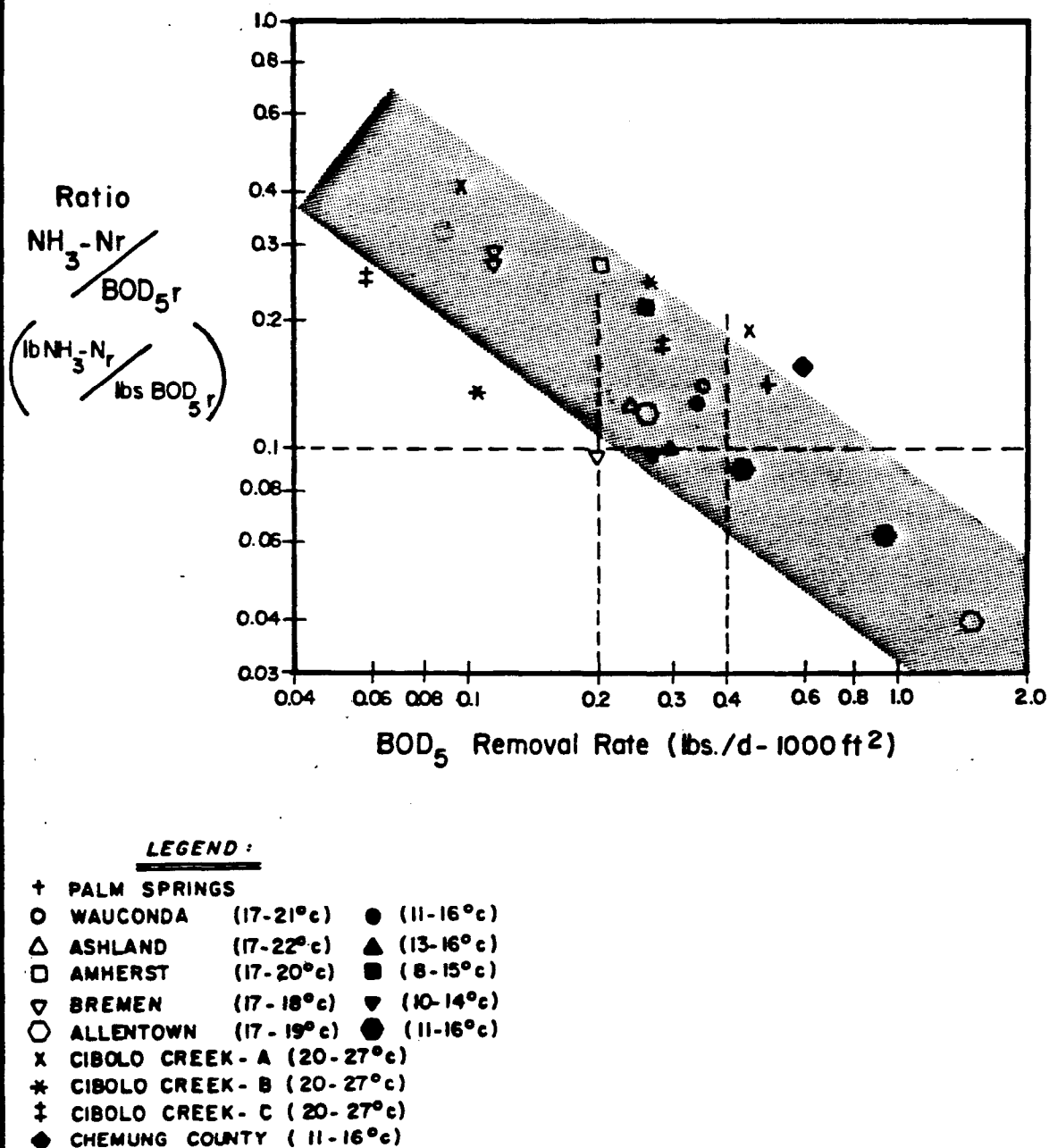


FIGURE 6-1.

RATIO OF $\text{NH}_3\text{-N}$ REMOVED TO BOD_5 REMOVED AS A FUNCTION OF THE BOD REMOVAL RATE

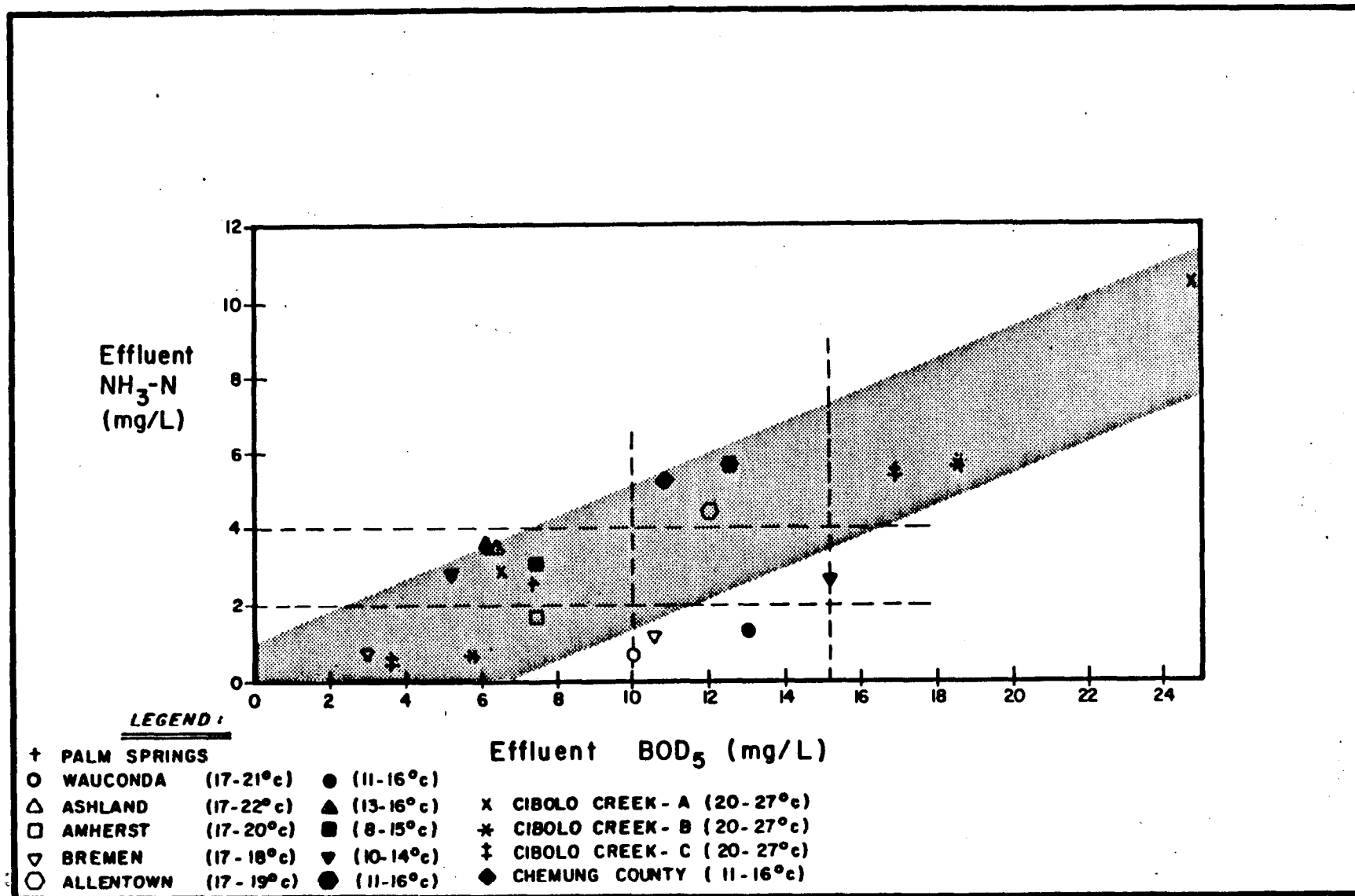
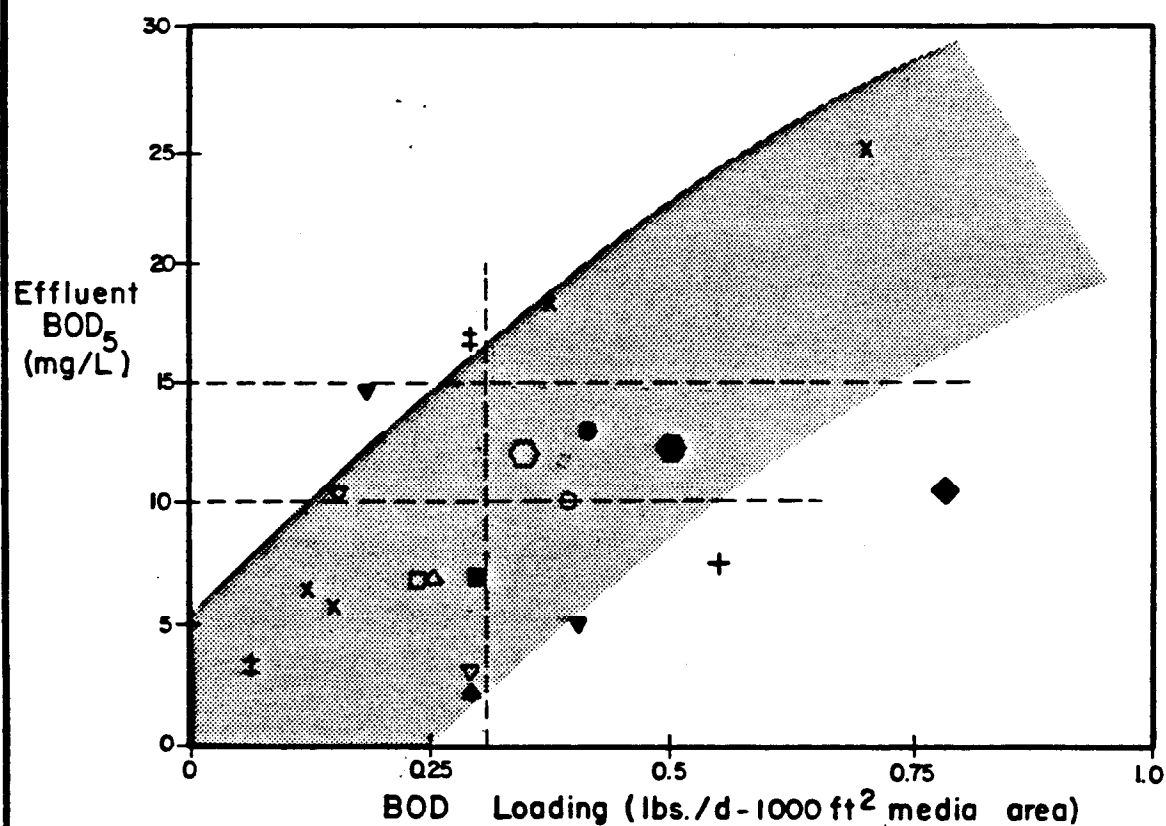


FIGURE 6-2.

EFFLUENT $\text{NH}_3\text{-N}$ LEVELS COMPARED TO EQUIVALENT BOD_5 EFFLUENT LEVELS



LEGEND :

- + PALM SPRINGS
- WAUCONDA (17-21°C) ● (11-16°C)
- △ ASHLAND (17-22°C) ▲ (13-16°C)
- AMHERST (17-20°C) ■ (8-15°C)
- ▽ BREMEN (17-18°C) ▼ (10-14°C)
- ALLENTOWN (17-19°C) ● (11-16°C)
- x CIBOLO CREEK - A (20-27°C)
- * CIBOLO CREEK - B (20-27°C)
- ‡ CIBOLO CREEK - C (20-27°C)
- ◆ CHEMUNG COUNTY (11-16°C)

FIGURE 6-3.

EFFLUENT BOD₅ CONCENTRATION AS A FUNCTION OF THE MEDIA AREA BOD LOADING

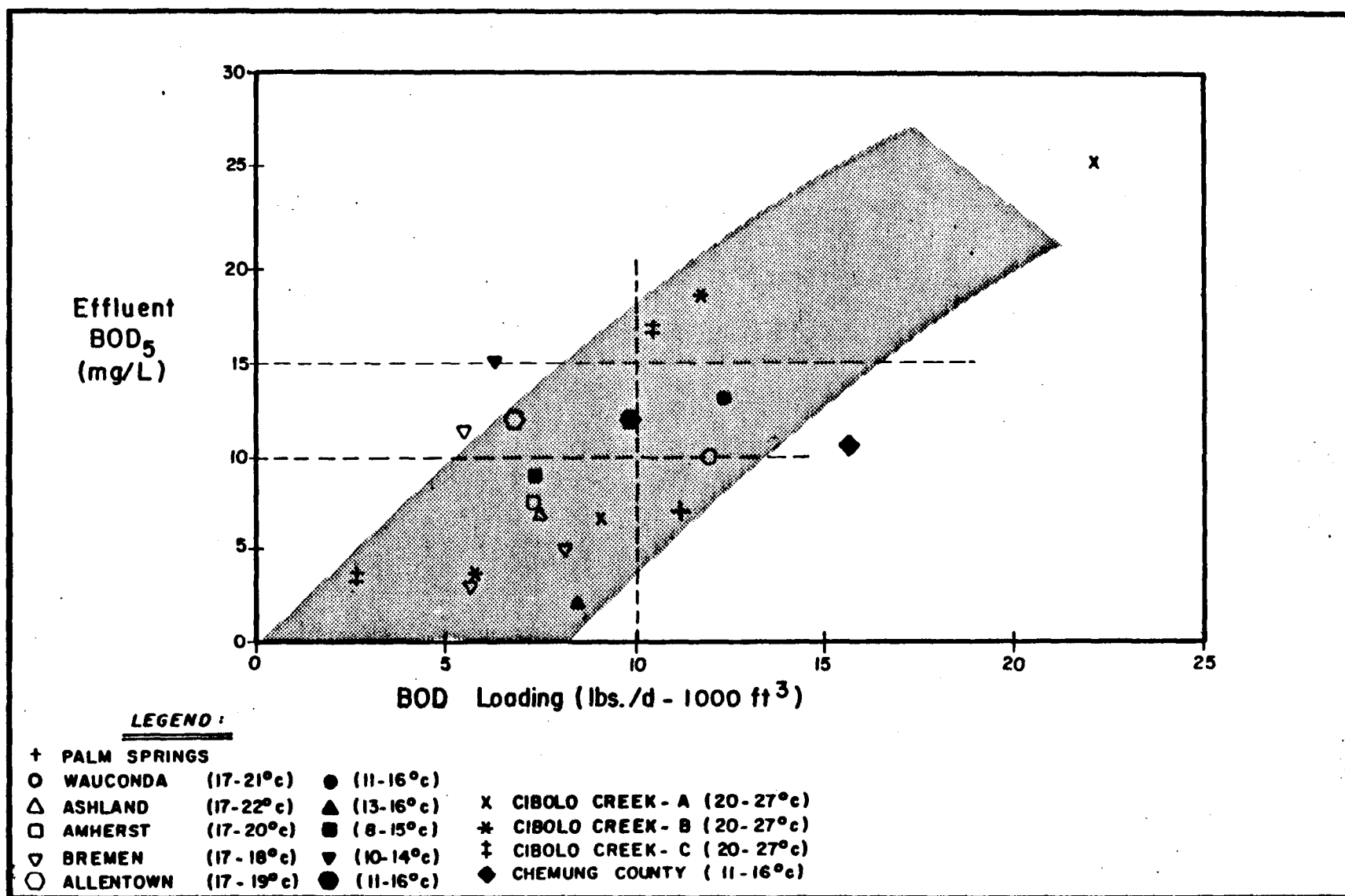
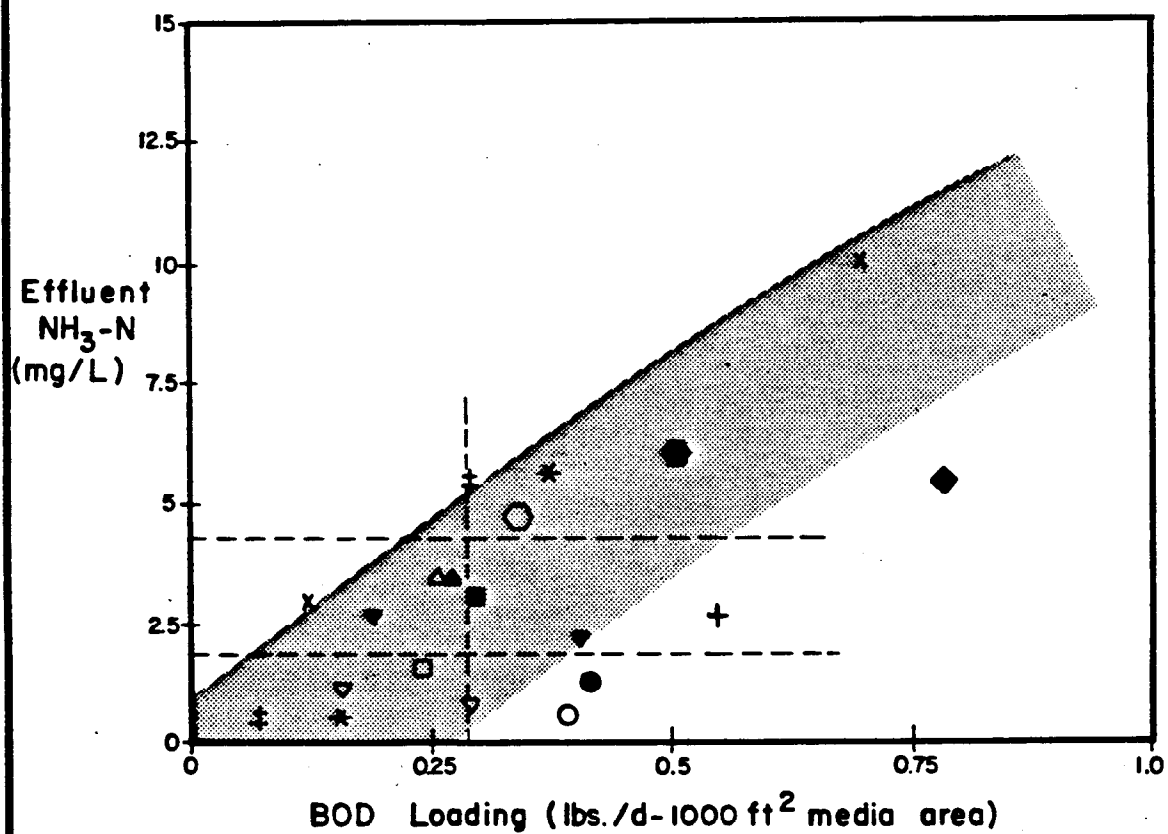


FIGURE 6-4.

EFFLUENT BOD₅ CONCENTRATION AS A FUNCTION OF THE VOLUMETRIC BOD LOADING



LEGEND:

- † PALM SPRINGS
- WAUCONDA (17-21°C) ● (11-16°C)
- △ ASHLAND (17-22°C) ▲ (13-16°C)
- AMHERST (17-20°C) ■ (8-15°C)
- ▽ BREMEN (17-18°C) ▼ (10-14°C)
- ALLENTOWN (17-19°C) ● (11-16°C)
- x CIBOLO CREEK - A (20-27°C)
- * CIBOLO CREEK - B (20-27°C)
- † CIBOLO CREEK - C (20-27°C)
- ◆ CHEMUNG COUNTY (11-16°C)

FIGURE 6-5.

EFFLUENT AMMONIA-NITROGEN CONCENTRATION AS A FUNCTION OF BOD MEDIA SURFACE LOADING

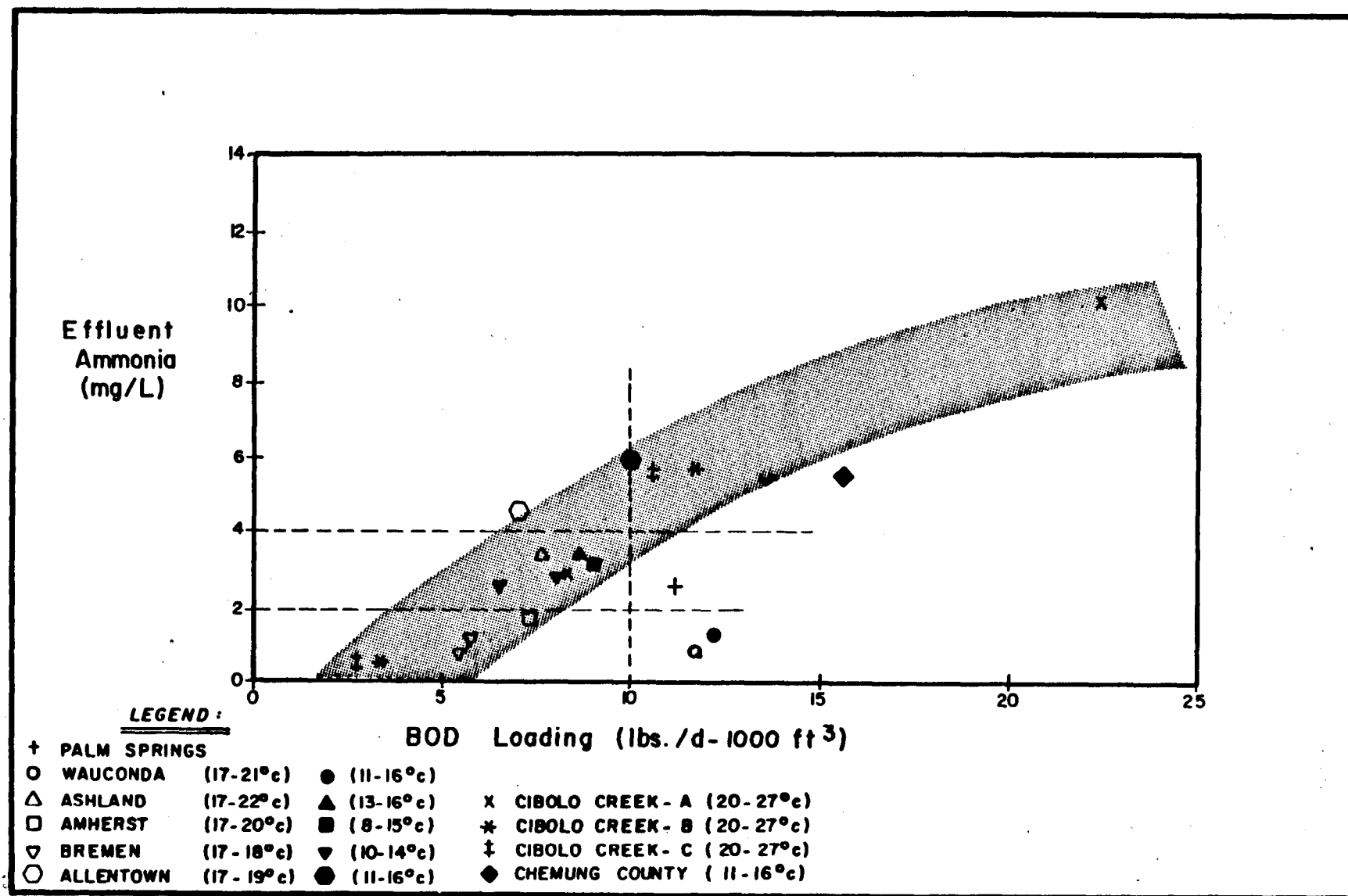


FIGURE 6-6.

EFFLUENT AMMONIA-NITROGEN CONCENTRATION AS A FUNCTION OF BOD VOLUMETRIC LOADING

This also shows that the BOD loadings need to be less than 10 lbs/1,000 ft³ for effective ammonia removal.

These loadings conform to those suggested by the USEPA Process Manual for Nitrogen Control (1975), which recommends an organic loading of 10 to 12 lbs BOD₅/1,000 ft³-d for nitrification in a single-stage trickling filter. On an areal basis, the USEPA design loadings are 0.1 to 0.3 lbs/1,000 ft²-d, depending on temperature and effluent targets (see Figures 4-1 and 4-2). These compare favorably to the loadings suggested on Figure 6-5.

The effect of hydraulic loading is shown on Figure 6-7, which presents the effluent ammonia level as a function of the hydraulic loading (gallons per day per ft² of reactor cross-sectional area), including recycle. Most plants practice recycle; and it is recommended by the EPA (1975) at a rate of approximately 100 percent Q for adequate media wetting.

The Wauconda plant is the lowest hydraulically loaded plant and does not practice recycle. Amherst does not recycle, but has a relatively high hydraulic loading of 500 to 600 gpd/ft². Ammonia levels in this case range between 1.5 and 3.5 mg/L, with applied ammonia levels similar to Wauconda. The Cibolo Creek plants all practice recirculation at relatively high rates, with the lowest ammonia levels accomplished through the second stage. Hydraulic loadings in these plants range from 1,000 to 1,600 gpd/ft².

Overall, recirculation is beneficial to trickling filter performance lowering the applied concentrations, assuring uniform surface wetting (particularly in the lower depths) and helping to control filter flies and predators. There is no clear indication of optimum rates from the data in Figure 6-7, although ratios in the order of 1 to 3 would appear to be adequate.

A review of the plant data on the basis of hydraulic loading and applied ammonia-nitrogen concentrations do not compare favorably with the design figures proposed by Gullicks and Cleasby (1986) (Figures 4-3 and 4-4). The removals (lbs NH₃-N/1,000 ft²-d) observed at the plants are typically 20 to 50 percent of the removals that would be suggested from Figures 4-3 and 4-4, for similar conditions. In all cases, the applied hydraulic loadings were at the

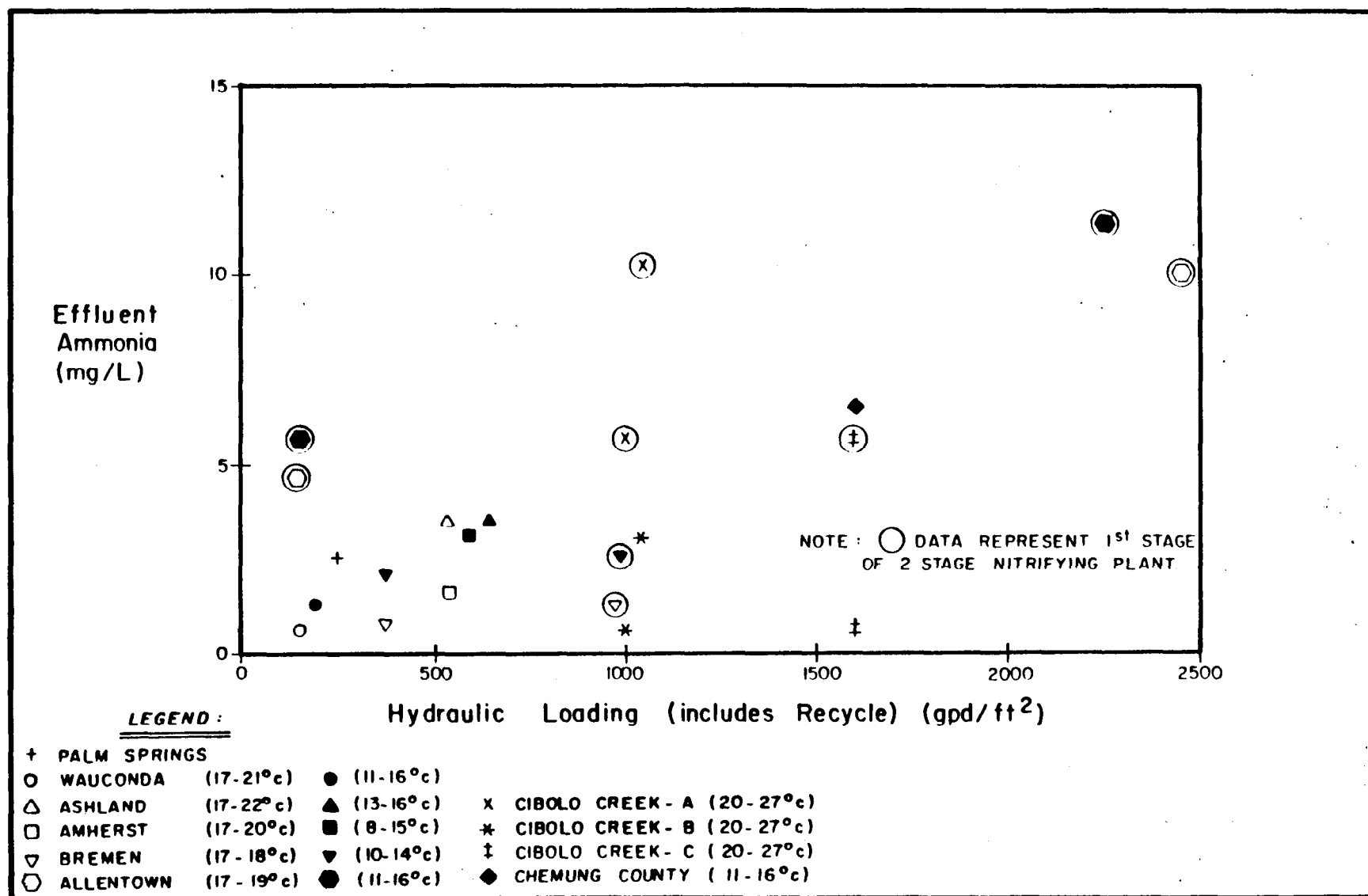


FIGURE 6-7.

EFFLUENT AMMONIA LEVELS AS A FUNCTION OF HYDRAULIC LOADING

low end of the curves (400 to 1,200 gpd/ft², or 0.2 to 0.6 L/S-m²), or below it (less than 400 gpd/ft or 0.2 L/S m²).

SECTION 7.

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APPENDIX A

SUMMARY DESCRIPTION OF NITRIFYING TRICKLING FILTER PLANTS

- 1. KENDALLVILLE, INDIANA**
- 2. AMHERST, OHIO**
- 3. YOUNGSTOWN, OHIO**
- 4. ALLENTOWN, PENNSYLVANIA**
- 5. ROCHESTER, INDIANA**
- 6. ASHLAND, OHIO**
- 7. PICKERINGTON, OHIO**
- 8. LANDSDALE, PENNSYLVANIA**
- 9. WAUSEON, OHIO**
- 10. BUCKEYE LAKE, OHIO**
- 11. CEDAR RAPIDS, IOWA**
- 12. STOCKTON, CALIFORNIA**
- 13. WAUCONDA, ILLINOIS**
- 14. CIBOLO CREEK, TEXAS**
- 15. PALM SPRINGS, CALIFORNIA**
- 16. BREMEN, INDIANA**
- 17. CHEMUNG COUNTY, NEW YORK**
- 18. READING, PENNSYLVANIA**
- 19. LAPORTE, INDIANA**
- 20. BOULDER, COLORADO**
- 21. SUNNYVALE, CALIFORNIA**
- 22. RENO, NEVADA**
- 23. EAST MONTGOMERY COUNTY, OHIO**
- 24. OZARK, ALABAMA**
- 25. NEW PROVIDENCE, NEW JERSEY**

APPENDIX A

1. KENDALLVILLE, INDIANA

Contact: Rick McGee
Phone: (219) 347-1362
Treatment Process: Two stage trickling filter - biotower combination.

Wastewater treatment works include comminutors, preaerated grit chambers, primary clarification, three trickling filters in parallel, secondary clarification and a biotower.

Comments:

Nitrification is reported to be taking place in the second stage biotower. Sampling is done on the influent and final effluent. Some data is available for first stage effluent.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	2.68
Design Peak Daily Flow, mgd:	6.0
Current Average Daily Flow, mgd:	1.4
Current Peak Daily Flow, mgd:	2.2
2. Influent Characteristics,

BOD ₅ , mg/L:	300-400
Suspended Solids, mg/L:	160-180
Ammonia Nitrogen, mg/L:	7-9
3. Effluent Characteristics,

BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	5
Ammonia Nitrogen, mg/L:	< 1
4. Permit Requirements,

BOD ₅ , mg/L:	15
Suspended Solids, mg/L:	15
Ammonia Nitrogen, mg/L:	2
5. Frequency of Sampling: Daily, Composite
6. Trickling Filters

Number of Units:	3 (2 Rock Media, 1 Plastic Media)
Series/Parallel:	Parallel
Diameter of Each Filter, Feet:	80
Depth of Rock Filter, Feet:	5.5
Depth of Plastic Filter, Feet:	6.5

7. Biotower

Number of Units:	1
Diameter, Feet:	80
Depth, Feet:	24
Media Type:	Plastic, Dense Cross Flow

2. AMHERST, OHIO

Contact:	Danny Damyan
Phone:	(216) 988-4920
Treatment Process:	Two trickling filters in series without intermediate clarifier.

Wastewater treatment works include screen, preaerated grit chamber, primary clarification, two trickling filters in series, final clarification and chlorination:

Comments:

Nitrification is reported to be affected during very cold temperatures. Data is available for influent and effluent ammonia levels. Frequency of sampling is three times a week.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	2
Design Peak Daily Flow, mgd:	4
Current Average Daily Flow, mgd:	2.03
Current Peak Daily Flow, mgd:	2.25

2. Influent Characteristics,

BOD ₅ , mg/L:	100
Suspended Solids, mg/L:	150
Ammonia Nitrogen, mg/L:	13.68

3. Effluent Characteristics,

BOD ₅ , mg/L:	< 10
Suspended Solids, mg/L:	6-8
Ammonia Nitrogen, mg/L:	3 (Winter)
	1.7 (Summer)

4. Permit Requirements,

BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	12
Ammonia Nitrogen, mg/L:	3 (Summer, max 7 Day Average)
	6 (Winter, max 7 Day Average)

5. Frequency of Sampling

Not known

6. Trickling Filters

Number of Units:	2
Series/Parallel:	Series
Intermediate Clarifier:	No
Size of Each Unit, ft ² :	40 x 90 (Rectangular)
Depth, Feet:	17
Media Type:	Plastic, Cross Flow

3. YOUNGSTOWN, OHIO

Contact: Larry Gurlea
 Phone: (216) 742-8820
 Treatment Process: Single-stage trickling filter with activated sludge process.

Wastewater treatment works include bar screen, two grit chambers, primary clarification, four trickling filters in parallel, activated sludge process, secondary clarification, microscreen, cascade aeration and chlorine contact tank.

Comments:

Most of the nitrification is reported in the trickling filter. Composite samples for ammonia are taken daily. Effluent ammonia levels are temperature dependent.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	35
Design Peak Daily Flow, mgd:	90
Current Average Daily Flow, mgd:	20-30
Current Peak Daily Flow, mgd:	60-65

2. Influent Characteristics,

BOD ₅ , mg/L:	115
Suspended Solids, mg/L:	250
Ammonia Nitrogen, mg/L:	8-10

3. Effluent Characteristics,

BOD ₅ , mg/L:	3-5
Suspended Solids, mg/L:	5-10
Ammonia Nitrogen, mg/L:	0.31

4. Permit Requirements,

BOD ₅ , mg/L:	12 (summer), 25 (winter)
Suspended Solids, mg/L:	20 (summer), 30 (winter)
Ammonia Nitrogen, mg/L:	3 (summer), 15 (winter)

5. Frequency of Sampling: Once/Day (Composite)

6. Trickling Filters

Number of Units:	4
Series/Parallel:	Parallel
Diameter of Each Filter, Feet:	100
Depth of Each Filter, Feet:	16
Media Type	Plastic, Cross Flow

4. ALLENTOWN, PENNSYLVANIA

Contact: Peter Schwenzer
 Phone: (215) 437-7682
 Treatment Process: Two - stage trickling filter.

Wastewater treatment works include bar screen aerated grit chamber, 4 primary settling tanks (usually 3 in operation), 4 high rate trickling filters in parallel, intermediate clarification, second stage trickling filters, final clarification and chlorination.

Comments:

Data is available for raw influent, primary clarifier effluent, intermediate clarifier effluent and final effluent.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	40
Design Peak Daily Flow, mgd:	-
Current Average Daily Flow, mgd:	32.87
Current Peak Daily Flow, mgd:	78

2. Influent Characteristics,

BOD ₅ , mg/L:	261
Suspended Solids, mg/L:	190
Ammonia Nitrogen, mg/L:	17

3. Effluent Characteristics,

BOD ₅ , mg/L:	12
Suspended Solids, mg/L:	11
Ammonia Nitrogen, mg/L:	4.7-5.9

4. Permit Requirements,

BOD ₅ , mg/L:	30
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	3 (summer), 9 (winter)

5. Frequency of Sampling: Once/day, (Composite)

6. Trickling Filters

Number of Stages:	Two
Number of Units in First Stage:	4
Series/Parallel:	Parallel
Diameter of Each Unit, Feet:	100
Depth of Each Unit, Feet:	32
Media Type:	Plastic, Vertical
Number of Units in Second Stage:	1
Size of the Unit, Area, ft ² :	348492
Depth of the Unit, Feet:	8
Media Type:	Rock

5. ROCHESTER, INDIANA

Contact:	Herb Corn
Phone:	(219) 223-3485
Treatment Process:	Three - stage trickling filter/biotower combination.

Wastewater treatment works include comminutor, 2 primary clarifiers, 1 first stage trickling filter, 3 first stage clarifiers, 1 second stage trickling filter, 2 second stage clarifiers, 1 biotower, final clarifier, and chlorination.

Comments:

Effluent ammonia is consistently less than 1 mg/L.

Salient Features:

- Wastewater Flows,

Design Average Daily Flow, mgd:	1.65
Design Peak Daily Flow, mgd:	2.48
Current Average Daily Flow, mgd:	0.8 to 0.93
Current Peak Daily Flow, mgd:	1.5
- Influent Characteristics,

BOD ₅ , mg/L:	340-1,000
Suspended Solids, mg/L:	220-380
Ammonia Nitrogen, mg/L:	22
- Effluent Characteristics,

BOD ₅ , mg/L:	12
Suspended Solids, mg/L:	21
Ammonia Nitrogen, mg/L:	0.6
- Permit Requirements,

CBOD ₅ , mg/L:	25
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	6 (summer), 12 (winter)

6. Trickling Filter/biotower:

Number of Stages:	3
Number of Units in Each Stage:	1

First Stage:

Type of Unit:	Trickling Filter
Diameter, Feet:	80
Depth, Feet:	6
Media Type:	Rock

Second Stage:

Type of Unit:	Trickling Filter
Diameter, Feet:	80
Depth, Feet:	6
Media Type:	Rock

Third Stage:

Type of Unit:	Biotower
Diameter, Feet:	80
Depth, Feet:	18
Media Type:	Plastic, 60°C Crossflow, 42 ft ² /ft ³

6. ASHLAND, OHIO

Contact:	Bob Sweinheart
Phone:	(419) 281-7041
Treatment Process:	Single - Stage trickling filter with solids contact process.

Wastewater treatment works include screen, preaeration, grit chamber, primary clarifier, two biotowers in parallel, solids contact tank, final clarifier and UV disinfection.

Comments:

Plant data shows very good nitrification efficiency during summer and fall. Nitrification efficiency is affected during the winter months.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	5
Design Peak Daily Flow, mgd:	10
Current Average Daily Flow, mgd:	2.96
Current Peak Daily Flow, mgd:	4.5

2. Influent Characteristics,

BOD ₅ , mg/L:	146
Suspended Solids, mg/L:	185
Ammonia Nitrogen, mg/L:	14.2

3. Effluent Characteristics,	
BOD ₅ , mg/L:	6
Suspended Solids, mg/L:	7
Ammonia Nitrogen, mg/L:	1-2
4. Permit Requirements,	
BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	10
Ammonia Nitrogen, mg/L:	2, 30 days avg. (summer)
	11, 30 days avg. (winter)
5. Frequency of Sampling:	3 times/week (composite)
6. Trickling Filters	
Number of Units:	2
Series/Parallel:	Parallel
Diameter of Each Filter, Feet:	80
Depth of Each Filter, Feet:	30
Media Type:	Plastic, Crossflow

7. PICKERINGTON, OHIO

Contact: Jerry Styler
 Phone: (614) 837-6470
 Treatment Process: Trickling filter with aeration tank.

Wastewater treatment works include screen, grit removal, one trickling filter, two aeration tanks, two solids contact clarifiers with flocculation zone, chlorination and dechlorination.

Comments:

Samples for ammonia are taken once a month as per permit requirement. Data on ammonia nitrogen is available for influent and final effluent.

Salient Features:

1. Wastewater Flows,	
Design Average Daily Flow, mgd:	0.58
Design Peak Daily Flow, mgd:	2.03
Current Average Daily Flow, mgd:	0.5
Current Peak Daily Flow, mgd:	1.6
2. Influent Characteristics,	
BOD ₅ , mg/L:	200
Suspended Solids, mg/L:	200
Ammonia Nitrogen, mg/L:	18
3. Effluent Characteristics,	
CBOD ₅ , mg/L:	< 2
Suspended Solids, mg/L:	6
Ammonia Nitrogen, mg/L:	0.11

4. Permit Requirements,	
BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	12
Ammonia Nitrogen, mg/L:	1.5 (summer), 4.0 (winter)
5. Frequency of Sampling:	Once/Month (Composite)
6. Trickling Filters	
Number of Units:	1
Depth of Each Filter, Feet:	27
Media Type:	Plastic Crossflow (60R)

8. LANDSDALE, PENNSYLVANIA

Contact: Dan Shinski
 Phone: (215) 361-8362
 Treatment Process: Activated sludge process with nitrification tower and denitrification basin.

Wastewater treatment works include bar screen, comminutor, aerated grit chamber, equalization basin, activated sludge process, secondary settling, two trickling filters in parallel, final clarifier, denitrification basin and chlorination.

Comments:

Most of the nitrification takes place in the first stage activated sludge process. Cold weather appears to affect nitrification. Composite samples for ammonia are taken three times a week.

Salient Features:

1. Wastewater Flows,	
Design Average Daily Flow, mgd:	2.5
Design Peak Daily Flow, mgd:	4.0
Current Average Daily Flow, mgd:	2.4
Current Peak Daily Flow, mgd:	4.0
2. Influent Characteristics,	
BOD ₅ , mg/L:	100
Suspended Solids, mg/L:	125
Ammonia Nitrogen, mg/L:	15
3. Effluent Characteristics,	
BOD ₅ , mg/L:	< 5
Suspended Solids, mg/L:	< 5
Ammonia Nitrogen, mg/L:	0
4. Permit Requirements,	
CBOD ₅ , mg/L:	22 (winter), 11 (summer)
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	1.9 (summer), 5.7 (winter)

5. Frequency of Sampling: 3 Times/Week (Composite)

6. Trickling Filters

Number of Units:	2
Series/Parallel:	Parallel
Diameter of Each Filter, Feet:	65
Depth of Each Filter, Feet:	20
Media Type:	Plastic, vertical

9. WAUSEON, OHIO

Contact: Leon Smith
 Phone: (419) 335-3026
 Treatment Process: Single - stage trickling filter with solids contact process.

Wastewater treatment works include bar screen, aerate grit channel, two primary clarifiers, two trickling filters in parallel, two solids contact aeration channels, two flocculating final clarifiers, chlorination and dechlorination.

Comments:

Detention time in the solids contact process is approximately one hour. Most of the nitrification takes place in the trickling filter. Grab samples for ammonia nitrogen are taken three times a week.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	1.5
Design Peak Daily Flow, mgd:	-
Current Average Daily Flow, mgd:	0.9
Current Peak Daily Flow, mgd:	3
2. Influent Characteristics,

BOD ₅ , mg/L:	150
Suspended Solids, mg/L:	215
Ammonia Nitrogen, mg/L:	18
3. Effluent Characteristics,

BOD ₅ , mg/L:	< 10
Suspended Solids, mg/L:	< 15
Ammonia Nitrogen, mg/L:	5
4. Permit Requirements,

BOD ₅ , mg/L:	15
Suspended Solids, mg/L:	17
Ammonia Nitrogen, mg/L:	1.5 (summer), 4.0 (winter)
5. Frequency of Sampling: 3 Times/Week (Grab)

6. Trickling Filters

Number of Units:	2
Series/Parallel:	Parallel
Diameter of Each Filter, Feet:	75
Depth of Each Filter, Feet:	14
Media Type:	Plastic, Crossflow

7. Solids Contact Process

Solid Contact Time, Min.:	60
Solids Retention Time, Days:	< 2

10. BUCKEYE LAKE, OHIO

Contact:

Phone:

Treatment Process: Single - Stage trickling filter with solids contact process.

Wastewater treatment works include comminutor, two primary clarifiers, two trickling filters in parallel, solid contact tank, air flocculation and two secondary clarifiers.

Comments:

Solids contact process incorporated to assist in the settling of suspended solids. Sampling for ammonia nitrogen is done for the influent and final effluent.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	1.1
Design Peak Daily Flow, mgd:	2.6
Current Average Daily Flow, mgd:	0.8-0.9
Current Peak Daily Flow, mgd:	2.6

2. Influent Characteristics,

BOD ₅ , mg/L:	105
Suspended Solids, mg/L:	106
Ammonia Nitrogen, mg/L:	40

3. Effluent Characteristics,

BOD ₅ , mg/L:	< 2
Suspended Solids, mg/L:	5
Ammonia Nitrogen, mg/L:	0.1-0.3

4. Permit Requirements,

BOD ₅ , mg/L:	15 (summer), 25 (winter)
Suspended Solids, mg/L:	20 (summer), 30 (winter)
Ammonia Nitrogen, mg/L:	3 (summer), no requirement for winter

5. Frequency of Sampling: 3 Times/Week
6. Trickling Filters
- | | |
|--------------------------------|-------------------|
| Number of Units: | 2 |
| Series/Parallel: | Parallel |
| Diameter of Each Filter, Feet: | 45 |
| Depth of Each Filter, Feet: | 42 |
| Media Type: | Crossflow Plastic |
7. Solids Contact Process
- | | |
|-----------------------------------|-----|
| Current Solid Contact Time, Min.: | 71 |
| Solids Retention Time, Days: | < 2 |

11. CEDAR RAPIDS, IOWA

Contact: Pat Ball
 Phone: (319) 398-5286
 Treatment Process: Single - Stage roughing filter with two - stage activated sludge process.

Wastewater treatment works include primary clarification, four high rate trickling filters in parallel, two stage activated sludge process, final clarification and chlorination.

Comments:

Nitrification efficiency of the roughing filter appears to be greatly affected by organic loading and ambient temperature.

Salient Features:

- Wastewater Flows,

Design Average Daily Flow, mgd:	42
Design Peak Daily Flow, mgd:	65
Current Average Daily Flow, mgd:	35
Current Peak Daily Flow, mgd:	46
- Influent Characteristics,

CBOD ₅ , mg/L:	300
Suspended Solids, mg/L:	430
Ammonia Nitrogen, mg/L:	20
- Effluent Characteristics,

BOD ₅ , mg/L:	5
Suspended Solids, mg/L:	17
Ammonia Nitrogen, mg/L:	< 1 0.5
- Permit Requirements,

BOD ₅ , mg/L:	30
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	7.5

5. Frequency of Sampling: Once/Day (Composite)
6. Trickling Filters
- | | |
|--------------------------------|-------------------|
| Number of Units: | 4 |
| Series/Parallel: | Parallel |
| Diameter of Each Filter, Feet: | 140 |
| Depth of Each Filter, Feet: | 24 |
| Media Type: | Plastic, Vertical |

12. STOCKTON, CALIFORNIA

Contact: Tim Anderson
 Phone: (209) 944-8734
 Treatment Process: Single - stage roughing filter with oxidation pond.

Wastewater treatment works include primary clarification, 3 trickling filters and 3 biotowers in parallel, oxidation pond, chlorination and dechlorination tanks. During summer, effluent from oxidation pond is further treated by DAF units and dual media filters before chlorination.

Comments:

During winter and fall, oxidation pond effluent is discharged after chlorination and dechlorination. In summer, effluent from oxidation pond is further treated by DAF units and dual media filters.

Salient Features:

- Wastewater Flows,

Design Average Daily Flow, mgd:	42
Design Peak Daily Flow, mgd:	64
Current Average Daily Flow, mgd:	28
Current Peak Daily Flow, mgd:	72
- Influent Characteristics,

BOD ₅ , mg/L:	300-900
Suspended Solids, mg/L:	350-500
Ammonia Nitrogen, mg/L:	25
- Effluent Characteristics,

BOD ₅ , mg/L:	20-30
Suspended Solids, mg/L:	10
Ammonia Nitrogen, mg/L:	17
	10 (Secondary Effluent)
- Permit Requirements,

BOD ₅ , mg/L:	30
Suspended Solids, mg/L:	10
Ammonia Nitrogen, mg/L:	None

5. Frequency of Sampling: 5 Days/Week
6. Trickling Filter/Biotower:
- | | |
|-----------------------------------|---------------------------------------|
| Total Number of Units: | 6: 3 Trickling Filter,
3 biotowers |
| Series/Parallel: | Parallel |
| Diameter of each T. Filter, Feet: | 150 |
| Depth of Each T. Filter, Feet: | 4 |
| Diameter of Each Biotower, Feet: | 150 |
| Depth of Each Biotower, Feet: | 22 |
| Media Type in Each Biotower: | Plastic, Vertical |

13. WAUCONDA, ILLINOIS

Contact: Mark Dierker
 Phone: (312) 526-9612
 Treatment Process: Single - stage biotower with solids contact process.

Wastewater treatment works include aerated grit tank, comminutor, two primary clarifiers, two plastic media trickling filters in parallel, aerated solids contact tank with flocculation chamber, two intermittent sand filters and chlorination.

Comments:

No problem is reported with nitrification during winter.

Salient Features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	1.4
Design Peak Daily Flow, mgd:	
Current Average Daily Flow, mgd:	0.7
Current Peak Daily Flow, mgd:	2.0
2. Influent Characteristics,

BOD ₅ , mg/L:	163
Suspended Solids, mg/L:	145
Ammonia Nitrogen, mg/L:	10-15
3. Effluent Characteristics,

BOD ₅ , mg/L:	< 10
Suspended Solids, mg/L:	< 5
Ammonia Nitrogen, mg/L:	0.05-0.1
4. Permit Requirements,

BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	12
Ammonia Nitrogen, mg/L:	1.4, 30 day average (summer)
	4, 30 day average (winter)

5. Frequency of Sampling: 3 Times/Week (Composite)

6. Trickling Filters

Number of Units:	2
Series/Parallel:	Parallel
Diameter of Each Filter, Feet:	50
Depth of Each Filter, Feet:	28

14. CIBOLO CREEK, TEXAS

Contact: Roy Bingham
 Phone: (512) 658-6243
 Treatment Process: Two - stage high rate trickling filter plant.

Three separate wastewater treatment streams. Each stream consists of one primary clarifier, one first stage trickling filter, one intermediary clarifier, one second stage trickling filter, one final clarifier, dual media sand filter and chlorine contact chamber.

Comments:

Effluent ammonia levels are consistently below 5 mg/L.

Salient Features:

1. Wastewater Flows, mgd:

Design Average Wastewater Flow, (from 3 plants combined)	6.2
Design Peak Wastewater Flow, (from 3 plants combined)	16
Current Daily Average Flow (from 3 plants combined)	2.23
Current Daily Maximum Flow (from 3 plants combined)	3.3

Plant A treats 29% of the total flow

Plant B treats 16% of the total flow

Plant C treats 55% of the total flow

2. Influent Characteristics

BOD ₅ , mg/L:	190
Suspended Solids, mg/L:	180
Ammonia Nitrogen, mg/L:	25

3. Effluent Characteristics:

CBOD ₅ , mg/L:	< 5
Suspended Solids, mg/L:	< 5
Ammonia Nitrogen, mg/L:	< 5

4. Permit Requirements:

CBOD ₅ , mg/L:	10
Suspended Solids, mg/L:	15
Ammonia Nitrogen, mg/L:	6 (If flow is < 4 mgd)
	4 (If flow is > 4 mgd)

5. Frequency of Sampling:

5 Days/Week (Effluent)
2 Days/Week (Influent)

6. Trickling Filters

a. Plant A

Number of Units:	2
Series/Parallel:	Series
Intermediary Clarifier:	Yes
Diameter of Each Filter, Feet:	55
Depth of First Filter, Feet:	8
Depth of Second Filter, Feet:	7
Media Type of First Filter:	Plastic, 32 sq. ft./cu. feet
Media Type of Second Filter:	Plastic, 64 sq. ft./cu. feet

b. Plant B

Number of Units:	2
Series/Parallel:	Series
Intermediary Clarifier:	Yes
Diameter of Each Filter, Feet:	55
Depth of Each Filter, Feet:	7
Media Type of First Filter:	Plastic, 32 sq. ft./cu. feet
Media Type of Second Filter:	Plastic, 64 sq. ft./cu. feet

c. Plant C

Number of Units:	2
Series/Parallel:	Series
Intermediary Clarifier:	Yes
Diameter of Each Filter, Feet:	82
Depth of First Filter, Feet:	16
Depth of Second Filter, Feet:	12
Media Type of Each Filter:	Plastic, alternate layers of vertical (27 sq. ft./cu. ft.) and cross flow (48 sq. ft./cu. ft)

15. PALM SPRINGS, CALIFORNIA

Contact:	Andy Fisichelli
Phone:	(619) 323-8166
Treatment Process:	Single - stage trickling filter.

The wastewater treatment works consist of bar screen, aerated grit chamber, primary clarification, four high rate slag media trickling filters in parallel employing 1:1 recirculation, secondary clarification, sludge thickener, and

anaerobic sludge digester. The secondary effluent is either disposed through percolation ponds for eventual recharge to the natural underlying aquifer or directed to the tertiary treatment system for irrigation reclamation usage.

Comments:

Effluent ammonia levels are reported to be less than 1 mg/L. No major problem reported with the operation of the trickling filters and nitrification.

Salient features:

1. Wastewater Flows,

Design Average Flow, mgd:	10.9
Design Peak Flow, mgd:	21.8
Current Average Flow, mgd:	7.53
Current Peak Flow, mgd:	9.71
Daily minimum, mgd:	6.17

2. Influent Characteristics:

BOD ₅ , mg/L:	153
Suspended Solids, mg/L:	123
Ammonia Nitrogen, mg/L:	9-15

3. Effluent Characteristics:

BOD ₅ , mg/L:	7
Suspended Solids, mg/L:	9
Ammonia Nitrogen, mg/L:	0.5

4. Permit Requirements:

BOD ₅ , mg/L:	30
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	None

5. Frequency of Sampling (NH₃-N)

Influent:	Once/week (Composite)
Effluent:	Once/week (Composite)

6. Trickling Filters

Number of Units:	4
Series/Parallel:	Parallel
Diameter of each, ft.:	140
Depth of each, ft.:	9.5
Volume of each, cf:	146,167
Organic loading # BOD/day/1,000 cf:	23.2
Hydraulic loading with recirculation, gpd/sq. ft.	354
Type of media:	Slag

16. BREMEN, INDIANA

Contact: Bill Reed
 Phone: (219) 988-4920
 Treatment Process: Two - stage biotower/trickling filter combination.

Wastewater treatment works consist of primary sedimentation, two plastic media biotowers in parallel, intermediate clarifier, rock media trickling filter, final clarifier, rapid sand filter and chlorine contact tank. The plant is required to meet effluent $\text{NH}_3\text{-N}$ limits of 6.0 mg/L in summer and 9.0 mg/L in winter.

Comments:

Nitrification is reported in the first stage biotower.

Salient Features:

1. Wastewater Flows,

Design Average Flow, mgd:	1.3
Current Average Flow, mgd:	1.1
Current Peak, mgd:	2.2
2. Influent Characteristics,

BOD ₅ , mg/L	125
Suspended Solids, mg/L:	154
Ammonia Nitrogen, mg/L:	8.8-10.7
3. Effluent Characteristics,

BOD ₅ , mg/L:	<10
Suspended Solids, mg/L:	<10
Ammonia Nitrogen, mg/L:	1.1-2.7
4. Permit Requirements,

BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	10
Ammonia Nitrogen, mg/L:	6 (summer)
	9 (winter)
5. Frequency of Sampling ($\text{NH}_3\text{-N}$)

Influent:	Daily
Secondary Effluent:	Daily
Trickling Filter Effluent:	Daily
6. Biotowers

Number of Units:	2
Parallel/Series:	Parallel
Diameter of each, feet:	35.5
Depth of each, feet:	32.0
Hydraulic Loading, gpd/s.f.:	0.77
Organic Loading, lbs. BOD/1000 cf:	20.0

Recirculation Ratio:	0.8:1
Type of media:	Plastic
Specific Surface Area of Media:	29-40 sf/cf.

7. Trickling Filter

Number of Units:	1
Diameter, ft.:	60.0
Depth, ft.:	6.0
Type of Media:	Rock
Design Hydraulic Loading, gpd/cf:	76 @ 900 gpm

17. CHEMUNG COUNTY, NEW YORK

Contact:	Dan McGovern
Phone:	(607) 733-1837
Treatment Process:	Two trickling filters in series without intermediate clarification.

Wastewater treatment works consist of comminutor, bar screen, aerated grit chamber, primary clarification, two rock media trickling filters in series, secondary clarification, post aeration tank and anaerobic sludge digester. Comments : Effluent ammonia is temperature dependent. Data on influent ammonia is available since October, 1989.

Salient Features

1. Wastewater Flows,

Current Average Flow, mgd:	5.8
Current Peak, mgd:	12
2. Influent Characteristics

BOD ₅ , mg/L:	66-136
Suspended Solids, mg/L:	120-150
Ammonia Nitrogen, mg/L:	6.5-15.6
3. Effluent Characteristics,

BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	8-12
Ammonia Nitrogen, mg/L:	5.4
4. Permit Requirements.

BOD ₅ , mg/L:	25
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	-
5. Frequency of Sampling (NH₃-N)

Influent:	Twice/week (Composite)
Effluent:	Twice/week (Composite)

6. Trickling Filters:	
Number of Units:	2
Parallel/Series:	Series
Intermediary Clarifier:	No
Diameter of Each, ft.:	135.0
Depth of Each, ft.:	6.0
Type of Media:	Rock

18. READING, PENNSYLVANIA

Contact:	Michael Rieber
Phone:	(215) 223-3485
Treatment Process:	Three-stage trickling filter.

Wastewater treatment works include primary clarifier, two primary trickling filters, two secondary trickling filters, secondary clarifier, one tertiary trickling filter, final clarification, chlorine contact chamber, and anaerobic sludge digestion.

Comments:

Influent ammonia is not measured. Final effluent ammonia levels are around 3.5 mg/L.

Salient features:

1. Wastewater Flows,	
Current Average Flow, mgd:	20.0
Daily Maximum Flow, mgd:	40.0
2. Influent Characteristics,	
BOD ₅ , mg/L:	400-500
Suspended Solids, mg/L:	600-700
Ammonia Nitrogen, mg/L:	20
3. Effluent Characteristics,	
BOD ₅ , mg/L:	25-30
Suspended Solids, mg/L:	15-20
Ammonia Nitrogen, mg/L:	3.5
4. Permit Requirements,	
BOD ₅ , mg/L:	30
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	5 (summer)
	15 (winter)

5. Trickling Filters

Total Number of Units:	5
Number of Primary Trickling Filters:	2; Series
Diameter of Each Primary T. Filter, ft.:	212
Number of Secondary T. Filter:	2; Parallel
Diameter of Each Secondary T. Filter, ft.:	212
Number of Tertiary T. Filter:	1
Diameter of Tertiary T. Filter, ft.:	154

19. LAPORTE, INDIANA

Contact:	Alex Toth
Phone:	(219) 362-2354
Treatment Process:	Two-stage biotower/trickling filter combination.

Wastewater treatment facility includes screening, grit removal, primary clarification, rotary trickling filter and fixed nozzle trickling filter in parallel, intermediate clarifier, two biological towers in parallel, final clarification, anaerobic sludge digestion, chlorination and dechlorination.

Comments:

Nitrification process appears to be seriously affected by very low ambient temperatures. Influent ammonia is not measured.

Salient Features:

1. Wastewater Flows,

Design Average Flow, mgd:	7.0
Current Average, mgd:	3.0
Current Peak, mgd:	4.5
2. Influent Characteristics,

BOD ₅ , mg/L:	100-120
Suspended Solids mg/L:	128
Ammonia Nitrogen, mg/L:	20
3. Effluent Characteristics,

BOD ₅ , mg/L:	8
Suspended Solids, mg/L:	12
Ammonia Nitrogen, mg/L:	2-3
4. Permit Requirements,

BOD ₅ , mg/L:	30
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	2 (summer)
	4 (winter)
5. Frequency of Sampling (NH₃-N)

Influent:	Daily
Effluent:	Daily

6. Trickling Filters

Number of Units:	2; 1 rotary, 1 fixed
Series/Parallel:	Parallel
Size of Fixed Nozzle Filter, ft ² :	2 Sections, each 178 X 125
Type of Media:	Limestone, 6 ft. deep
Diameter of Rotary T. Filter, ft.:	116.0
Depth of Rotary T. Filter, ft.:	6.0
Type of Media:	Synthetic, Pack-type

7. Biotowers

Number of Units:	2
Series/Parallel:	Parallel
Diameter of Each, ft.:	70.0
Depth of Each, ft.:	20.0
Type of Media:	Synthetic, Pack-type
Data Availability for NH ₃ -N	

20. BOULDER, COLORADO

Contact:	Ernie Oram
Phone:	(303) 441-3259
Treatment Process:	Two-stage trickling filter with solids contact process.

Wastewater treatment works include bar screen, grit chamber, four primary clarifiers, four trickling filters in parallel, four solids contact tank, three secondary clarifiers, one nitrifying biotower, chlorination chamber and dechlorination unit.

Comments:

At present only one third of the flow is nitrified. Rest is sent to the chlorination chamber after solids contact tank.

Salient features:

1. Wastewater Flows,

Design Average Daily Flow, mgd:	46.0
Current Average Daily Flow, mgd:	15.0

2. Influent Characteristics,

BOD ₅ , mg/L:	
Suspended Solids, mg/L:	
Ammonia Nitrogen, mg/L:	

3. Effluent Characteristics,

BOD ₅ , mg/L:	15
Suspended Solids, mg/L:	10
Ammonia Nitrogen, mg/L:	5

4. Permit Requirements,	
BOD ₅ , mg/L:	30
Suspended Solids, mg/L:	30
Ammonia Nitrogen, mg/L:	13 (summer) 20 (winter)

5. Trickling Filters	
Number of Units:	4
Series/Parallel:	Parallel
Diameter of Each Filter, Feet:	48
Depth of Filter, Feet:	8
Media:	Rock

6. Biotower	
Number of Units:	1
Diameter, Feet:	48
Depth, Feet:	16
Media Type:	Plastic

21. SUNNYVALE, CALIFORNIA

Contact:	Jean Willroth
Phone:	(408) 730-7260
Treatment Process:	Oxidation pond with trickling filter.

22. RENO, NEVADA

Contact:	Arthur Molin
Phone:	(702) 785-2230
Treatment Process:	Single-stage trickling filter with activated sludge process

Comments:

Nitrification appears to be taking place in the activated sludge process. Data on ammonia nitrogen is available for influent and final effluent only.

23. EAST MONTGOMERY COUNTY, OHIO

Contact:	
Phone:	
Treatment Process:	Single-Stage trickling filter with solids contact process.

Wastewater treatment works consists of flow equalization, primary clarification with chemical addition, three trickling filters, an aerated return sludge and contact channel, and three flocculating vacuum sweep final clarifiers.

24. OZARK, ALABAMA

Contact: Joe Wainwright
 Phone: (205) 774-8447
 Treatment Process: Two-stage trickling filter. Comments : Each stage has plastic media trickling filters in parallel mode. First stage has high recycle (6:1) to reduce solids build up.

1. Wastewater Flows,

Design Average Flow, mgd:	2
Current Average Flow, mgd:	1
2. Influent characteristics,

BOD ₅ , mg/L:	100-150
Suspended Solids, mg/L:	100-150
Ammonia Nitrogen, mg/L:	10-20
3. Effluent Characteristics,

BOD ₅ , mg/L:	10
Suspended Solids, mg/L:	10
Ammonia Nitrogen, mg/L:	<1
4. Permit Requirements

BOD ₅ , mg/L:	25
Suspended Solids, mg/L:	25
Ammonia Nitrogen, mg/L:	5
5. Frequency of Sampling (NH₃-N)

Influent:	Once/Week
Effluent:	Once/Week
6. First Stage Biotower:

Number of Units:	2
Series/Parallel:	Parallel
Diameter of Each Tower, ft:	48
Depth of Each Tower, ft:	20
Recirculation:	6:1
Media:	Plastic, Serpentine Shape Corrugation
Specific Surface Area of Media:	27 sq. ft/cu. ft.
7. Second Stage Biotower:

Number of Units:	2
Series/Parallel:	Parallel
Diameter of Each Tower, Feet:	48
Depth of Each Tower, Feet:	20
Recirculation:	None
Media:	Plastic 45° Corrugation
Specific Surface Area of Media:	33 sq. ft./cu. ft.

25. NEW PROVIDENCE, NEW JERSEY

Contact: Dan Ranich

Phone: (201) 665-1077

Treatment Process: Two trickling filters in series without intermediate clarifier.

Comments:

First trickling filter has plastic media while second one has rock media. There is 1:1 recycle from final clarifier to the first trickling filter. Typical effluent ammonia levels are between 2 and 4 mg/L.

Salient Features:

1. Wastewater Flows,

Design Peak Flow, mgd:	6.0
Current Average Flow, mgd:	0.8
Current Peak Flow, mgd:	5.0
2. Influent Characteristics,

BOD ₅ , mg/L:	160-200
Suspended Solids, mg/L:	125-175
Ammonia Nitrogen, mg/L:	30
3. Effluent Characteristics,

BOD ₅ , mg/L:	<18
Suspended Solids, mg/L:	<16
Ammonia Nitrogen, mg/L:	2-4
4. Permit Requirements,

BOD ₅ , mg/L:	16 (30 days average)
Suspended Solids, mg/L:	16 (30 days average)
Ammonia Nitrogen, mg/L:	4 (30 days average)
5. Frequency of Sampling (NH₃-N)

Influent:	Once/Week
Effluent:	Once/Week
6. Trickling Filter,

Number of Units:	2 (1 plastic media) (1 rock media)
Series/Parallel:	Series
Intermediate clarifier:	None
Diameter of Plastic Media filter, ft:	36
Depth of Plastic Media Filter, ft:	14.5
Diameter of Rock Media, Filter ft:	65
Depth of Rock Media Filter, ft:	6
Recirculation:	1:1

APPENDIX B

PERFORMANCE AND OPERATING DATA FOR SELECTED PLANTS

TABLE B-1.	PALM SPRINGS, CALIFORNIA
TABLE B-2.	CHEMUNG COUNTY, NEW YORK
TABLE B-3.	AMHERST, OHIO
TABLE B-4A.	WAUCONDA, ILLINOIS 1987
TABLE B-4B.	WAUCONDA, ILLINOIS 1988
TABLE B-5.	ASHLAND, OHIO
TABLE B-6.	BREMEN, INDIANA
TABLE B-7.	ALLENTOWN, PENNSYLVANIA
TABLE B-8.	CIBOLO, TEXAS; PLANT A
TABLE B-9.	CIBOLO, TEXAS; PLANT B
TABLE B-10.	CIBOLO, TEXAS; PLANT C

TABLE B-1. OPERATING DATA FOR PALM SPRINGS WWTP SHOWING MONTHLY AVERAGES FOR THE YEAR 1989

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)		Average TSS (mg/L)		Average NH ₃ -N (mg/L)		Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier			
January	7.30	23.0	117	10.75	81	11.25	17.90	0.64	12.22	1.86	118
February	7.65	23.0	129	14.67	89	19.33	20.60	10.60	14.08	2.24	124
March	8.22	25.8	124	10.80	91	12.00	22.78	5.10	14.55	2.66	133
April	8.07	25.8	99	6.75	80	8.50	21.97	4.96	11.16	2.52	131
May	7.66	25.8	111	6.50	84	10.00	17.98	3.42	12.12	1.97	125
June	7.50	28.3	90	5.60	78	7.60	16.82	1.65	9.59	1.80	122
July	7.20	28.3	71	3.75	68	7.50	15.32	0.27	7.32	1.57	117
August	7.17	28.3	68	3.75	75	6.00	18.10	1.35	6.99	1.85	116
September	7.56	28.3	89	5.20	68	5.60	19.72	0.50	9.55	2.12	123
October	8.15	25.5	101	6.00	87	6.00	21.25	0.37	11.78	2.48	132
November	8.28	25.5	111	6.00	94	10.33	20.80	1.44	13.10	2.45	134
December	8.02	23.0	107	9.40	83	8.00	21.63	1.03	12.25	2.48	130

^aCalculated assuming 35 percent removal in the primary clarifier

TABLE B-2. OPERATING DATA OF CHEMUNG COUNTY WWTP SHOWING MONTHLY AVERAGES FROM NOVEMBER 1989 TO APRIL 1990

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)		Average TSS (mg/L)		Average NH ₃ -N (mg/L)		Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier			
November	4.10	16.0	42.6	8	94	10	13.0	3.0	8.48	2.58	286
December	3.79	13.0	60.5	14	100	15	15.6	6.8	11.16	2.86	268
January	4.15	13.0	88.0	11	99	11	14.2	7.3	17.75	2.85	290
February	8.08	11.0	-	9	63	8	7.6	3.3	-	2.97	564
March	6.74	12.0	43.5	10	66	11	10.6	6.8	14.25	3.46	472
April	8.10	12.1	43.0	13	56	15	6.5	5.4	16.91	2.55	566

^aCalculated assuming 35 percent removal in the primary clarifier

TABLE B-3. OPERATING DATA OF AMHERST WWTW SHOWING MONTHLY AVERAGES FROM FEBRUARY 1989 TO JANUARY 1990

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)		Average TSS (mg/L)		Average NH ₃ -N (mg/L)		Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier			
February	2.06	8.0	89	11.9	74	11.9	12.2	-	12.5	1.71	572
March	2.42	9.6	62	10.9	56	11.7	14.3	-	10.2	2.35	672
April	2.74	10.4	62	8.1	88	8.7	9.3	3.6	11.5	1.74	761
May	2.42	14.1	62	10.2	118	14.5	7.6	2.2	10.1	1.25	672
June	2.32	17.3	40	8.2	216	9.5	8.9	2.0	6.3	1.40	644
July	2.04	20.0	61	8.4	196	9.2	14.3	1.2	8.5	1.98	567
August	1.57	20.3	80	6.9	192	8.1	18.4	1.6	8.5	1.97	436
September	1.52	19.6	67	6.3	183	8.5	17.1	1.9	7.0	1.77	422
October	1.52	15.7	56	4.8	132	6.5	17.0	1.4	5.8	1.77	422
November	1.78	13.3	59	3.5	99	7.5	17.8	1.8	7.1	2.17	494
December	1.75	11.8	99	5.6	129	9.3	-	4.9	11.8	-	486
January	2.29	10.6	48	5.5	89	10.2	-	4.3	7.5	-	636

^aCalculated assuming 35 percent removal in the primary clarifier

TABLE B-4a. OPERATING DATA OF WAUCONDA WWTP SHOWING MONTHLY AVERAGES FOR THE YEAR 1987

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)		Average TSS (mg/L)		Average NH ₃ -N (mg/L)		Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier			
January	0.55	-	132	36	73	36	18.4	7.10	11.01	1.5	280
February	0.56	11.6	168	37	126	42	15.7	4.70	14.27	1.3	285
March	0.78	12.2	101	17	68	12	15.0	1.59	11.95	1.8	397
April	0.96	12.7	80	12	71	18	8.3	0.08	11.65	1.2	489
May	0.76	15	106	15	81	9	13.4	0.10	12.22	1.6	387
June	0.56	17.2	119	12	76	6	17.2	0.18	10.11	1.5	285
July	0.63	18.3	142	10	106	15	16.8	0.91	13.57	1.6	321
August	0.91	18.3	138	19	84	8	17.0	0.56	19.05	2.4	463
September	0.76	-	143	12	73	5	16.6	0.46	16.49	1.9	387
October	0.52	-	117	8	82	6	15.3	0.22	9.23	1.2	265
November	0.62	-	123	13	100	4	10.9	1.75	11.57	1.0	316
December	1.04	-	96	13	50	5	6.0	0.08	15.15	0.9	530

TABLE B-4b. OPERATING DATA OF WAUCONDA WWTW SHOWING MONTHLY AVERAGES FOR THE YEAR 1988

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)		Average TSS (mg/L)		Average NH ₃ -N (mg/L)		Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier			
January	0.99	11.6	78	15	70	10	12.4	0.39	11.71	1.9	504
February	0.83	13.8	77	9	125	4	17.6	0.34	9.69	2.2	423
March	0.80	12.2	101	11	79	14	17.0	0.25	12.26	2.1	407
April	1.00	12.2	76	9	104	20	14.4	0.14	11.53	2.2	509
May	0.64	13.8	146	10	81	8	14.1	0.10	14.17	1.4	326
June	0.55	17.7	128	8	73	9	15.6	0.19	10.68	1.3	280
July	0.55	19.4	123	8	59	4	14.3	0.07	10.26	1.2	280
August	0.61	21.1	124	10	68	7	13.3	0.26	11.47	1.2	311
September	0.55	20.2	109	9	75	9	16.2	0.31	9.09	1.3	280
October	0.48	19.4	122	9	81	6	17.0	3.6	8.88	4.9	244
November	0.60	16.1	104	15	60	17	14.6	0.74	9.47	1.4	306
December	0.48	14.4	115	12	61	22	13.1	0.28	8.37	1.0	244

TABLE B-5. OPERATING DATA OF ASHLAND WWTP SHOWING MONTHLY AVERAGES FROM APRIL 1989 TO MARCH 1990

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)		Average TSS (mg/L)		Average NH ₃ -N (mg/L)		Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter ^a	From Secondary Clarifier	To Trickling Filter	From Secondary Clarifier			
April	3.67	15	70	2	49	18	8.7	1.40	6.47	0.80	369
May	3.73	16	77	-	60	23	11.8	3.30	7.20	1.10	375
June	4.07	19	69	-	64	12	10.7	1.60	7.05	1.09	409
July	2.56	20	98	-	101	9	13.2	2.40	6.32	0.85	258
August	2.27	22	108	-	120	8	15.4	0.60	6.16	0.87	228
September	2.28	21	125	-	125	7	18.6	1.60	7.21	1.06	230
October	2.22	20	123	-	104	8	17.4	6.00	6.88	0.97	224
November	2.51	17	100	6	105	9	17.4	8.80	6.32	1.09	253
December	2.10	15	101	7	87	7	20.0	11.00	5.33	1.05	212
January	2.90	13	98	8	82	10	13.3	4.60	7.13	0.97	292
February	4.34	15	72	-	65	8	8.5	0.60	7.80	0.92	436
March	2.79	15	96	6	88	10	15.4	0.80	6.71	1.07	280

^aCalculated assuming 35 percent removal in the primary clarifier

TABLE B-6. OPERATING DATA OF BREMEN WWTP SHOWING MONTHLY AVERAGES FOR THE YEAR 1989

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)			Average NH ₃ -N (mg/L)			Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter	From Secondary Clarifier	Final Effluent	To Trickling Filter	From Secondary Clarifier	Final Effluent			
January	1.28	11.1	55	17.0	6.0	8.9	1.80	1.35	9.17	1.48	636
February	1.15	11.1	49	18.0	4.6	11.2	2.72	2.61	7.44	1.70	581
March	1.14	11.1	35	11.0	4.8	9.0	1.43	1.17	5.26	1.35	576
April	1.18	10.6	24	9.0	3.1	8.5	1.65	0.93	3.74	1.33	596
May	1.10	13.9	41	9.6	2.1	9.5	1.46	0.88	5.96	1.38	556
June	1.31	16.7	38	8.0	2.9	7.2	0.65	0.52	6.57	1.25	662
July	1.10	17.8	43	11.0	3.2	8.4	0.83	0.60	6.26	1.22	556
August	1.05	18.3	34	12.0	3.0	8.8	1.51	1.20	4.70	1.22	530
September	1.02	17.8	31	9.0	2.4	8.9	1.33	0.67	4.16	1.20	515
October	0.95	16.7	56	13.0	3.8	10.5	1.29	0.94	7.02	1.32	480
November	0.98	14.4	41	16.0	5.2	10.9	2.77	1.91	5.33	1.42	495
December	0.93	11.7	60	26.0	10.7	17.0	7.23	5.76	7.39	2.09	470

TABLE B-7. OPERATING DATA OF ALLENTOWN WWTP SHOWING MONTHLY AVERAGES FOR THE YEAR 1989

Month	Average Flow (mgd)	Temperature of Raw Sewage (°C)	Average BOD (mg/L)			Average NH ₃ -N (mg/L)			Organic Loading lbs/1,000 ft ³ .d	Ammonia Loading lbs/1,000 ft ³ .d	Hydraulic Loading gpd/ft ²
			To Trickling Filter	From Intermediate Clarifier	Final Effluent	To Trickling Filter	From Intermediate Clarifier	Final Effluent			
January	31.34	12.2	137	72	17	15.6	1.27	8.0	71.23	9.73	1,995
February	31.01	11.6	128	134	18	15.7	16.1	8.4	65.8	9.86	1,974
March	31.47	12.2	114	89	11	14.8	15.3	7.3	59.52	9.28	2,003
April	32.43	13.3	114	84	15	15.0	14.9	6.2	61.34	9.29	2,065
May	36.97	14.4	101	60	15	11.8	11.8	5.0	61.95	7.73	2,354
June	36.39	16.6	120	48	16	12.7	8.6	5.4	72.44	8.41	2,316
July	34.93	18.3	126	57	13	13.6	10.3	5.4	91.81	8.78	2,224
August	33.23	19.4	123	50	10	13.2	11.0	4.2	67.80	8.09	2,115
September	33.25	17.7	118	45	9	12.8	10.2	3.8	65.08	7.98	2,117
October	32.78	16.1	113	48	7	12.1	9.6	2.8	61.44	7.54	2,087
November	30.40	15.5	119	44	6	13.2	9.4	2.7	60.00	7.91	1,935
December	30.32	13.3	116	54	10	15.1	12.8	6.5	58.34	8.87	1,930

TABLE B-8. SUMMARY OF CIBOLO CREEK, PLANT A PERFORMANCE DATA

Date	Process Flow	Ammonia-Nitrogen			BOD ₅		
		Primary Effluent (mg/L)	1st Stage Effluent (mg/L)	2nd Stage Effluent (mg/L)	Primary Effluent (mg/L)	1st Stage Effluent (mg/L)	2nd Stage Effluent (mg/L)
06/07/88	0.74	19.0	8.3	1.6	69	18	4.9
07/14/88	0.66	18.5	14.1	4.8	93	28	9.3
08/16/88	0.67	20.0	11.3	2.9	79	19	7.8
08/23/88	0.65	19.3	12.6	3.1	87	29	8.0
09/08/88	0.59	19.5	13.4	5.7	84	37	9.5
10/27/88	0.65	21.0	14.7	6.4	84	34	7.9
11/29/88	0.64	24.0	15.1	5.2	64	28	8.0
01/03/89	0.66	20.3	6.3	0.2	88	26	4.2
02/14/89	0.63	19.7	7.5	0.2	97	23	3.8
03/09/89	0.62	21.5	8.4	0.6	101	31	3.5
10/31/89	0.61	23.0	12.0	1.9	46	11	3.8
11/16/89	0.60	19.6	2.5	1.1	55	23	5.1

TABLE B-9. SUMMARY OF CIBOLO CREEK, PLANT B PERFORMANCE DATA

Date	Process Flow	Ammonia-Nitrogen			BOD ₅		
		Primary Effluent (mg/L)	1st Stage Effluent (mg/L)	2nd Stage Effluent (mg/L)	Primary Effluent (mg/L)	1st Stage Effluent (mg/L)	2nd Stage Effluent (mg/L)
08/18/88	0.36	19.9	7.0	1.0	64	19	4.7
09/01/88	0.36	18.3	7.4	1.0	77	23	7.7
09/13/88	0.35	16.0	6.9	0.4	55	16	6.1
09/15/88	0.34	16.5	5.3	0.5	61	19	5.4
01/12/89	0.36	20.0	7.1	0.9	101	18	6.4
02/02/89	0.35	16.2	1.6	0.1	66	17	4.3
03/02/89	0.34	15.5	7.1	0.3	81	28	4.8
10/12/89	0.35	18.1	4.0	0.2	44	11	7.0
11/14/89	0.34	18.2	4.5	0.2	55	16	5.4

TABLE B-10. SUMMARY OF CIBOLO CREEK, PLANT C PERFORMANCE DATA

Date	Process Flow	Ammonia-Nitrogen			BOD ₅		
		Primary Effluent (mg/L)	1st Stage Effluent (mg/L)	2nd Stage Effluent (mg/L)	Primary Effluent (mg/L)	1st Stage Effluent (mg/L)	2nd Stage Effluent (mg/L)
05/17/88	1.27	18.3	1.6	0.0	97	9	1.2
08/25/88	1.30	17.9	10.2	1.1	92	21	4.9
09/22/88	1.29	20.7	11.2	1.0	84	23	4.1
11/03/88	1.19	16.2	8.5	0.6	71	17	3.5
01/17/89	1.19	22.2	2.3	0.3	104	20	4.1
02/21/89	1.19	23.4	1.3	0.3	101	17	2.7
03/16/89	1.24	22.7	1.3	0.2	100	17	2.6
10/05/89	1/22	23/2	7.5	0.6	67	17	4.1
11/07/89	1.18	24.7	7.0	0.6	56	14	5.1

