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Cold-climate nitrification on plastic media trickling filters

Harvey Allen Gullicks
Iowa State University

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COLD-CLIMATE NITRIFICATION ON PLASTIC MEDIA TRICKLING FILTERS

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Cold-climate nitrification on plastic media trickling filters

by

Harvey Allen Gullicks

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Department: Civil Engineering
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DEDICATION

To my wife, Jean, and our sons, Donnie and Grant, whose love, patience and understanding have made both family life and professional growth possible and enjoyable, and to Dr. Donald Naismith, Shirley Naismith, Dr. Jonathan Berg, Laurie Berg, and Warren and Connie Dunham for their support throughout the difficult times.

NOMENCLATURE AND ABBREVIATIONS

Nomenclature

A	Cross sectional area perpendicular to the direction of mass transfer, cm^2
a_s	specific surface area
a_w	wetted specific surface
a_t	total specific surface
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
COD	chemical oxygen demand
D	media depth
D_w	diffusivity of the limiting reactant in the wastewater, cm^2/d
D_f	diffusivity of the limiting reactant in biofilm, cm^2/d
D_{fa}	diffusivity of the electron acceptor in biofilm, cm^2/d
D_{fd}	diffusivity of the electron donor in biofilm, cm^2/d
D_o	diffusivity of oxygen, m^2/s
D_s	diffusivity of organic matter, m^2/s
f_n	stoichiometry ratio of oxygen to nitrogen, gO_2/gN
f_s	stoichiometry ratio of oxygen to BOD, $gO_2/gBOD$
g	acceleration of gravity
J	mass transfer rate, mg/d
k	maximum specific rate of utilization of the limiting reactant, mass of reactant/mass of biofilm • d

k_D	treatability coefficient for media depth, D, at 20°C
K_i	Haldane inhibition constant, mg/cm^3
k_La	observed air stripping mass transfer coefficient
k_La_w	air stripping mass transfer coefficient predicted by Onda's correlations
k_n	specific rate of NH_4^+-N uptake in biofilm, gN/gVSS • s
K_s	half velocity constant = growth limiting substrate concentration at half the maximum growth rate, mg/cm^3
k_s	specific rate of organic substrate uptake in biofilm, gBOD/gVSS • s
K_{sa}	electron acceptor half velocity constant
K_{sd}	electron donor half velocity constant
K_{sf}	zero-order specific rate of organic substrate oxidation in biofilm, g/m^3 • s
k_{20}	soluble substrate treatability coefficient at 20°C (may be further restricted to 20 ft. media depth)
L	superficial mass velocity of liquid, kg/hr • m^2 tower cross section
L_o	penetration of oxygen into the biofilm
L_s	penetration of organic substrate into the biofilm
$L_1 + L_2$	effective liquid diffusion layer thickness, cm
MW	molecular weight of limiting reactant
MWa	molecular weight of electron acceptor
MW_d	molecular weight of electron donor

MW_N	molecular weight of nitrogen
n	dimensionless constant depending on media properties and wastewater distribution
NH_4^+-N	ammonium nitrogen
NO_2^--N	nitrite nitrogen
NO_3^--N	nitrate nitrogen
NOD	nitrogenous oxygen demand
Q	influent wastewater flow without recirculation
Q_T	total applied hydraulic load
q	cross sectional hydraulic loading rate
R	recycle ratio
Re_L	Reynolds number at the applied liquid velocity
Re_M	Reynolds number at the minimum liquid wetting velocity
S	growth limiting reactant concentration, mg/cm^3
S_b	soluble substrate concentration applied including recirculation
S_e	soluble substrate concentration in settled effluent, mg/l
S_f	concentration of the limiting reactant in the biofilm mg/cm^3
S_{fa}	concentration of electron acceptor at any depth in biofilm, mg/cm^3
S_{fd}	concentration of electron donor at any depth in biofilm, mg/cm^3

S_i	soluble substrate concentration in influent wastewater flow without recirculation, mg/l
S_o	concentration of the limiting reactant in the bulk liquid, mg/cm^3
S_o^*	bulk liquid dissolved oxygen concentration, g/m^3
S_{oa}	concentration of electron acceptor in bulk liquid, mg/cm^3
S_{od}	concentration of electron donor in bulk liquid, mg/cm^3
S_s	concentration of limiting reactant at the biofilm-liquid interface, mg/cm^3
S_s^*	bulk liquid organic carbon concentration, g soluble BOD/m^3
SS	suspended solids
T	wastewater temperature
t	time, d or average hydraulic residence time, minutes
TKN	total Kjeldahl nitrogen
TOD	total oxygen demand
V	volumetric flow rate, cm^3/s
VSS	volatile suspended solids
W	width of plane, cm
WPCP	Water Pollution Control Plant
X^*	specific nitrifier concentration at the biofilm surface, gVSS/m^3
X_f	biofilm density, mass of biofilm/cm^3

Y_n or Y_N	specific nitrifier organism yield coefficient, mass nitrifiers/mass N oxidized
Y_s	specific heterotroph yield coefficient, gVSS/gBOD
Z	distance in the direction of mass transfer, cm
γ	biofilm density, $gVSS/m^3$
ε	media bed porosity
η	external wetting efficiency
θ	angle of inclination from horizontal
μ or μ_L	dynamic viscosity of wastewater, g/cm • s
u	specific growth rate of microorganisms, $\frac{\text{mass microorganism}}{\text{mass biofilm} \cdot t}$
$\hat{\mu}$	maximum specific growth rate of microorganism, $\frac{\text{mass microorganism}}{\text{mass biofilm} \cdot t}$
$\hat{\mu}_N$	maximum specific growth rate of nitrifiers, $\frac{\text{mass nitrifiers}}{\text{mass biofilm} \cdot d}$
ν	stoichiometric coefficient of limiting reactant
ν_N	stoichiometric coefficient of nitrogen
ν_a	stoichiometric coefficient of electron acceptor
ν_d	stoichiometric coefficient of electron donor
ρ or ρ_L	density of water, g/cm^3
σ	surface tension of the liquid, kg/hr^2
σ_c	critical surface tension of the packing material, kg/hr^2

Abbreviations

cm	centimeter
°C	degrees Celsius
d	day
g	gram
hr	hour
°K	degrees Kelvin
kg	kilogram
l or L	liter
m	meter
m^2 or sq. m	square meters
m^3 or cu. m	cubic meters
mg or MG	milligram
s or sec	second

INTRODUCTION

The trickling filter process was first used in the United States for wastewater treatment in 1908 (Tsugita et al., 1977). The trickling filter consists of a tower, containing a medium with a high specific surface area and a high void volume per unit medium volume. As wastewater is distributed to the top of the medium, it trickles down through the medium voids and over the medium surface area on which microorganisms are attached. The microorganisms attached to the medium are referred to as the biofilm or biomass. The succession of communities of microorganisms produced by microbial competition under various loading conditions and at various depths in the trickling filter will be addressed in a subsequent section. The microorganisms in the biofilm utilize the organic material and nutrients in the wastewater for growth, thereby removing or altering these contaminants.

The implementation of more stringent water quality legislation in 1972 has left many trickling filter plants designed before that time in violation of the discharge standards for biochemical oxygen demand (BOD), suspended solids (SS), and ammonium nitrogen (NH_4^+-N). Consequently, many designers have come to view the trickling filter process only as a pretreatment process. The activated sludge process has generally been accepted as the process-of-choice for nitrification, the biological conversion of NH_4^+-N to nitrite (NO_2^--N) and nitrate (NO_3^--N). Young (1974) reported that inflexibility in trickling filter operation was responsible for the trickling filter's reputation for uncontrollable nitrification performance.

The advent of new, lightweight plastic media for trickling filters has improved the performance of trickling filters. Several studies have shown that trickling filters are capable of producing effluents with consistently low ammonia nitrogen concentrations even in cold climates when carbonaceous oxygen demand loadings are low (Sampayo, 1973, 1974, 1976, and 1981, Sampayo and Metcalf, 1984, Duddles and Richardson, 1973, Duddles et al., 1974, Baxter and Woodman, 1973, Bruce et al., 1975, and Gujer and Boller, 1984). Gujer and Boller (1984) reported that tertiary nitrifying trickling filters do not require additional sedimentation tanks. The effluent can be directly filtered just as secondary effluent is directly filterable. The trickling filter should be considered to be a viable nitrification process.

Trickling Filter Application for Nitrification

Nitrification can be achieved in trickling filters in two processes. Either combined carbon oxidation-nitrification or separate stage processes may be used. These processes are distinguished on the basis of the BOD_5/Total Kjeldahl Nitrogen (TKN) ratio for the wastewater being treated (Parker et al., 1975). If the ratio is less than 3.0 and the nitrogenous oxygen demand (NOD) is at least 60 percent of the total oxygen demand (TOD), the system is classified as a separate-stage process. If the ratio is greater than 5.0 and the

NOD is less than 50 percent of the TOD, the system is classified as a combined carbon oxidation-nitrification process. Trickling filters treating wastewaters with ratios between 3.0 and 5.0 are considered to provide an intermediate degree of separation of the carbon oxidation and nitrification.

In general, the combined carbon oxidation-nitrification process is applied more frequently as a pretreatment to subsequent processes that provide an effluent meeting the necessary discharge requirements. Brown and Caldwell (1980) reported that the Stockton, California, forced-draft, combined carbon oxidation-nitrification trickling filter plant achieved 80-90 percent nitrification and removed approximately 50 percent of the organic nitrogen with 6.7 m. of vertical plastic media with a specific surface of 89 sq. m./cu. m.. Suwan arpa (1974) reported that heterotrophic organism growth accounted for substantial nitrogen uptake, but that NH_4^+-N was not the only nitrogen source for heterotroph growth.

When separate-stage nitrification is applied, staging, which is the operation of trickling filters in series, is often the selected design. Figure 1 demonstrates the schematic flow pattern used in staging of trickling filters. Staging allows a high quality nitrified effluent to be produced.

Plastic media, with large specific surface areas relative to rock and other media types, are generally selected for nitrifying trickling filters because their light weight and corrugated construction allows tall towers to be used and because their high void volumes help

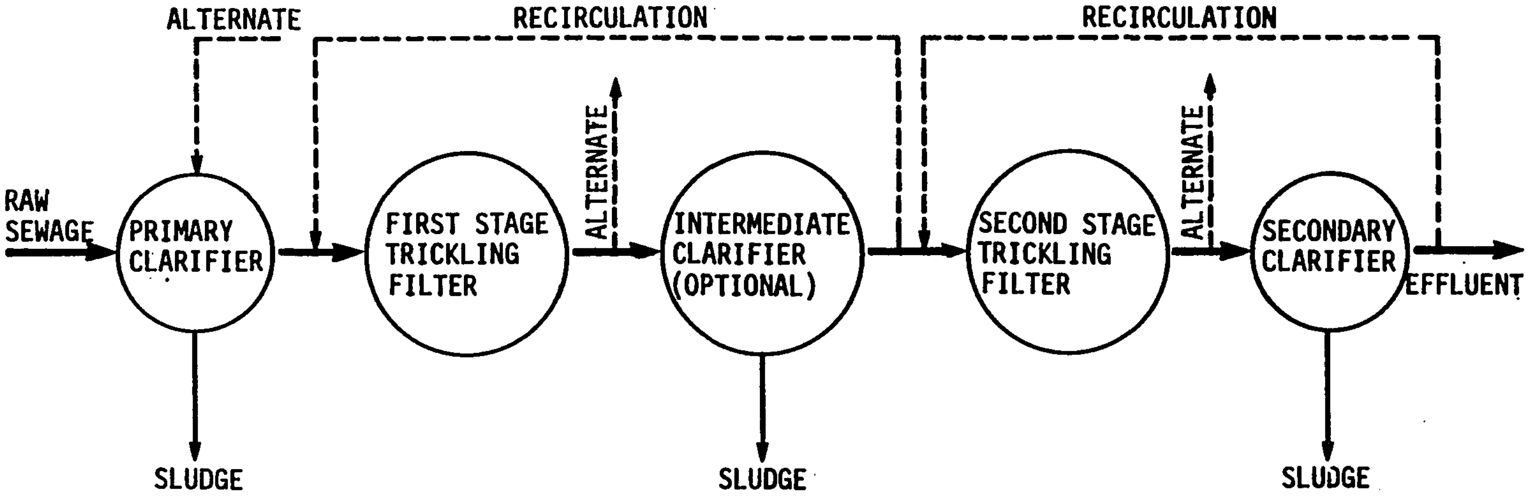


Figure 1. Staging of filters. After Tsugita et al. (1977)

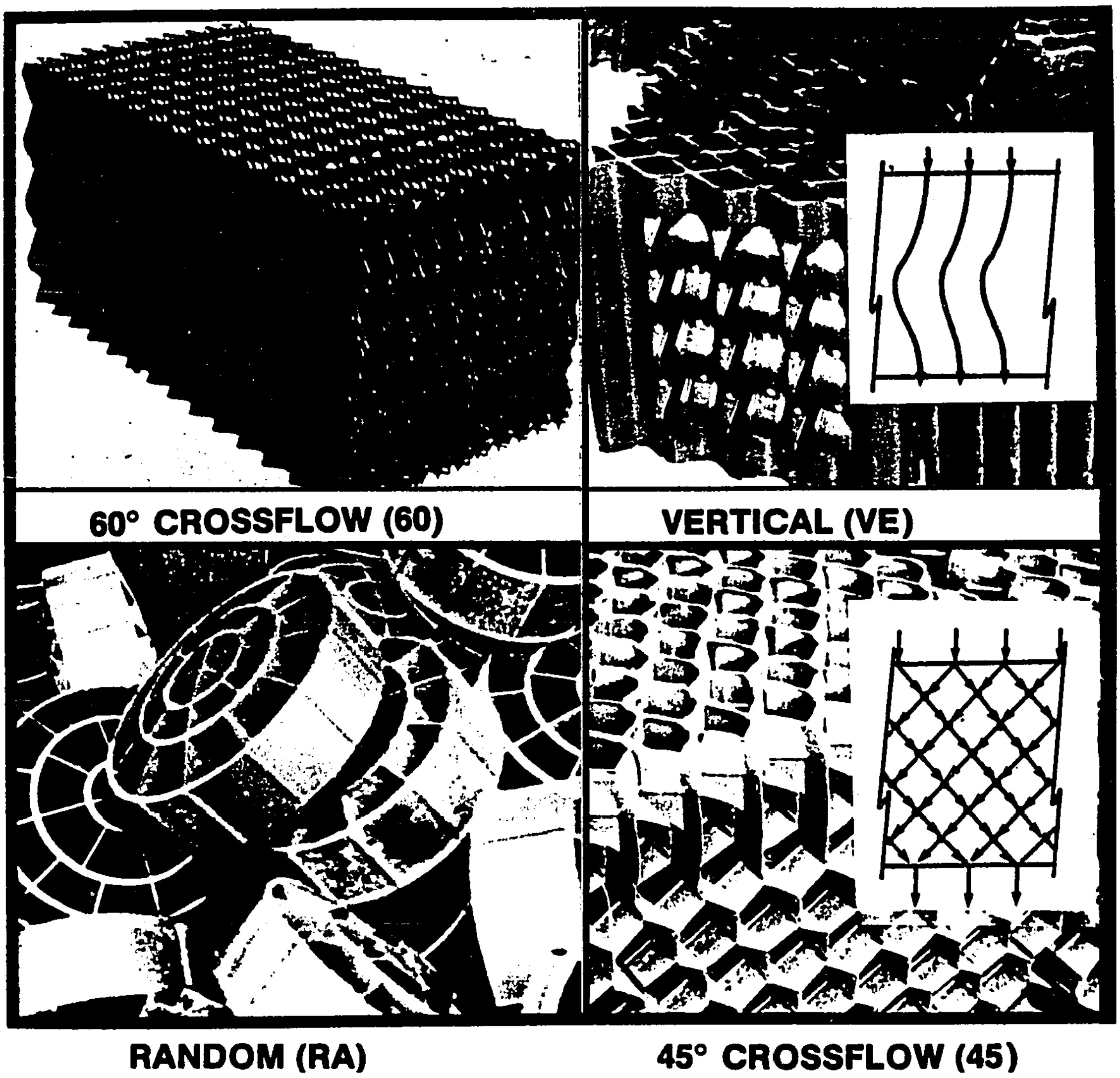
prevent clogging and improve air circulation through the tower. Plastic media may be classified as random, vertical or cross-flow media depending on the placement in the tower and on the hydraulic flow pattern they provide. Figure 2 demonstrates this classification system.

Average hydraulic loading rates of 0.34 to 1.7 $l/m^2.s$ are typically used for trickling filters filled with plastic media. Total BOD_5 loading rates and soluble BOD_5 concentrations must be low in order to achieve high degrees of nitrification. It is generally recommended that the total BOD_5 loading rate not exceed about 4 kg/1000 m^2 of specific surface area/d and that the soluble BOD_5 not exceed 20 to 30 mg/l (Parker and Richards, 1985). Figures 3a and 3b demonstrate the onset of nitrification at soluble BOD_5 values less than 20 mg/l.

A model developed by Wanner and Gujer (1984) predicted that the activity of nitrifiers is dependent on the activity of heterotrophs. Their model predicted that nitrifying microorganisms did not exist in biofilms at soluble chemical oxygen demand (COD) concentrations greater than 27 mg/l.

Current Status of Design Procedures for Nitrification

The degree of nitrification achieved in a trickling filter depends on many operating parameters. The effects of variations in these operating parameters are discussed in detail in subsequent sections. The most important operating parameters are the wastewater



60° CROSSFLOW (60)

VERTICAL (VE)

RANDOM (RA)

45° CROSSFLOW (45)

Figure 2. Trickling filter media. After Harrison and Daigger (1985) and Parker and Merrill (1984)

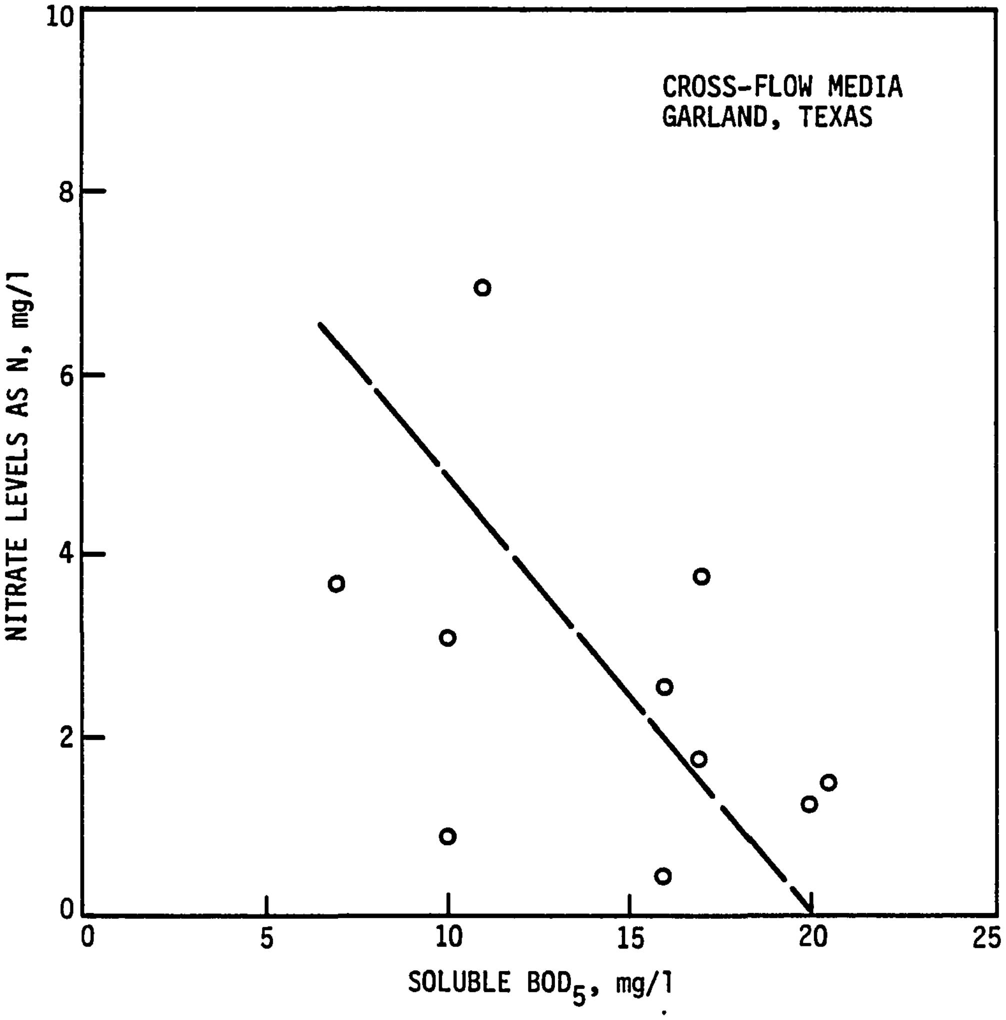


Figure 3a. Nitrification versus soluble BOD_5 concentration. After Parker and Richards (1985)

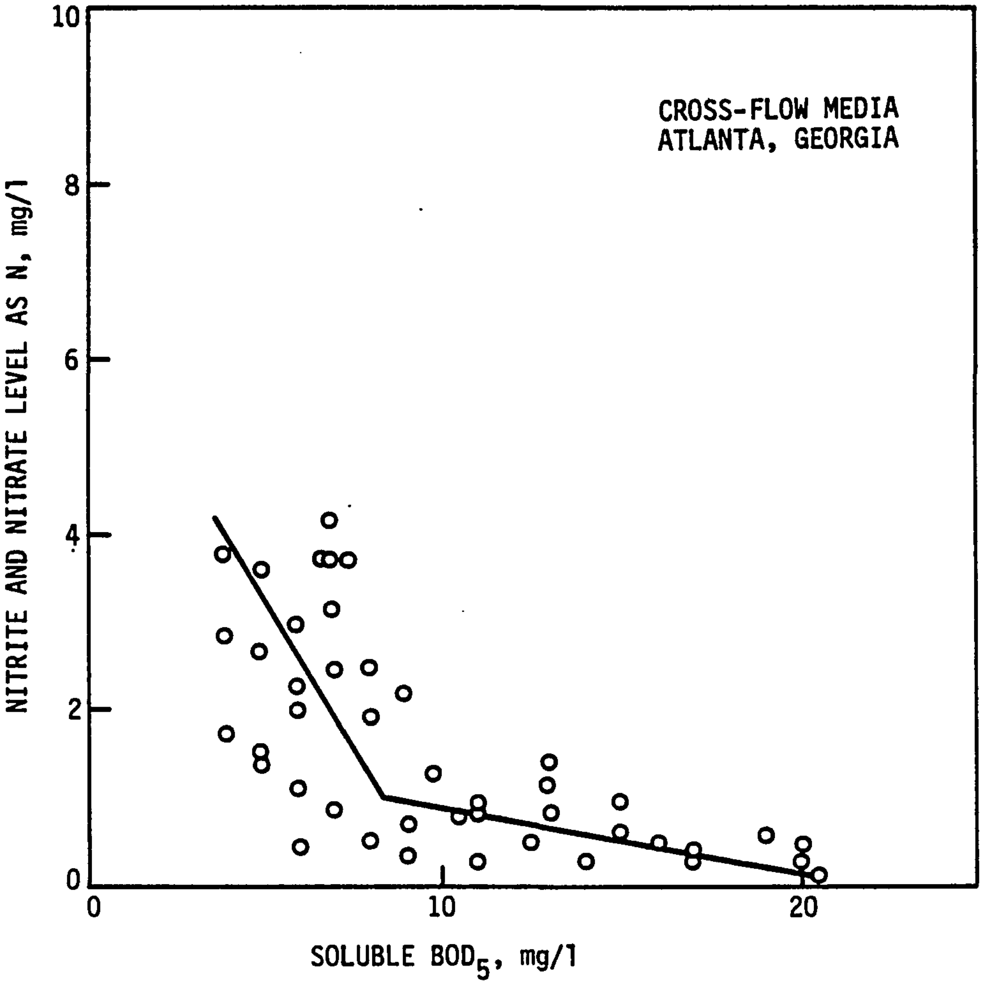


Figure 3b. Nitrification versus soluble BOD$_5$. After Parker and Richards (1985)

temperature, pH, and alkalinity, the hydraulic loading rate, the NH_4^+-N concentration, the recycle ratio, and the organic loading.

There are several mathematical models (Williamson and McCarty, 1976a and 1976b, Suidan, 1986, Rittmann and McCarty, 1978, 1980a, 1980b, and 1981, Harremoes, 1982, and Strand, 1986) for trickling filters that attempt to include nitrification kinetics, the effects of some of the critical operating parameters, and recent fixed-film theoretical concepts. The models are complex and cumbersome, and a good deal of uncertainty is associated with the constants in the models. The current methods for the design of nitrifying trickling filters have been largely or entirely based on empirical data.

Figures 4, 5, 6, and 7 are examples of the types of design curves currently used for nitrification in plastic media trickling filters. The curves present an empirical relationship between the desired effluent NH_4^+-N concentration and the required surface area of media. Strictly speaking, these curves are applicable only to municipal wastewaters and the conditions under which the data were generated. The data were collected for plastic media trickling filters that followed primary treatment and secondary treatment for carbonaceous BOD removal. Secondary sedimentation was included before the nitrification towers. The curves were developed for specific plastic media types, characteristics, and depths, and the curves should not be extrapolated directly to other media types, characteristics, and depths, although the design engineer has few other options in the initial stages of design.

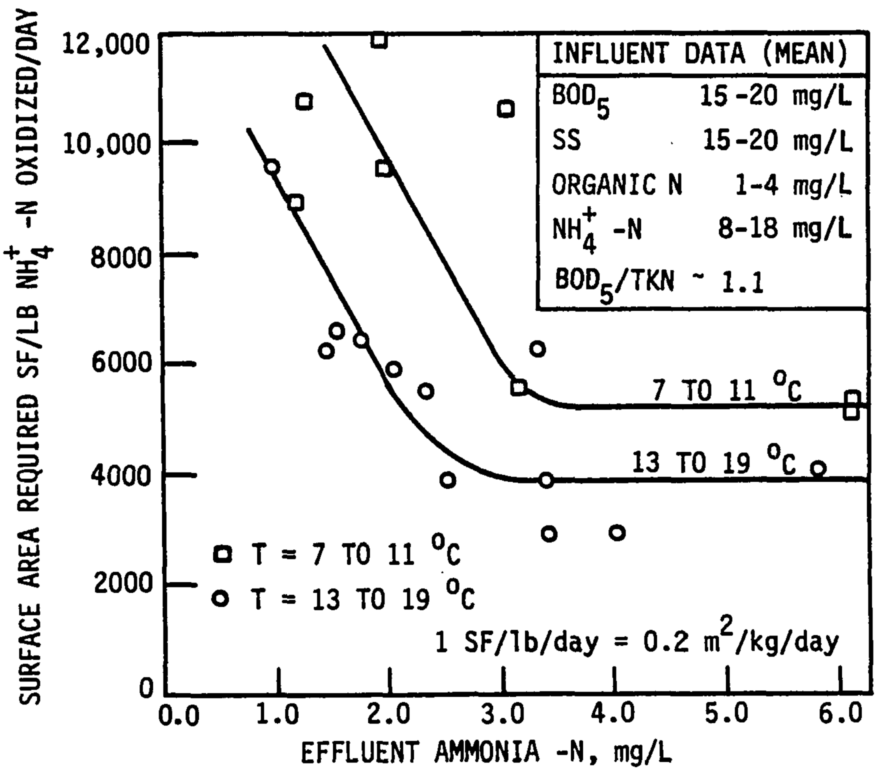


Figure 4. EPA Process Design Manual design curve: Midland, Michigan data

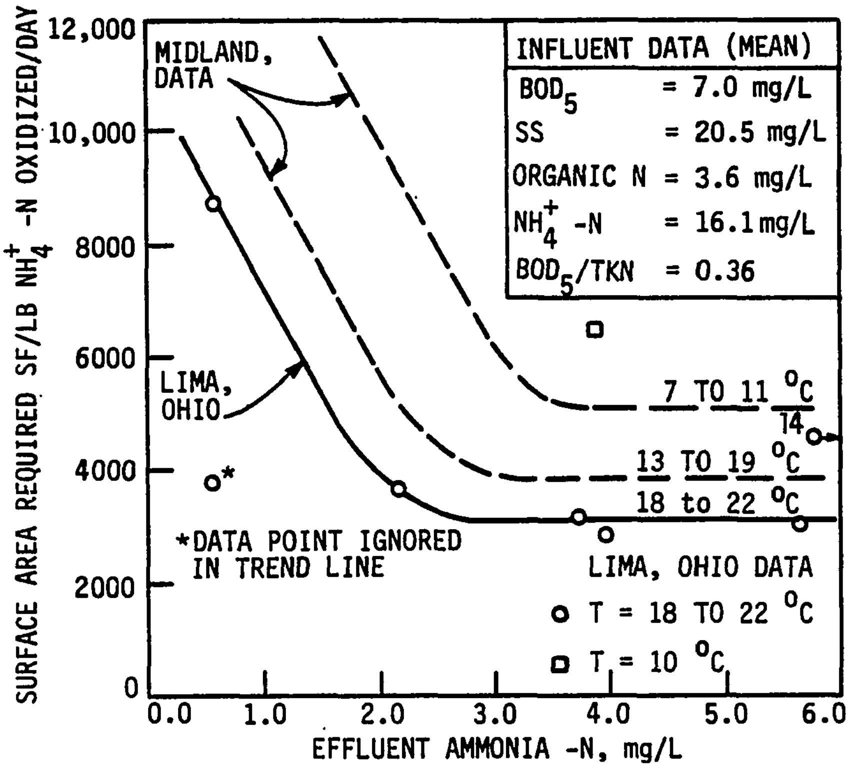


Figure 5. EPA Process Design Manual design curve: Lima, Ohio data

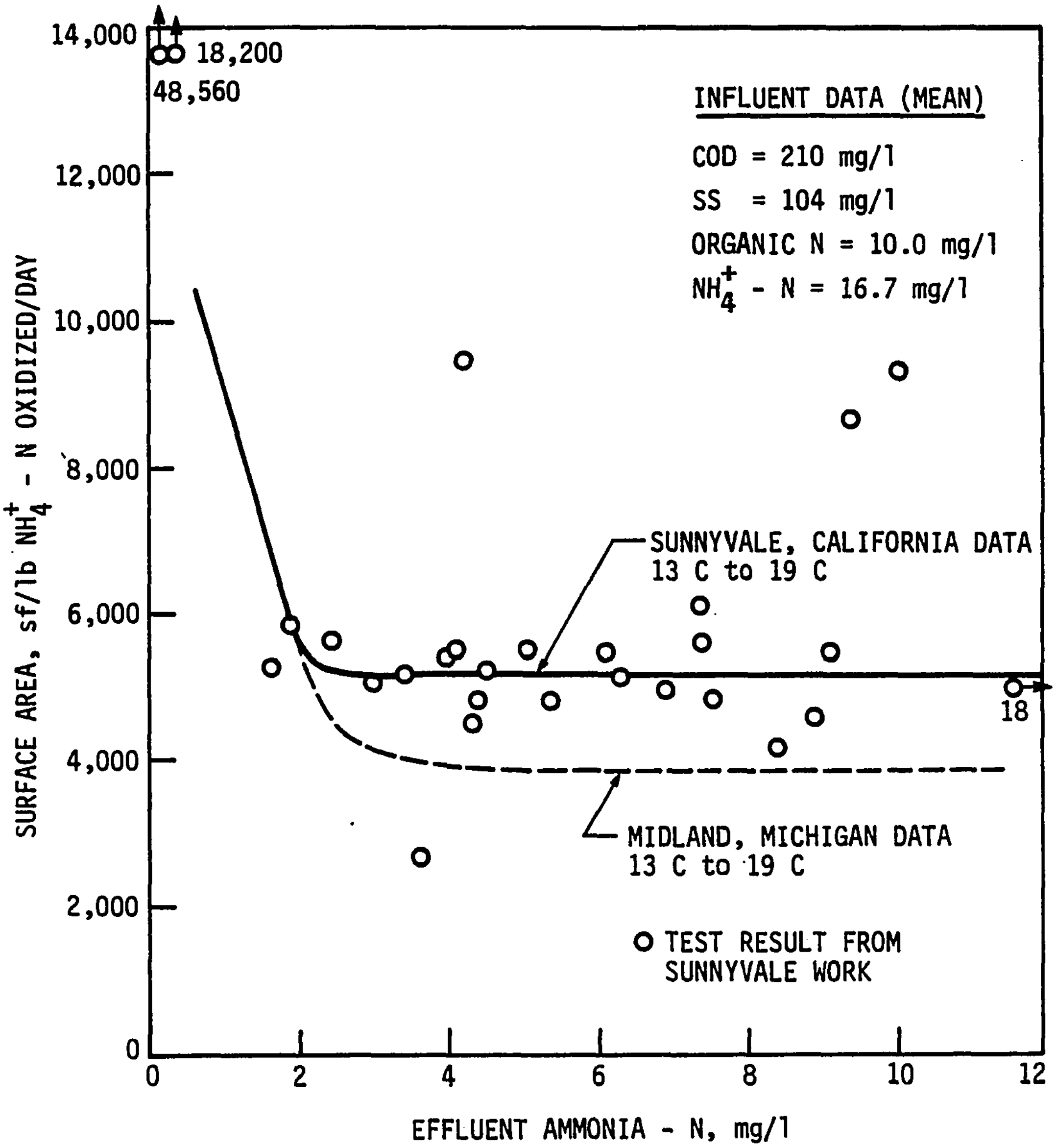


Figure 6. EPA Process Design Manual design curve: Sunnyvale, California data

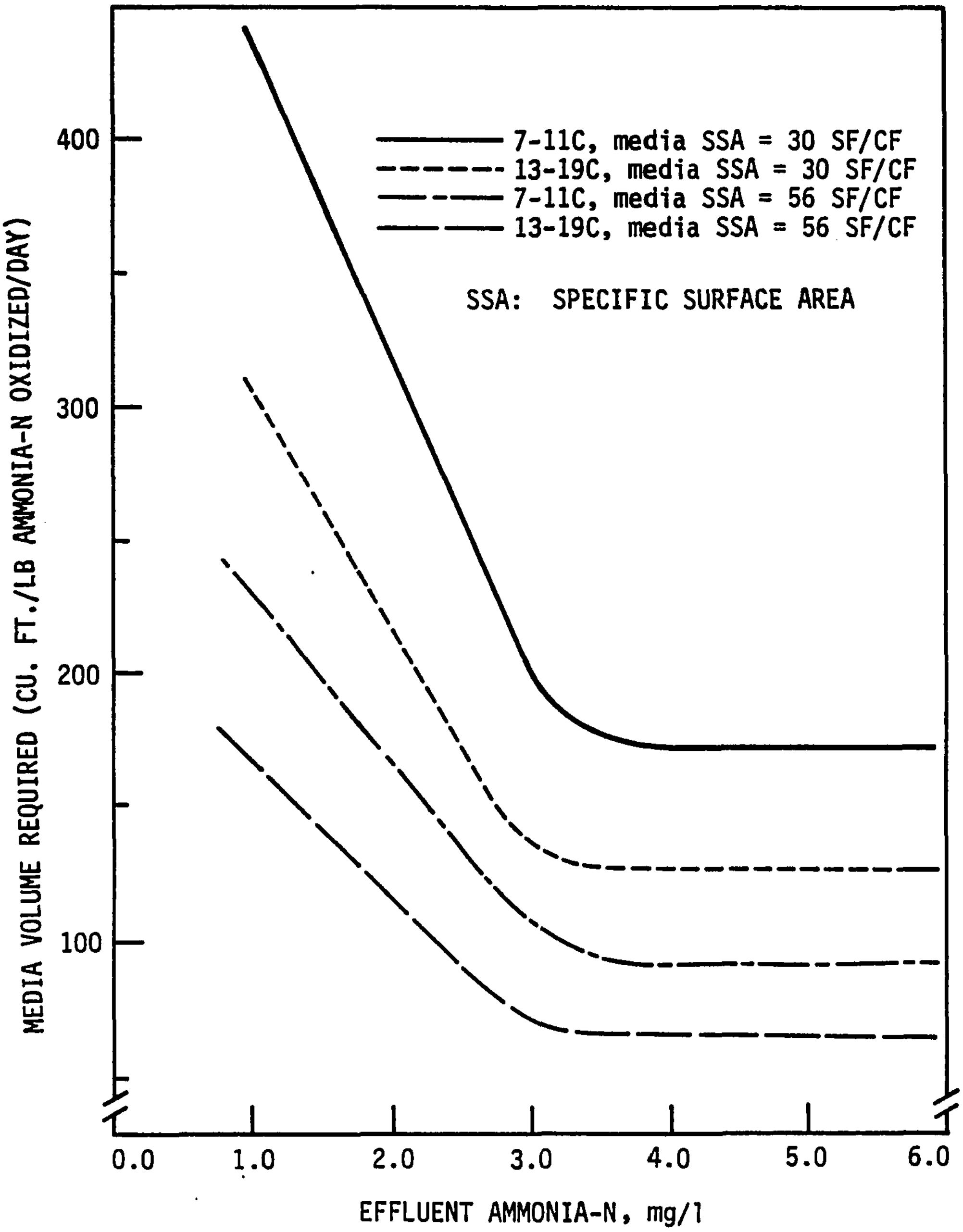


Figure 7. Filterpak ammonia loading curves. After Lewis (1984)

Figure 4 contains some computational errors and Figures 4, 5, 6, and 7 contain conceptual shortcomings which leave their validity in question. Figure 4 contains points that were inaccurately calculated or plotted, and the effects of the independent NH_4^+-N loading rate parameters on the effluent NH_4^+-N concentration are obscured in all four figures. The excessive scatter of the data points clearly illustrates that the effects of the hydraulic loading rate and the influent NH_4^+-N concentration to the tower are not accounted for adequately. Figure 8 shows the effect of NH_4^+-N loading on NH_4^+-N concentration in the tower effluent.

Need for Research

The design of trickling filters for nitrification will likely continue to be based on empirical data in the foreseeable future. The currently available nitrification data, unlike the massive carbonaceous BOD_5 data base, do not provide a sufficient background for evaluation of all the constants needed for the mathematical models. There are many types of plastic media on the market; however, most of the existing data are for media developed more than a decade ago. The data base for the more recently developed cross-flow media is small and largely inaccessible for proprietary reasons. The basis for design must include the effects of NH_4^+-N loading parameters and the other operating variables if it is to be of use in optimizing and designing nitrification trickling filters.

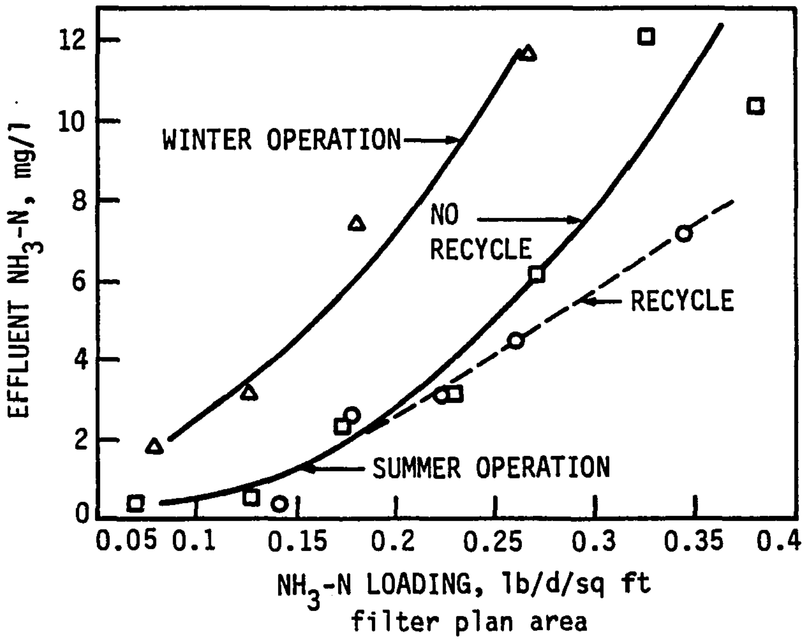


Figure 8. Ammonia loading vs. NH_3-N in tower effluent. After Adams et al. (1981)

Gullicks and Cleasby (1986) proposed new empirical curves (Figures 9 and 10) that would account for the effects of NH_4^+-N loading parameters. These curves were based on the pilot studies conducted at Midland, Michigan, (Duddles and Richardson, 1973 and Duddles et al., 1974) and Bloom Township, Illinois (Baxter and Woodman, Inc. 1973). These curves still retained some of the objectionable limitations discussed above since they were based on pilot data developed with only one type of plastic medium and only one medium depth.

Parker (1984a and 1984b) has called for trickling filter research on trickling filter design models and on media research and design. He acknowledged the recent development of fairly complex biofilm models by the academic community, but observed that they have not been applied by the design community because of their complexity and unproven nature. Consultants have continued to use simplistic design equations and empirical design curves.

Parker reported that the available trickling filter BOD data base consists almost entirely of influent and effluent data only and that very few data from intermediate points exist. The lack of trickling filter nitrification profile data is even greater. Parker called for full-scale trickling filter towers to be built with intermediate sampling points to allow collection of profile data on full-scale units in the future. He stated that profile data would be obtained from a couple of towers in cooperation with the Environmental Protection Agency (EPA) in 1986.

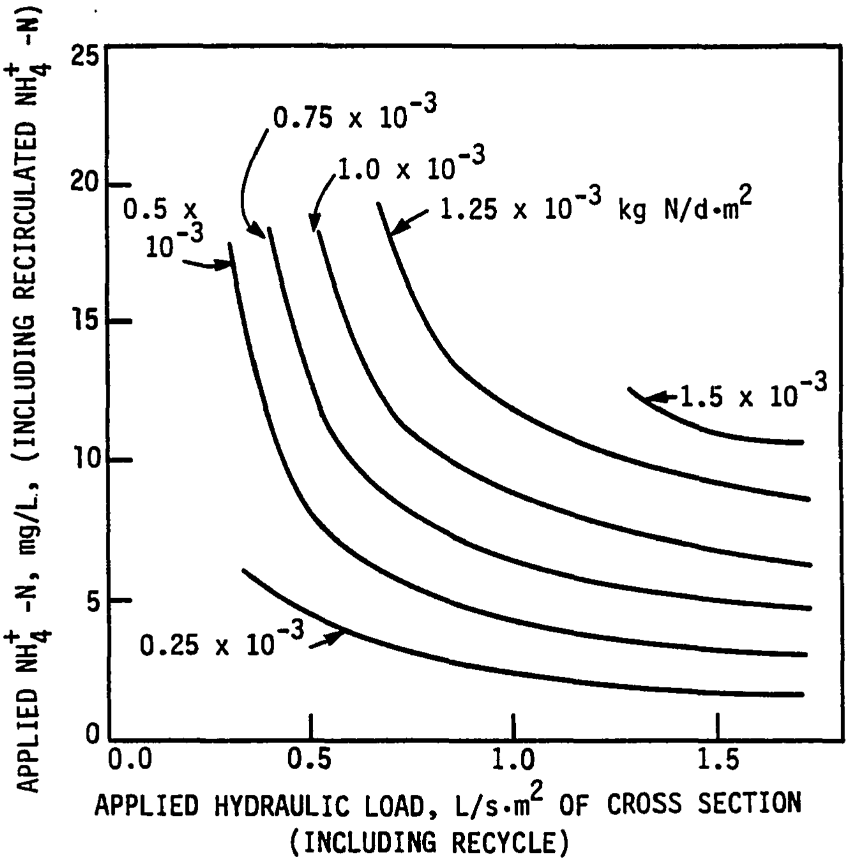


Figure 9. Predicted NH_4^+-N removal, kg/d • m^2 of media surface, versus applied hydraulic load and applied NH_4^+-N for nitrification of municipal secondary clarifier effluent (BOD_5 < 30 mg/L and SS < 30 mg/L), wastewater temperatures > 14°C, and 6.55 m of vertical plastic media (specific surface = 88.6 m^2/m^3). After Gullicks and Cleasby (1986)

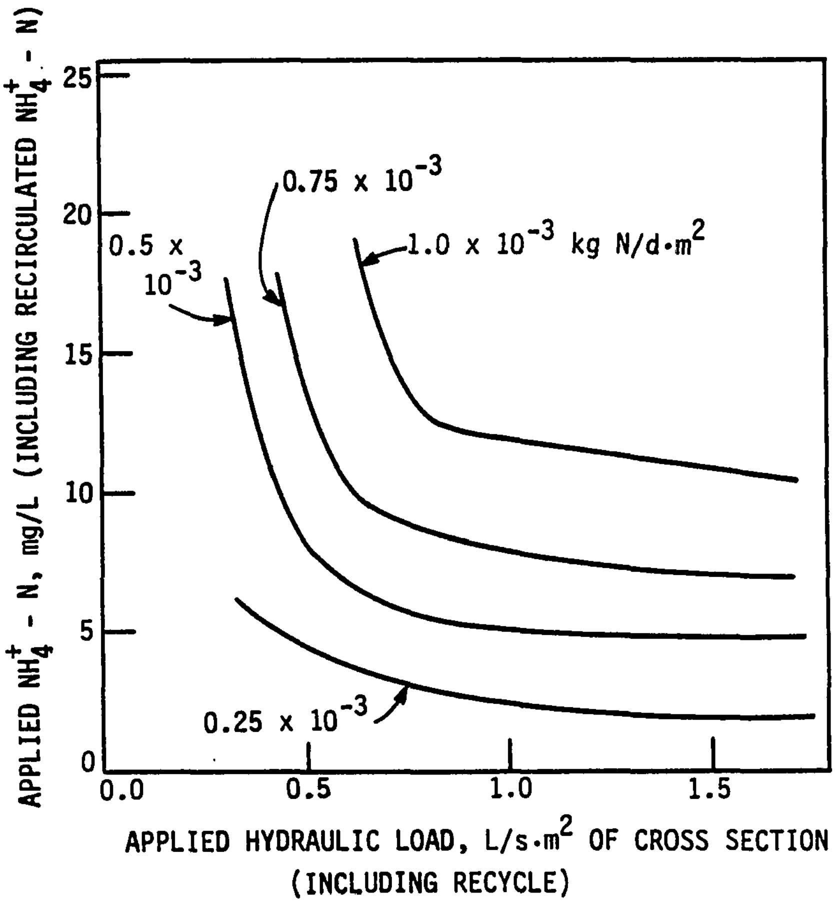


Figure 10. Predicted NH_4^+-N removal, kg/d · m^2 of media surface, versus applied hydraulic load and applied NH_4^+-N for nitrification of municipal secondary clarifier effluent (BOD_5 < 30 mg/L and SS < 30 mg/L), wastewater temperatures 10-14°C, and 6.55 m of vertical plastic media (specific surface = 88.6 m^2/m^3). After Gullicks and Cleasby (1986)

Most, if not all, of the available design models and curves include the total dry specific surface area term rather than an effective or wetted surface area term. In most cases, an increase in the specific surface area is assumed to give a proportional increase in the mass removal capacity of a given volume of media (refer to Figure 7). This is seldom a correct assumption (Brown and Caldwell, 1980, and Sarner, 1984), however, the data necessary to establish the correct relationship between media specific surface area and mass removal capacity for a given volume of media are lacking.

The effects of flow patterns within different media configurations and the effects of different wastewater application methods have recently received greater attention. Unfortunately, much of this information has been evaluated only by simplistic design equation methods rather than in conjunction with proposed fixed-film models. The media manufacturers have claimed that cross-flow media possess superior hydraulic residence times, surface wetting characteristics, and oxygen transfer characteristics. The superior hydraulic residence times of cross-flow media have been demonstrated by tracer test methods (Albertson and Davies, 1984, Albertson and Eckenfelder, 1984, Drury et al., 1986, Harrison and Daigger, 1985, Parker and Merrill, 1984, and Richards and Reinhart, 1986).

The surface wetting and oxygen transfer superiority claims are largely speculative and disputed at this time. Total wetted surface area and total oxygen transfer area undoubtedly increase with increases in specific surface area, but no data exist to show that cross-flow media wetted surface areas are greater than the wetted surface areas of vertical-flow media when both have the same total specific surface area. The work of Logan et al. (1986) suggests that cross-flow media provide better liquid phase mass transfer than vertical-flow media (and, therefore, better oxygen mass transfer) because mixing of the liquid film occurs at more configuration nodes.

The majority of pilot-scale trickling filter data have been collected using continuous dosing of wastewater to the filter. Few studies have included intermittent dosing of the wastewater even though full-scale plants typically are dosed intermittently by rotating distributors.

The majority of nitrification data available for trickling filters are for wastewater temperatures greater than 15°C. Cold climate data are needed to allow designers to extend trickling filter technology to cold-climate nitrification process designs.

PURPOSE AND OBJECTIVES

The city of Ames, Iowa, plans to construct a new dual-stage trickling filter water pollution control plant (WPCP) to replace the existing, overloaded, conventional trickling filter plant. The new plant is expected to provide carbonaceous BOD removal in the first stage filter and nitrification in the second stage filter. Iowa State University obtained a grant from the city of Ames to study cold-climate, separate-stage nitrification in a pilot-scale trickling filter filled with high specific surface, cross-flow plastic media. The experimental investigation reported herein was conducted at the existing Ames WPCP and was limited to separate-stage nitrification.

There has been a lack of nitrification data for trickling filters, particularly in cold climates. Ammonium profile data (concentration versus tower depth) in trickling filters are lacking. Few nitrification data are available for cross-flow media. The effective media surface area is unknown at this time, and researchers and designers use the dry specific surface area of the media in their equations and models. The recently developed, theoretically based fixed-film models are largely unproven due to the lack of available profile data. The majority of equations currently used in design assume first-order kinetics despite the fact that the upper portions of trickling filters often follow zero-order kinetics (with respect to the contaminant substrate). Data from intermittently-dosed, pilot-scale plants are lacking.

The investigation was undertaken to examine the effects of a range of hydraulic loading rates and influent NH_4^+-N concentrations on nitrification in cross-flow plastic media at wastewater temperatures ranging from 6° to 14°C. Limited data were collected at wastewater temperatures greater than 15°C to allow comparison of nitrification performance reported in the literature with that achieved in this experimental work.

The specific objectives of this study were to:

1. Determine the individual effects of hydraulic loading rate and influent NH_4^+-N concentration on areal nitrification rates.
2. Determine the effect of wastewater temperature on areal nitrification rates.
3. Compare continuously-dosed pilot plant and intermittently-dosed pilot plant performance.
4. Provide NH_4^+-N, DO, NO_2^--N + NO_3^--N, TKN, COD, pH, and wastewater temperature profile data in cross-flow plastic media.
5 Verify or disprove zero-order nitrification kinetics with respect to NH_4^+-N concentrations, which is predicted at concentrations greater than 4 mg/l.
6. Examine the effective or wetted specific surface area of the cross-flow media, and if possible, establish a relationship between the hydraulic loading rate, the dry media specific surface area, and the wetted specific surface area.
7. Examine some of the theoretically-based, fixed-film models to determine if they adequately predict the nitrification performance observed in the pilot-scale plant.

8. Improve the design curves previously proposed by Gullicks and Cleasby (1986).

REVIEW OF LITERATURE

Nitrogen, in one or more of its numerous oxidation states, is a key component of life processes for all plants and animals. Nitrogen forms most important to environmental engineers are organic, gaseous, nitrite, nitrate, and ammonia nitrogen which possess oxidation states of -3, 0, +3, +5, and -3, respectively.

The conversion of ammonia to nitrite and nitrite to nitrate, a process called nitrification, is accomplished biologically by two principal autotrophic bacteria genera, Nitrosomonas and Nitrobacter. Autotrophic nitrifying organisms derive their energy from the oxidation of inorganic nitrogen substances, rather than organic matter; and they utilize carbon dioxide as a carbon source for synthesis, rather than organic carbon.

Nitrifier Growth

Nitrosomonas and Nitrobacter must both be available to achieve complete nitrification. Nitrosomonas can only convert ammonia to nitrite, while Nitrobacter can only convert nitrite to nitrate. The growth rate of Nitrosomonas is limited by the concentration of NH_4^+-N, while the growth of Nitrobacter is limited by the concentration of NO_2^--N. The kinetics of biological growth are usually described by the Monod kinetic equation:

$$\mu = \hat{\mu} \frac{S}{K_s + S} \tag{1}$$

where: μ = specific growth rate of microorganisms, $\frac{\text{mass of microorganism}}{\text{mass of biofilm} \cdot t}$

$\hat{\mu}$ = maximum specific growth rate of microorganisms, $\frac{\text{mass of microorganism}}{\text{mass of biofilm} \cdot t}$

K_s = half velocity constant = growth limiting substrate concentration at half the maximum growth rate, mg/cm^3.

S = growth limiting substrate concentration, mg/cm^3.

The Haldane kinetic equation, which includes an inhibitory term in the denominator is gaining in popularity. It is expressed as follows (Rozich and Castens, 1986):

$$\mu = \frac{\hat{\mu}S}{K_s + S + S^2/K_i} \tag{2}$$

where: K_i = Haldane inhibition constant, mg/cm^3.

Figure 11 gives a graphical comparison of the Monod and Haldane kinetic growth rate equations. Rozich and Castens (1986) conducted a completely-mixed, two-stage, continuous culture study and reported that nitrification kinetics are represented more accurately by the Haldane equation. Table 1 gives values for $\hat{\mu}$, K_s, and K_i calculated using a biomass mass balance equation and using a substrate mass balance equation. The Haldane equation gave comparable values for both mass balances, while the Monod equation did not. Allowable parameter ranges for which Haldane kinetics are valid are also given in Table 1.

Inhibition kinetics is of greater significance in activated sludge processes than in fixed-film processes where the rate-limiting reactant

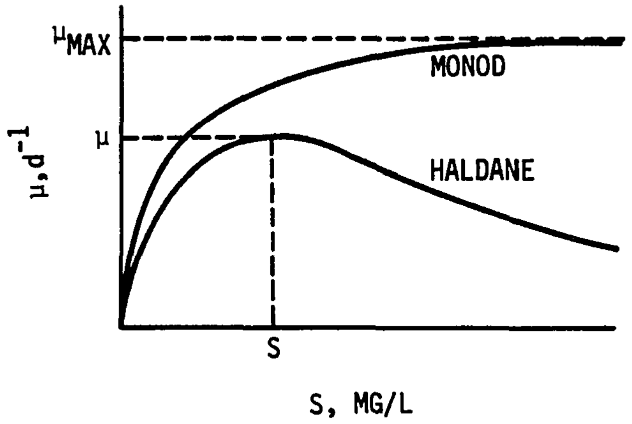


Figure 11. Comparison of Monod (noninhibitory) and Haldane (inhibitory) growth rate models. After Rozich and Castens (1986)

Table 1. Results of the growth model fits to nitrifier growth rate data. After Rozich and Castens (1986)

	Biomass Mass Balance Basis		Substrate Mass Balance Basis		
Parameter	Monod Equation	Haldane Equation	Monod Equation	Haldane Equation	Allowable Parameter Ranges for Haldane Equation Validity
$\hat{\mu}$ $\frac{\text{mass of microorganism}}{\text{mass of cells} \cdot \text{day}}$	0.25	1.20	0.90	1.23	$1.20 \text{ X } \hat{\mu} < 3.60$
K_s, mg N/l at $\frac{1}{2}$ $\hat{\mu}$	0.8	2.7	2.1	2.6	$1 \leq K_s \leq 20$
K_i, mg N/l		19.7		19.9	$5 \leq K_i \leq 100$

may be oxygen rather than NH_4^+-N. The discussion in the subsequent section dealing with the determination of the flux-limiting reactant will make this point clear.

The maximum growth rate of Nitrobacter is much greater than that of Nitrosomonas. K_s values, mg N/l, for both species are small. Thus, nitrite cannot accumulate to high concentrations in biological treatment systems under steady state conditions, and the conversion of NH_4^+-N to nitrite is the rate-limiting step for nitrifier growth.

Calculations based on thermodynamic theory predict that 0.29 mg Nitrosomonas will be synthesized per mg of ammonia nitrogen oxidized. Similarly, 0.084 mg Nitrobacter will be synthesized per mg of nitrite nitrogen oxidized. Experimentally measured yield values are considerably lower than these values probably because of microorganism maintenance functions (Haug and McCarty, 1971).

Nitrification usually occurs in aqueous carbonic acid systems at pH values less than 8.3. The consumption of carbon dioxide by the organisms results in some depletion of the dissolved carbon dioxide form (carbonic acid, H_2CO_3). Simultaneously, the production of free acid (H^+) by the organisms proceeds immediately through reaction with bicarbonate (HCO_3^-) to carbonic acid. Synthesis-oxidation equations have been developed for Nitrosomonas and Nitrobacter using representative yield values of 0.15 and 0.02 mg VSS per mg of nitrogen oxidized, respectively, and representative oxygen consumption measurements (Gujer and Jenkins, 1974 and Water Pollution Research Laboratory, England, 1971). These equations are:

$$55\ NH_4^+ + 76\ O_2 + 109\ HCO_3 \xrightarrow{\text{Nitrosomonas}} C_5H_7NO_2 + 54\ NO_2^- + 57\ H_2O + 104\ H_2CO_3 \qquad (3)$$

$$400\ NO_2^- + NH_4^+ + 4\ H_2CO_3 + HCO_3^- + 195\ O_2 \xrightarrow{\text{Nitrobacter}} C_5H_7NO_2 + 3\ H_2O + 400\ NO_3^- \qquad (4)$$

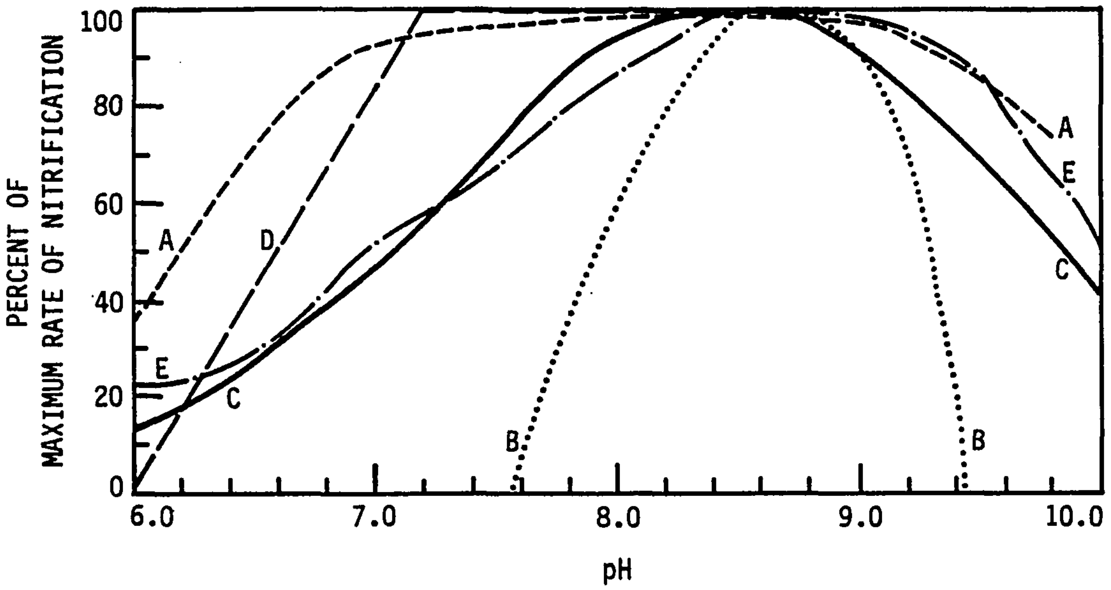
overall synthesis and oxidation reaction:

$$NH_4^+ + 1.86\ O_2 + 1.98\ HCO_3^- \rightarrow 0.0206\ C_5H_7NO_2 + 1.041\ H_2O + 0.980\ NO_3^- + 1.88\ H_2CO_3 \qquad (5)$$

The synthesis-oxidation equation indicates that approximately 7 mg of alkalinity are consumed per mg of NH_4^+-N oxidized and that the H_2CO_3 concentration increases. Thus, the pH of the system decreases. In an open system, such as the trickling filter, carbon dioxide is continually stripped from the wastewater retarding the pH depression as long as sufficient alkalinity was present initially in the wastewater. Gujer and Boller (1984) reported that alkalinity was rate limiting at bulk liquid concentrations less than 1 meq/l (50 mg/l as $CaCO_3$). Figure 12 shows that nitrification rates are significantly lower at pH values below 7.

Trickling Filter Fixed-Film Theory

Sarner (1981), Richards (1984), Richards and Reinhart (1986), Muslu (1983), Harrison and Daigger (1985), Germain (1966), and Parker and Merrill (1984) have shown that the trickling filter behaves like a plug flow reactor with varying degrees of dispersion. That is,



KEY SYMBOL	ENVIROMENT	REFERENCE
A	NITROSOMONAS - pure culture	ENGLE AND ALEXANDER (1958)
B	NITROSOMONAS - pure culture	MEYERHOF (1917)
C	ACTIVATED SLUDGE AT 20 C	SAWYER ET AL. (1973)
D	ACTIVATED SLUDGE	DOWNING AND KNOWLES (1966)
E	ATTACHED GROWTH REACTOR AT 22 C	HUANG AND HOPSON (1974 a,b)

Figure 12. Effect of pH on nitrification rate. After Sawyer et al. (1973)

wastewater distributed to the top of the filter at any given time tends to flow as a unit from the top to the bottom of the tower.

Maier et al. (1967), Williamson and McCarty (1976a and 1976b), and Logan et al. (1986) have shown that the flow of wastewater over the surface of media in trickling filters at the hydraulic loading rates in common use is laminar. This implies that a nearly-stagnant layer exists next to the biofilm and that the bulk flow is smooth and streamlined as represented in Figure 13.

Substrate must diffuse through the bulk liquid layer, across the "stagnant" layer, and into the biofilm layer where microorganisms use it for growth. Oxygen must diffuse across the air-liquid interface, across the entire bulk liquid layer, across the "stagnant" layer, and into the biofilm layer where microorganisms utilize it. The bulk liquid layer is considered to be void of microorganisms in order to simplify the modeling of mass transport in trickling filters. This is a valid approximation in view of the relative populations of the microorganisms in the biofilm and in the liquid.

Diffusion through the bulk liquid and the "stagnant" layer at the biofilm interface is largely dependent on the liquid nearest the biofilm. Thus, diffusion through the bulk liquid and the "stagnant" layer is arbitrarily represented by diffusion through an effective or equivalent liquid diffusion layer.

Figure 14 is a schematic representation of the potentially rate-limiting phenomena in biofilm reactions and substrate concentration

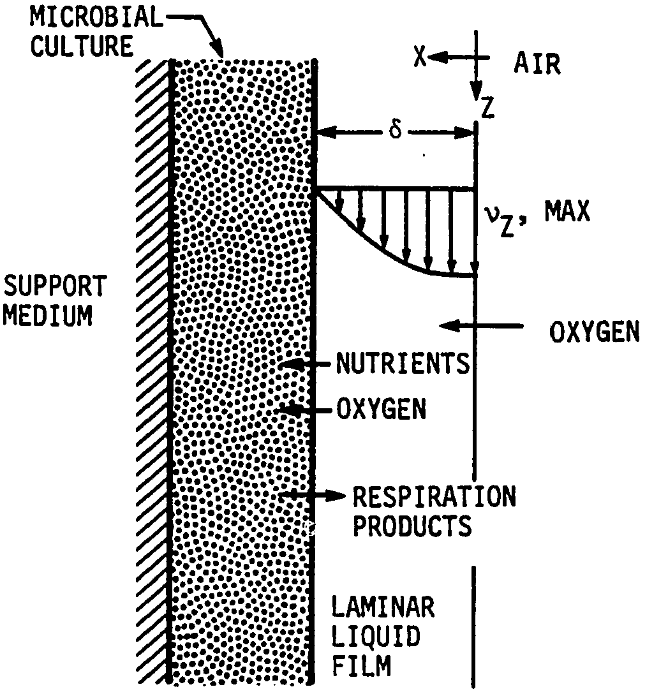


Figure 13. Schematic model of the trickling filtration process. After Vaughan and Holder (1984).

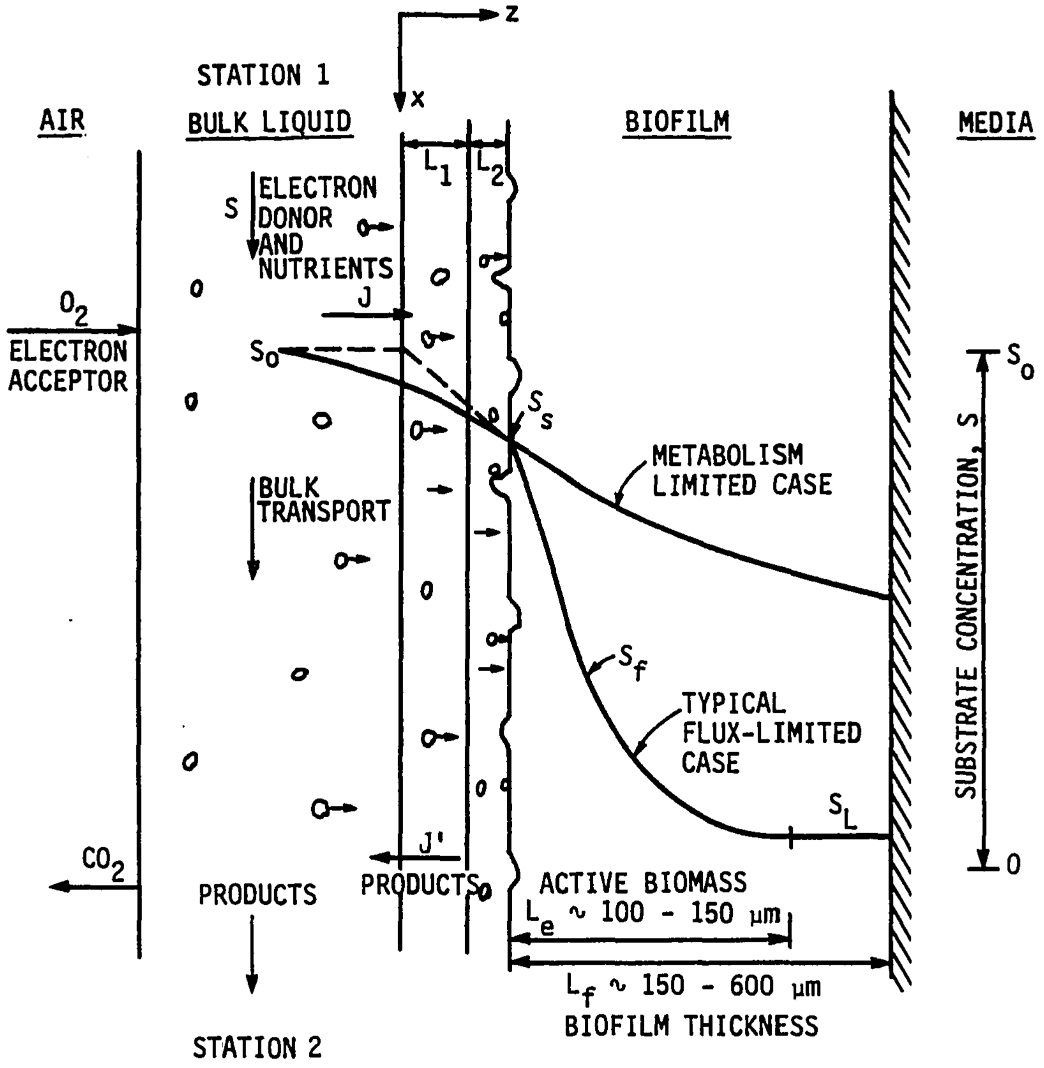


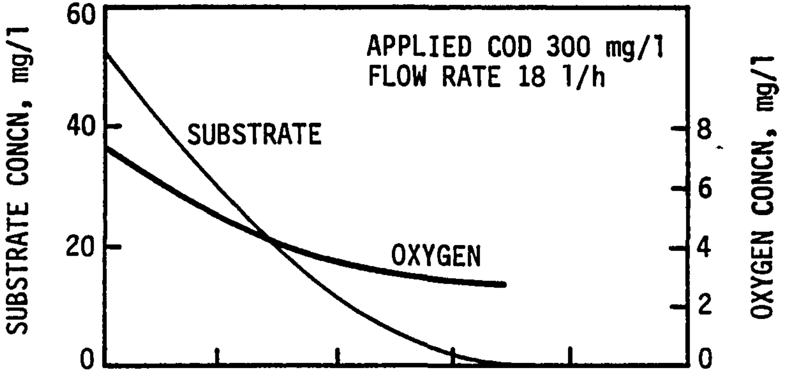
Figure 14. Schematic showing the potentially rate-limiting phenomena in biofilm reactions and substrate concentration profiles. After Gullicks and Cleasby (1986)

profiles. The biofilm thickness is greater than the active biomass layer in nearly all situations, except when excess sloughing or hydraulic shearing of the biofilm occur. The rate of substrate utilization is usually flux-limited (i.e., mass transport limited). The limitation of the rate of substrate utilization by the ability of the microorganisms to process the reactants, a process called metabolism limitation, typically occurs only when excess sloughing or hydraulic shearing of the biofilm occur so that all reactants fully penetrate the biofilm at concentrations high enough to sustain growth.

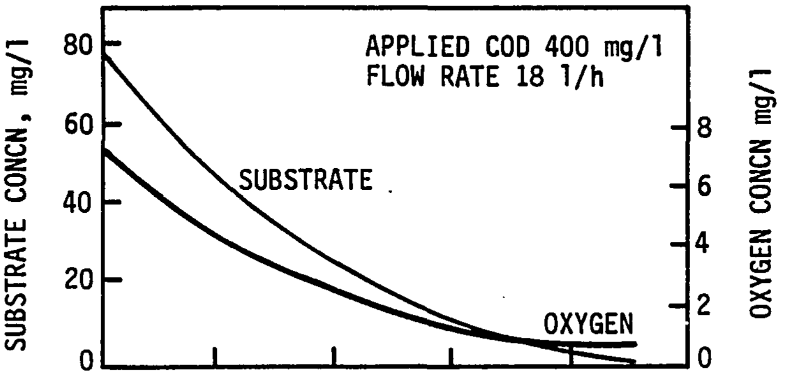
Flux-Limitation of Substrate Uptake

Harris and Hansford (1976) demonstrated that the rate of substrate uptake in trickling filters could be flux-limited by the substrate, or by oxygen, or by both the substrate and oxygen simultaneously depending on which reactant is depleted first within the biofilm depth as shown in Figure 15. Simultaneous substrate and oxygen flux limitation occurs over a narrow region of the normal range of bulk liquid substrate concentrations applied in fixed-film nitrification processes (Rittmann and Dovantzis, 1983). Therefore, consideration of a single reactant as the flux-limiting species simplifies the mathematics necessary for modeling, and the error, in any case, probably is not greater than the uncertainties related to measurement of the many parameters associated with the Monod or Haldane kinetic equations, or for that matter, the measurement of the constants associated with fixed-film modeling and design equations.

(a) SUBSTRATE LIMITATION



(b) SIMULTANEOUS SUBSTRATE AND OXYGEN LIMITATION



(c) OXYGEN LIMITATION

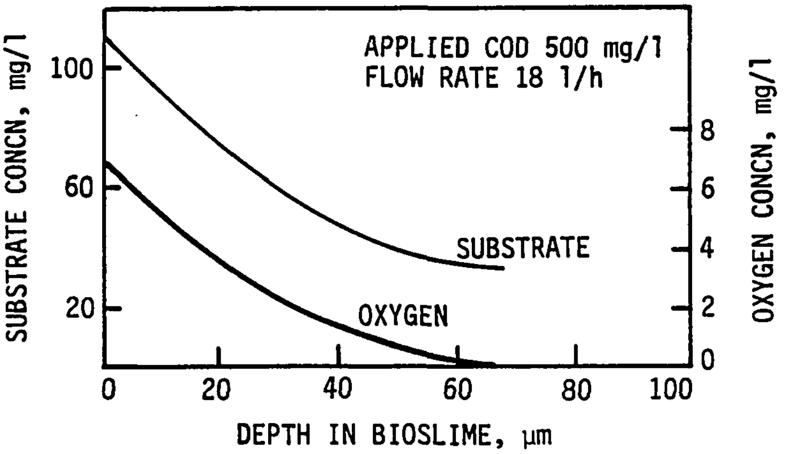


Figure 15. Typical oxygen and substrate concentration profiles in a biofilm. After Harris and Hansford (1976)

Mass transfer in the liquid phase can be represented by Equation 6 when a single reactant is rate-limiting (Williamson and McCarty, 1976a).

$$J = -AD_w \frac{dS}{dZ} = -AD_W \, (S_s - S_o)/L_1 + L_2) \qquad (6)$$

where

J = mass transfer rate, mg/d

A = cross sectional area perpendicular to the direction of mass transfer, cm^2

D_w = diffusivity of the limiting reactant, either oxygen or substrate, in the wastewater, cm^2/d

S_o = concentration of the limiting reactant in the bulk liquid, mg/cm^3

S_s = concentration of the limiting reactant at the biofilm-liquid interface, mg/cm^3

L_1+L_2 = the effective liquid diffusion layer thickness, cm. L_2 is relatively constant. L_1 varies with hydraulic loading.

Z = distance in the direction of mass transfer, cm.

The utilization or rate of uptake of the single limiting reactant in the biofilm is proportional to the biomass density and follows a saturation functional pattern commonly represented by Monod kinetics. The ammonium oxidation rate can be related to the Nitrosomonas growth rate for any single limiting reactant as follows:

$$\frac{dS_f}{dt} = -k\ S_f X_f/(K_s + S_f) = -\frac{\hat{\mu}_N}{Y_N}\ \frac{\nu\ MW}{\nu_N MW_N}\ \frac{X_f S_f}{K_s + S_f} \qquad (7)$$

where:

S_f = concentration of the limiting reactant, either oxygen or substrate, in the biofilm, mg/cm³

t = time, d

k = maximum specific rate of utilization of the limiting reactant, mass of reactant/mass of biofilm • d

K_s = limiting reactant half-velocity coefficient, mg/cm³

X_f = biofilm density, mg/cm³

Y_N = specific nitrifier organism yield coefficient, $\frac{\text{mass of nitrifiers}}{\text{mass N oxidized}}$

$\hat{\mu}_N$ = maximum specific growth rate of nitrifiers, $\frac{\text{mass of nitrifiers}}{\text{mass of biofilm} \cdot \text{d}}$

ν = stoichiometric coefficient of limiting reactant in Eq. 5

ν_N = stoichiometric coefficient of nitrogen in Eq. 5

MW = molecular weight of limiting reactant

MW_N = molecular weight of nitrogen

Molecular diffusion in the biofilm is related to the limiting reactant gradient by Fick's second law.

$$\frac{dS_f}{dt} = D_f \frac{d^2 S_f}{dZ^2} \qquad (8)$$

Where:

D_f = the diffusivity of the limiting reactant in the biofilm (cm^2/d).

Consequently,

$$\frac{d^2S_f}{dZ^2} = \frac{dS_f}{dt} \cdot \frac{1}{D_f} = -kX_fS_f/(D_f \cdot (K_s + S_f)) \qquad (9)$$

Analytical solutions to this differential equation are not available except for limiting cases of the Monod equation where $S_s >> K_s$ or $S_s << K_s$. Where flux limitation exists, the solution must satisfy the following boundary equations for deep biofilms: $S_f = S_s$ at $Z = 0$ (relative to the biofilm surface; $Z = L_1 + L_2$ relative to the axes of Figure 14); $dS_f/dZ = 0$ at $Z = L_e$ (relative to the biofilm surface); and $S_f = S_L$ at $Z = L_e$ (relative to the biofilm surface) where L_e is the active biofilm thickness (cm) and S_L is some limiting reactant concentration equal to a small fraction of the corresponding half-velocity coefficient.

Williamson and McCarty (1976a and 1976b) demonstrated that the electron acceptor, oxygen, will be both the flux-limiting and metabolism-limiting reactant species if the following conditions are satisfied:

$$S_{oa} < \frac{D_{fd} \cdot \nu_a \cdot MW_a}{D_{fa} \cdot \nu_d \cdot MW_d} S_{od} \qquad (10)$$

$$S_{fa} < K_{sa} S_{fd}/K_{sd} \qquad (11)$$

where:

S_{oa} = bulk liquid oxygen concentration, mg/l

S_{od} = bulk liquid NH_4^+-N, (substrate) concentration, mg/l

D_{fa} = diffusivity of oxygen in the biofilm, cm^2/d

D_{fd} = diffusivity of NH_4^+-N in the biofilm, cm^2/d

ν_a = stoichiometric coefficient of oxygen in Eq. 5

ν_d = stoichiometric coefficient of NH_4^+-N in Eq. 5

S_{fa} = oxygen concentration at any depth in the biofilm, mg/l

S_{fd} = NH_4^+-N (substrate) concentration at any depth in the biofilm, mg/l

K_{sa} = oxygen half-velocity coefficient, mg/l

K_{sd} = NH_4^+-N half-velocity coefficient, mg/l

MW_a = molecular weight of oxygen

MW_d = molecular weight of nitrogen

Parker and Merrill (1984) showed that BOD removal in a trickling filter plant at Malmo followed zero-order kinetics in the upper zone and first-order kinetics in the lower zone, as predicted by the equations of Williamson and McCarty. Richards and Reinhart (1986) obtained similar results for pilot-scale trickling filters at Atlanta, Georgia.

Using the Williamson and McCarty equations 10 and 11, Gullicks and Cleasby (1986) showed that the electron acceptor, oxygen, was both the metabolism-limiting and the flux-limiting reactant for bulk liquid NH_4^+-N concentrations greater than 4 mg/L even when the bulk liquid was nearly saturated with dissolved oxygen. Therefore, in most domestic wastewater treatment trickling filter applications, oxygen will be the limiting reactant through a substantial portion of the media depth or even the entire media depth in some cases.

In those depths of the nitrification tower where the NH_4^+-N concentration is greater than 4 mg/L, the oxidation of NH_4^+-N will be a linear function of filter depth (zero-order with respect to NH_4^+-N concentration) if the bulk liquid oxygen concentration is assumed to be constant with filter depth. Nearly constant oxygen concentration with depth is probable if adequate air ventilation is provided so that the partial pressure of oxygen is essentially the same at all depths in the tower.

Atasi and Borchardt (1984) have summarized the bulk liquid substrate kinetics that would be observed for various biofilm kinetics and for partial or full penetration of the substrate in the biofilm. They concluded that zero-order substrate kinetics are observed in the bulk liquid when the intrinsic biofilm reaction rate is pseudo-zero-order ($K_s < S$) and the substrate fully penetrates the biofilm.

Nitrification has been reported at D. O. concentrations as low as 0.5 mg/l, but at much lower rates than at higher D. O. concentrations (Culp and Heim, 1978 and O'Shaughnessy et al., 1984). Wuhrmann (1960) demonstrated that activated sludge plants achieved higher nitrification efficiency at D. O. concentrations of 4-7 mg/l than at

1 mg/l when other operating conditions were similar. The Ministry of Technology (1965) demonstrated that the rate of nitrification in activated sludge plants was about 10 percent higher with D. O. concentrations of 4-8 mg/l than with a D. O. concentration of 2 mg/l.

Schoberl and Engel (1964) used a polarographic laboratory technique and reported that growth of Nitrosomonas was oxygen-limited at D. O. concentrations of 0.9 mg/l and that growth of Nitrobacter was oxygen-limited at D. O. concentrations of 2 mg/l. They also found that the limiting D. O. concentration increased as the concentration of nitrifier cells increased. This implies that limiting D. O. concentrations in fixed-films may be higher than those in suspended growth reactors. Meyerhof (1917) and Ulken (1963) also found Nitrobacter to be more sensitive to oxygen depletion than Nitrosomonas.

Bulk liquid D. O. concentrations are considerably higher than 0.5 mg/l in nitrifying trickling filters with low organic loadings, but D. O. concentrations in the biofilm, which have not been measured, could drop below 0.5 mg/l before fully penetrating the biofilm. Brown and Caldwell (1980) reported improvement in nitrification in a biofilter when forced draft was increased.

Near-linear removal of NH_4^+-N with depth is evident in the literature for NH_4^+-N concentrations greater than about 4 mg/L (Duddles and Richardson, 1973, O'Shaughnessy et al., 1984, Huang and Hopson, 1974b, Wilderer et al., 1982, and Parker and Richards, 1985). Bruce et al. (1975) reported that ammonia mass removal rates in their nitrifying trickling filters did not change when the influent ammonia concentrations were increased from 20-40 mg/l over a four week period. Gujer and Boller (1984) reported that nitrification in a 138 cm dual media (expanded shale and sand) final filter was oxygen-limited at NH_4^+-N influent concentrations greater than 1.7 mg/l when the superficial velocity was 10 m/hr. Examples of zero-order bulk liquid NH_4^+-N kinetics observations are shown in Figures 16-19.

O'Shaughnessy et al. (1984) reported that the specific rate of NH_4^+-N uptake, k (mg N/mg VSS • d), was best described by the following least squares regression equation:

$$k = 0.947 \left(1 - \exp(-1.35C)\right) \qquad (12)$$

where

k = specific rate of NH_4^+-N uptake for <u>Nitrosomonas</u> at 28°C, mg N/mg VSS • d

C = concentration of NH_4^+-N, mg/l

Equation 12 predicts zero-order (constant $k = 0.95\ d^{-1}$) nitrification at NH_4^+-N concentrations greater than 4 mg/l.

If nitrification rates in fixed-film reactors at known NH_4^+-N and D. O. bulk liquid concentrations are compared to the nitrification rate at some arbitrary reference condition, some rate-limitation conclusions can be established. Monod kinetics imply that NH_4^+-N bulk liquid concentrations should have a direct effect on nitrification

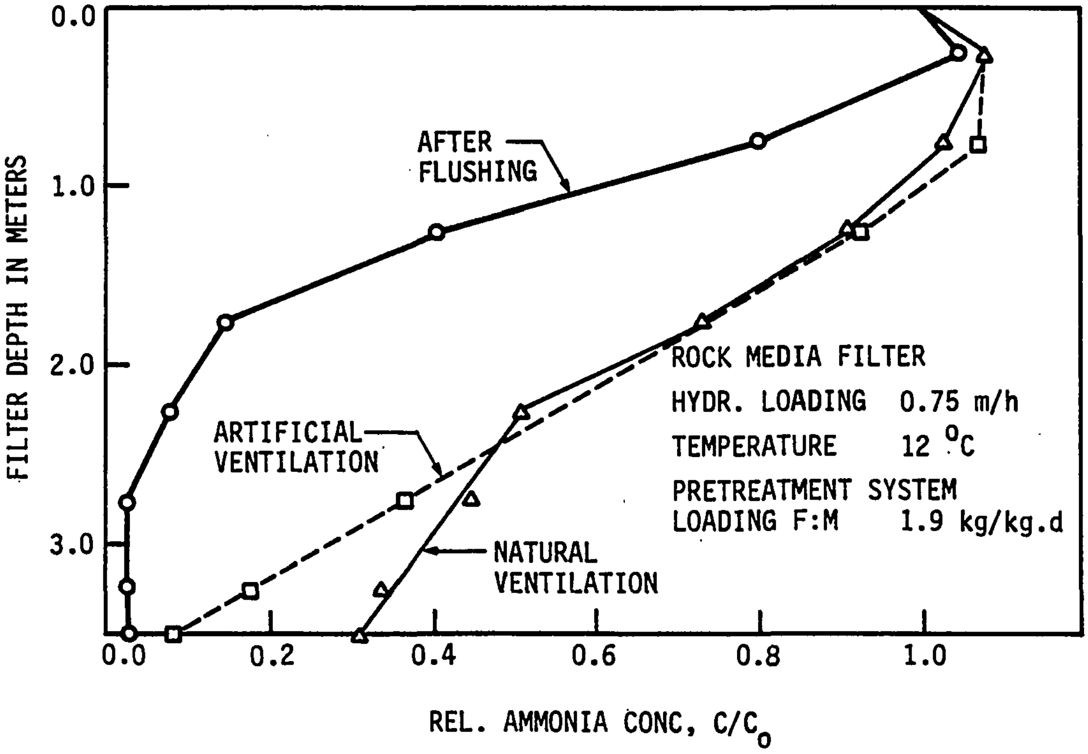


Figure 16. Effect of artificial ventilation and occasional flushing respectively on the nitrification efficiency. After Wilderer et al. (1982)

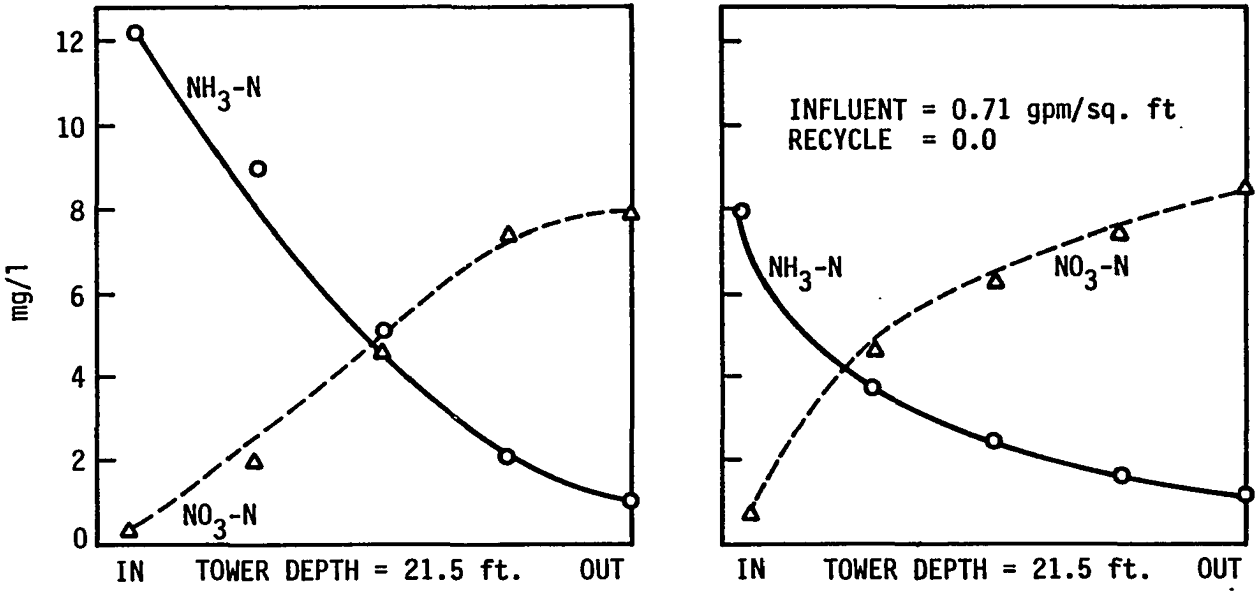


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Figure 17. Nitrifying tower nitrogen species profiles. After Duddles and Richardson (1973)

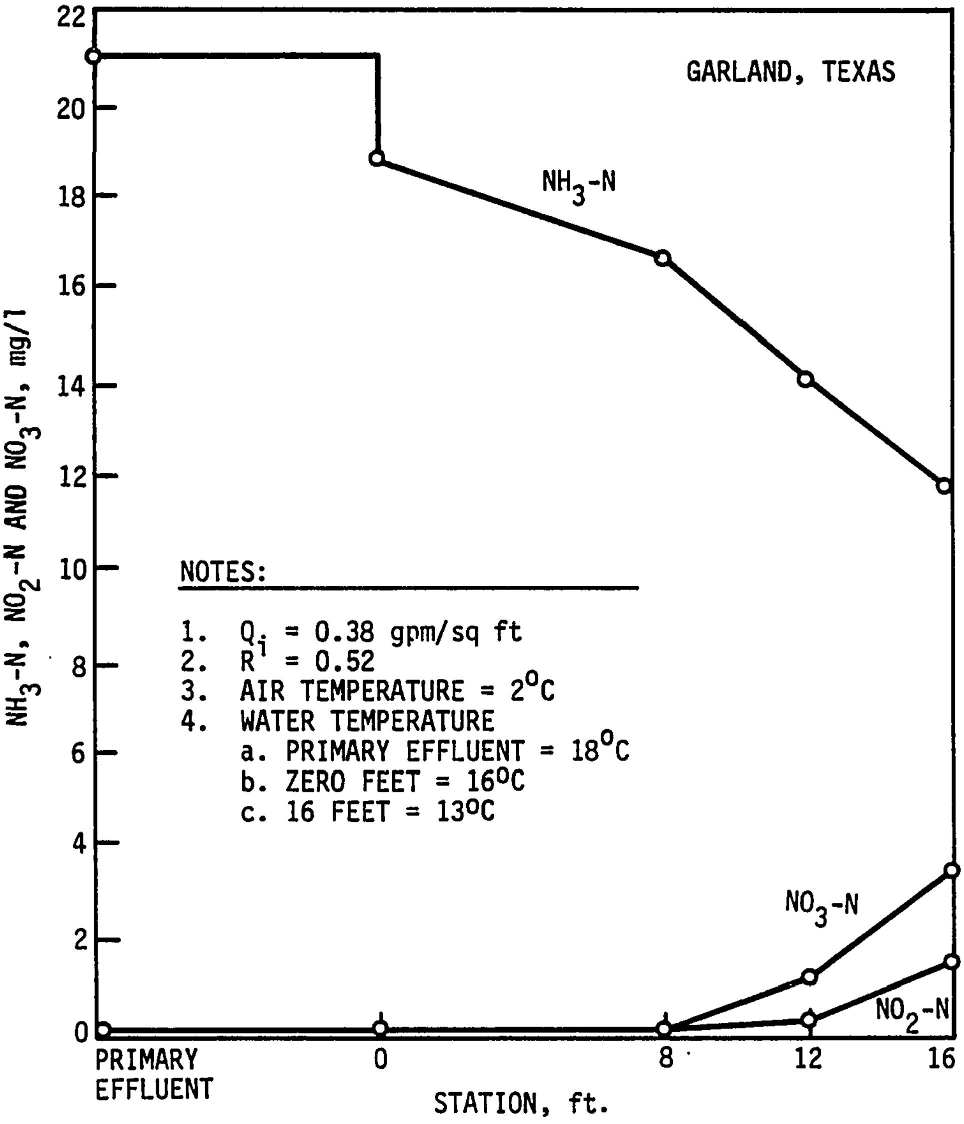

Figure 18a. Nitrifying tower nitrogen species profiles. After Parker and Richards (1985)

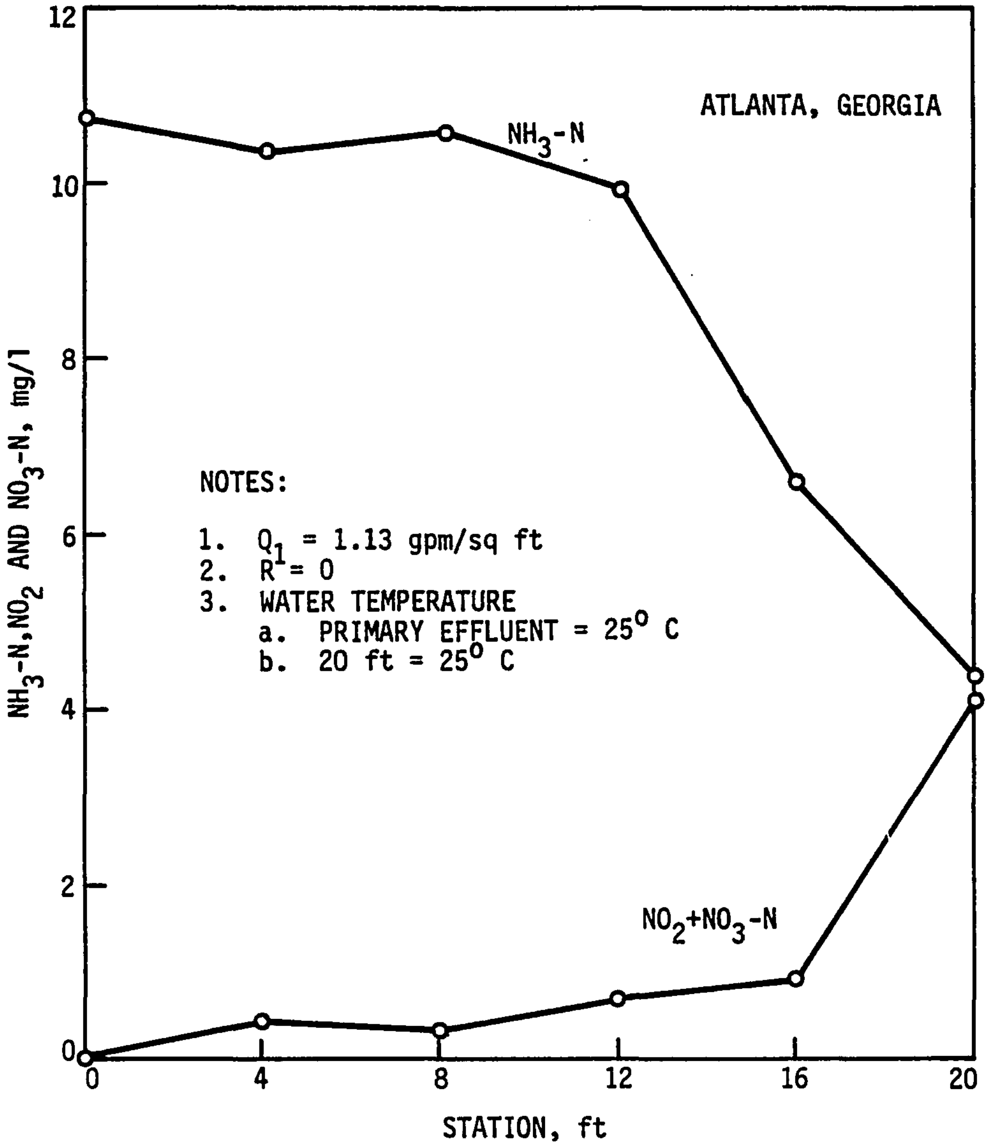

Figure 18b. Nitrifying tower nitrogen species profiles. After Parker and Richards (1985)

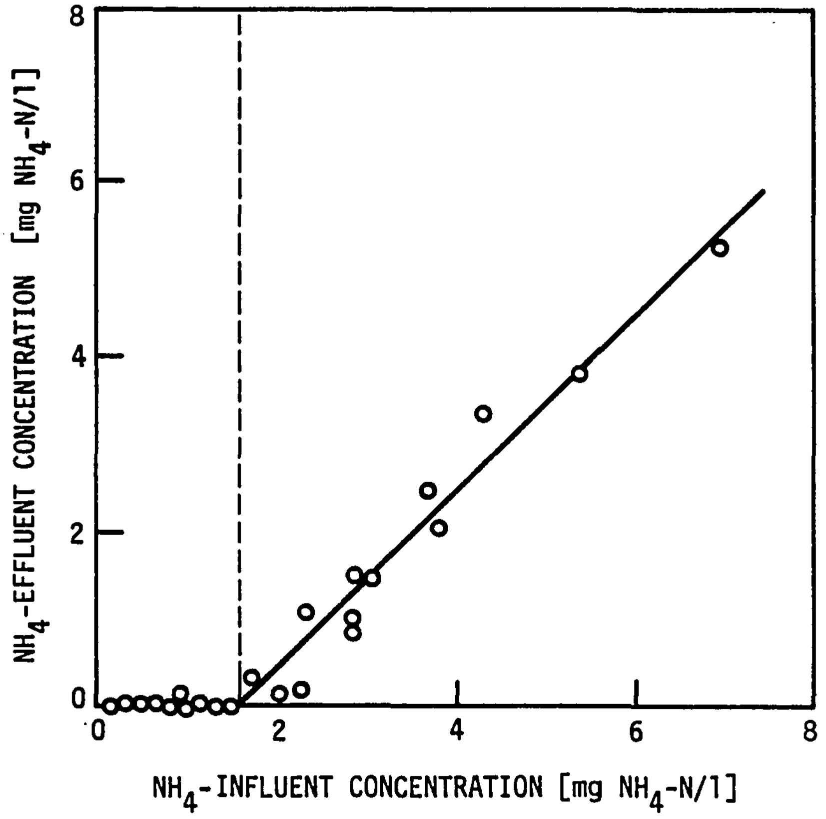

Figure 19. Correlation between influent and effluent ammonia concentration in a nitrifying dual media filter after a trickling filter. Above a removal of 1.7 mg NH_4-N/l nitrification becomes oxygen limited (superficial velocity 10 m/h, total depth of filterbed 135 cm; dual media sand and expanded slate). After Gujer and Boller (1984)

rates unless oxygen or some other reactant is the rate-limiting reactant. This is true whether the process is flux-limited or metabolism-limited.

Bulk liquid NH_4^+-N and D. O. reference concentrations of 15 and 5 mg/l, respectively, were selected in Table 2. Table 2 shows that near linear removal of NH_4^+-N with tower depth could only be observed if oxygen were the rate-limiting reactant. It cannot be discerned from bulk liquid NH_4^+-N concentration versus tower depth plots whether oxygen flux-limitation or oxygen metabolism-limitation is predominant.

The use of inhibition kinetics (the Haldane equation) for oxygen flux-limited conditions appears to offer little, if any, improvement over Monod kinetics. The Haldane inhibition kinetics offer some improvement for NH_4^+-N limitation (really NH_4^+-N inhibition) conditions at high bulk liquid NH_4^+-N concentrations (Rozich and Castens, 1986). However, NH_4^+-N concentrations high enough to cause inhibition are not likely to exist in domestic wastewater trickling filter nitrification processes. At low NH_4^+-N concentrations, Monod and Haldane kinetics predict essentially the same nitrifier growth rates for NH_4^+-N limitation conditions.

Effects of Operating Parameters on Nitrification in Trickling Filters

In most cases, the rate at which trickling filters can process substrate is controlled by the factors that control the flux of one or more reactant species. Flux of reactants is controlled by the following factors:

Table 2. Expected areal rate response for oxygen or substrate limitation conditions

NH_4^+-N Conc. Bulk Liquid mg/l	D.O. Conc. Liquid mg/l	Rate of Areal NH_4^+-N Uptake	Implication of Observed Rate of Areal NH_4^+-N
15	5	Reference Level	Reference Level
20	5	a) No Change	Oxygen Limited
		b) Increase	Ammonium-Limited
15	7	a) Increase	Oxygen-Limited
		b) No Change	Limitation by Species Other Than O_2 or NH_4^+-N

1. The biofilm area, thickness and density available for mass transport and utilization.
2. The concentration gradient of the reactants from the bulk liquid to the biofilm.
3. The coefficients of molecular diffusion for the reactants in the bulk liquid and in the biofilm.
4. The mean detention time of wastewater flow through the trickling filter.

Each of the above factors is controlled by one or more operating parameters. A number of additional operating parameters are important because they affect competition between the various microorganisms that inhabit the trickling filter. Table 3 lists the operating parameters that may affect the performance of nitrification trickling filter towers.

Wastewater temperature effects

Maier et al. (1967), Harris and Hansford (1976), Benzie et al. (1963), Antonie (1976), and others demonstrated that increasing the temperature of the wastewater feed causes greater substrate removal for the fixed-film process. This would be expected whether the process is flux-limited or metabolism-limited. The Nernst-Einstein equation for coefficients of diffusion adequately describes the effect of temperature.

$$C = D_w \mu / T \qquad (13)$$

Table 3. Effects of operating parameters on nitrification in trickling filters

Operating Parameter	Effect on Nitification Rate, mass/time	Effect on Percent Removal	Factors in Observed Effects
1. Wastewater temperature	Rate increase with temperature increase	Increase with temperature increase	Diffusivity coefficients, biofilm activity
2. Hydraulic loading rate	Rate increase with hydraulic loading increase	Decrease with hydraulic loading increase	Liquid diffusional resistance, hydraulic retention time, biofilm surface activity, scouring, percent active biofilm area
3. Ammonium concentration	Rate increase for greater ammonium concentration up to 4 mg/l	Decrease with greater ammonium concentration	Substrate diffusional driving force
4. Suspended solids	Rate decrease for greater suspended solids	Decrease with greater suspended solids	Competition for substrate by adsorption, percent active biofilm area
5. Alkalinity	Rate decrease for alkalinity less than 1 meq/l	Decrease with alkalinity less than 1 meq/l	pH buffering
6. pH	Rate decrease for decreasing pH. Optimum pH 8.3	Decrease with decreasing pH	Biofilm activity
7. Toxicants	Rate decrease	Decrease	Biofilm activity

Table 3. (Continued)

Operating Parameter	Effect on nitrification Rate, mass/time	Effect on Percent Removal	Factors in Observed Effects
8. BOD_5/TKN Ratio	Rate decrease with ratio increase	Decrease with ratio increase	Oxygen depletion, biofilm species competition
9. Media Configuration	Rate increase with increasing hydraulic retention time and distribution properties	Increase with increasing hydraulic retention time and distribution properties	Hydraulic retention time, flow distribution, possibly oxygen mass transfer
10. Media Specific Surface	Rate decrease per unit total surface area with media specific surface increase	Slight increase for equal depth comparison	Percent active biofilm area, total active biofilm area
11. Recirculation	Small or nonobservable effects in summer. Probable rate decrease in winter	Small or nonobservable effect in summer. Probable decrease in winter	Hydraulic retention time per pass, multiple passes, dilution of bulk liquid contaminants and nutrients, dissolved oxygen increase, wastewater temperature modification

Table 3. (Continued)

Operating Parameter	Effect on Nitrification Rate, mass/time	Effect on Percent Removal	Factors in Observed Effects
12. Intermittent dosing	Rate increase at low average hydraulic loading rates. Small effect at greater hydraulic loading rates	Increase at low average hydraulic loading rates. Small effect at greater hydraulic loading rates	Hydraulic retention time, percent active biofilm area, liquid diffusional resistance, biofilm surface activity, scouring
13. Air circulation	Rate increase when ammonia concentration is greater than 4 mg/l and bulk liquid dissolved oxygen is not near saturation	Increase for oxygen-limited nitrification and low bulk liquid dissolved oxygen	Oxygen diffusional driving force

where:

C = constant

D_w = molecular diffusion coefficient in wastewater, cm^2/s

μ = dynamic viscosity of wastewater, $g/cm \cdot s$

T = absolute wastewater temperature, °K

Molecular diffusion coefficients are seen to be directly proportional to the absolute temperature and inversely proportional to the dynamic viscosity. The diffusion coefficients increase as the temperature increases leading to an increase in the removal of substrate.

The mean detention time is also a function of the viscosity. The Nusselt equation for laminar flow down an inclined plane demonstrates that mean detention time must decrease at higher wastewater temperatures since velocity of flow increases at lower viscosities.

$$\delta = \left(\frac{3V\mu}{\rho\ g\ \sin\theta}\right)^{1/3} \alpha \frac{V}{w \cdot \text{velocity}} \tag{14}$$

where:

V = volumetric flow rate, cm^3/s

μ = dynamic viscosity, $g/cm \cdot s$

ρ = density of water, g/cm^3

g = acceleration of gravity, cm/s^2

δ = bulk liquid film thickness, cm

θ = angle of inclination from horizontal

w = width of plane, cm

For a constant mass loading to the system, increasing the wastewater temperature results in a reduction in the time for mass transfer and disregarding the effect on diffusion coefficients, the substrate mass removal and percent removal should decrease. Of course, the increase in flow velocity also decreases the effective liquid diffusion layer thickness ($L_1 + L_2$ of Figure 14), thus increasing the concentration gradient from the bulk liquid to the biofilm. The detention time reduction and the concentration gradient increase have opposing effects on the removal of substrate. Cleasby (1985) has shown that consideration of temperature effects on diffusion and detention time, while neglecting concentration gradient effects, adequately predicted substrate removal for data from the inclined plane, fixed-film study of Maier et al. (1967).

The net result of temperature-related diffusion coefficient and flow velocity effects on substrate removal can be summarized as follows:

> At greater wastewater temperatures, the flat plate substrate removal increases predicted from diffusion coefficient increases are reduced approximately in proportion to the decrease in mean detention time. The more irregular biofilm surfaces associated with corrugated plastic media may reduce the wastewater temperature effects on mean detention time.

The effects of wastewater temperature, influent substrate concentration, and hydraulic loading rate on mass removal of substrate, percent removal, bulk liquid thickness, bulk liquid velocity, and detention time have been clearly summarized by DeBoer (1984) and Cleasby (1985) in Tables 4 and 5 using data from the glucose removal, inclined plane biofilm study of Maier et al. (1967). It is important to clarify that bulk liquid film thickness is not synonymous with boundary layer thickness and that the majority of the resistance to mass transfer in the bulk liquid is associated with the boundary layer located along the biofilm surface.

Substrate loading rate effects

The most important operating variable from the plant operator's perspective is the substrate loading rate. The substrate loading rate can be varied by changing either the hydraulic loading rate or the influent substrate concentration, or both.

Harris and Hansford (1976), Sarner (1984 and 1986), and Maier et al. (1967) demonstrated that increasing either the hydraulic loading rate or the influent substrate concentration (at concentrations equal to or below the value at which oxygen is limiting) increased the mass removal per unit area per unit time. However, the percent removal efficiency was reduced. At all substrate concentrations in the oxygen-limitation region the rate of substrate removal was nearly constant for any constant hydraulic loading rate (Harris and Hansford,

Table 4. Analysis of data from Maier flat plate biofilm study. After DeBoer (1984)

Influent Conc. in mg/L	Flow Rate		Temp °C	Glucose Removed mg/10 min	Mass Applied mg/m^{2}hr
	ml/10 min	gpm/ft^2			
27.5	300	0.66	10.6	2.0	744
	300	0.66	37.3	2.8	744
	600	1.31	10.6	3.2	1488
	600	1.31	37.3	4.0	1488
65.5	300	0.66	10.6	4.3	1771
	300	0.66	37.3	6.8	1771
	600	1.31	10.6	6.4	3543
	600	1.31	37.3	11.3	3543
127.5	300	0.66	10.6	7.0	3449
	300	0.66	37.3	11.3	3449
	600	1.31	10.6	8.9	6897
	600	1.31	37.3	17.8	6897

Mass Removed mg/m^{2}hr	% Removal	Liquid Film Thickness cm	Bulk Fluid Velocity cm/sec	Detention Time sec
180	24	0.024	1.9	32
252	34	0.020	2.3	27
289	19	0.031	2.9	21
361	24	0.025	3.6	17
388	22	0.024	1.9	32
613	35	0.020	2.3	27
577	16	0.031	2.9	21
1019	29	0.025	3.6	17
631	18	0.024	1.9	32
1019	30	0.020	2.3	27
802	12	0.031	2.9	21
1605	23	0.025	3.6	17

Table 5. Observed and predicted effects of temperature on removal using the data from Table 4. After Cleasby (1985)

Influent Glucose Concentration mg/l	Flow Rate ml/10 min	Observed Ratio of removal at 37.3°/10.6°	Predicted Ratio[a] of removal at 37.3°/10.6°
27.5	300	1.40	1.71
	600	1.25	1.64
65.5	300	1.58	1.71
	600	1.76	1.64
127.5	300	1.61	1.71
	600	2.00	1.64
		Avg. 1.60	Avg. 1.67

[a] Predicted from Diffusion Coeff (37.3°/10.6°) x Mean Detention (37.3°/10.6°).

1976). The oxygen-limited constant rate of substrate removal was zero-order with respect to the substrate concentration.

If the substrate or oxygen concentration in the bulk liquid is increased, the concentration gradient from the liquid to the biofilm increases; therefore, the mass transport of substrate or oxygen to the biofilm increases. If the hydraulic loading rate is increased, the boundary layer thickness associated with laminar flow at the liquid-biofilm interface is reduced. The effect is equivalent to an increase in the concentration gradient from the liquid to the biofilm if the liquid concentration is held constant. The increased gradient increases the mass transport of substrate or oxygen to the biofilm.

In addition, increasing the hydraulic loading rate increases the wetted surface area of the media providing more biofilm area for mass transport and utilization (Onda et al., 1968, and Crine, 1986). Crine (1986) predicted that an upper limit, less than complete wetting, exists for wetted area.

Brown and Caldwell (1980) defined the minimum wetting rate as "the minimum total hydraulic loading to ensure complete wetting of the media surface, which allows the media to be fully effective in biological treatment." Manufacturers typically recommend minimum wetting rates of 0.34-0.55 $1/m^2 \cdot s$ for plastic media to promote good wastewater flow distribution to the media. Data correlating wetted surface area with hydraulic loading rate are lacking. An upper limit on wetted surface area at typical minimum wetting rates is unlikely based on air stripping data (Onda et al., 1968). An upper limit on wetted surface area at higher hydraulic loading rates cannot be ruled out, however.

Recycle causes a complex interaction of the factors that affect the substrate loading rate. Parker and Richards (1985) and Brown and Caldwell (1980) reported that recycle was beneficial to wastewater treatment in trickling filters. Germain (1966), Richards (1984), Richards and Reinhart (1986), and Albertson and Davies (1984) reported that recycle has little effect on percent removal efficiency. Albertson and Davies (1984) presented data from pilot studies at Huntingdon, Pennsylvania and the Chino Basin, California and concluded that higher wetting rates rather than recirculation accounted for the better performance of the trickling filter processes.

It is logical that recycle should have little effect on treatment efficiency if the opposing effects of the reduced bulk liquid concentrations versus the decreased boundary layer thickness, increased wetted area, and improved biofilm shearing and flushing are considered. Nitrification may be improved by the dilution of BOD concentrations in the influent which would reduce competition for oxygen available in the biofilter for nitrification (Culp and Heim, 1978). In addition, the reduction in the retention time in each pass through the tower is offset by the additional passes through the tower so that the total time opportunity for mass transfer is similar to that without recycle.

Recycle has been credited with reduction of toxic materials or inhibitors and dampening of shock loadings (Oleszkiewicz, 1980). Recycle may be beneficial at low hydraulic loadings to maintain the minimum wetting rate and for severe oxygen limitation situations. Recycle reduces psychoda fly and clogging problems by improving the flow distribution at low influent hydraulic loads. Benzie et al. (1963) and Benzie (1969) showed that recycle may be detrimental in winter climates because of wastewater cooling. They reported that the efficiency of trickling filters was reduced when the air and sewage temperatures were equal and that recirculation helped eliminate this drop in efficiency.

A recirculation design offering flexible operation may be beneficial for achieving denitrification. Gujer and Boller (1984) reported that summer nitrite concentrations in nitrifying wastewater treatment process effluents are higher than winter nitrite concentrations because of the relative growth rates of Nitrobacter and Nitrosomonas. The growth rate of Nitrobacter compared to that of Nitrosomonas is higher in winter than in summer. Nitrite concentration data of Duddles and Richardson (1973) were in agreement.

Nitrite can be as toxic to aquatic life as ammonia. Therefore, summer designs of nitrifying fixed-film processes should consider effluent nitrite concentrations, and may be controlled by effluent nitrite concentrations. Wanner and Gujer (1984) predicted that denitrification in nitrifying fixed-film processes was possible only when recycle allowed conditions in the upper part of the media to be favorable. Young (1974) supported this position and cited the opposing environmental conditions necessary for nitrification and denitrification.

Conditions are favorable when oxygen concentrations and pH deep in the film are low, oxidized nitrogen is present, and organic substrate is present. This would imply that recycle in separate-stage nitrification should direct effluent from the nitrifying biofilter back to the top of the carbon oxidation biofilter during summer operation.

Brown and Caldwell (1980) reported that recirculation increased the bulk liquid D. O. concentration of the trickling filter influent. However, they could not verify whether an increase in recirculation, an increase in forced draft, or a combination of these factors was responsible for the observed improvement in nitrification performance at Stockton, California. They reported short circuiting of final clarifiers to be a problem during morning hours of winter operation.

The short circuiting was determined to be caused by temperature gradients in the clarifiers. The forced draft convection operation was modified so that fewer fans were operated during the cooler night hours and additional fans were operated during the day hours to minimize temperature fluctuation in the trickling filter effluent.

Johnson and van Durme (1986) reported that recirculation of biological sludge through biofilters resulted in oxygen-limitation. The reported rate of soluble BOD removal increased with increased oxygen transfer rate, which increased with increased total hydraulic loading rate. They reported the oxygen transfer rate to be 0.0031 kg O_2/d • m^2 of media surface area • m of media depth/unit wetting rate above 0.5 L/m^2 • s.

Most of the pilot-scale trickling filter studies conducted in the past have used continuous or nearly continuous dosing of the media with wastewater rather than the periodic dosing typical of large rotary distributors used in most full-scale trickling filters. Lumb and Barnes (1948), Tomlinson and Hall (1955), Craft and Ingols (1973), Richards (1984), Richards and Reinhart (1986), Hutchinson (1975), Cook and Katzberger (1977), and Bruce and Merkens (1973) have reported that periodic dosing provided better trickling filter performance. Improved performance was most pronounced at low hydraulic loading rates.

Periodic dosing reduces the retention time in the media, and a decrease in the removal of substrate would logically be expected. However, it has been observed that periodic dosing and continuous dosing with identical media and average hydraulic loading rates provided essentially equal treatment (Richards and Reinhart, 1986). thus, decreased retention time must be compensated for by other factors.

These factors are likely to include the decrease in resistance to diffusion of reactants into the biofilm due to the reduction in the liquid-biofilm boundary layer thickness and/or the increased bulk liquid turbulence, the additional shearing of the biofilm resulting in a more active exposed biomass, improved distribution of wastewater flow, and better oxygen transfer from the bulk liquid to the biofilm. Richards and Reinhart (1986) and Sarner (1984 and 1986) pointed out that liquid retention time and biofilm-reactant contact time are not synonymous since substrate-biofilm sorption may be significant and that contact time may not be significantly changed when retention time decreases. They failed, however, to recognize and account for the potential increase in the effective biofilm surface area that periodic dosing would be expected to produce. The increase in the effective biofilm surface area is likely to be the single largest contributor to the observed performance improvement of periodic dosing versus continuous dosing.

Competition between microorganism species

Wilderer et al. (1982) showed that nitrification in trickling filters can be upset by inadequate consideration of competition between microorganism populations within the media. They demonstrated that separate biological carbonaceous and nitrogenous BOD treatment processes operated in series favor establishment of a succession of biocommunities for effective organic carbon removal and nitrification. Wanner and Gujer (1984) reached the same conclusion and showed that carbon oxidizing heterotrophs quickly overgrow nitrifiers in trickling filters if carbonaceous BOD loadings are not low. Wild et al. (1971) reported that instantaneous, short-term increases or decreases in BOD loading did not affect the rate of nitrification in activated sludge plants. Similar responses to instantaneous short-term BOD loading changes would be expected for trickling filter plants.

The purpose of the carbonaceous BOD removal stage is conversion of organic carbon into biomass and subsequent separation of the biomass before the nitrification stage. Wanner and Gujer (1984) found that when competition for a common reactant existed, the faster growing species may overgrow the slower growing species at high substrate concentrations and may be washed out of the biofilm at low substrate concentrations. Carbonaceous BOD and biomass carryover to the nitrification stage promotes establishment of heterotrophs and protozoa populations in the nitrification stage. Nitrification begins only when carbonaceous BOD and biomass in the liquid phase have been reduced to levels where the nitrifying bacteria population is favored by the filter environment. Figures 3a and 3b (Parker and Richards, 1985) demonstrated that nitrification did not begin until the soluble BOD_5 concentration fell below 20 mg/L.

Wanner and Gujer (1984) found that the faster growing species tend to exist near the biofilm surface and that the slower growing species tend to exist at greater depths in the biofilm. Thus, slow growing species can be maintained in the biofilm even when total biomass growth rates exceed the maximum growth rate of the slow growing species. This no doubt influences the relative stability observed for trickling filter processes with loading variations. However, at long-term, high organic substrate concentrations, nitrifier populations may be totally displaced from the biofilm. Wanner and Gujer (1984) predicted that nitrifiers could be totally displaced from the biofilm at soluble organic substrate concentrations greater than 27 mg COD/1.

Particulate effects

Sarner (1981, 1984, and 1986) and Zimmerle et al. (1982) reported that soluble substrate removal in trickling filters is impeded by suspended or colloidal matter in the liquid feed. Sarner (1984 and 1986) suggested that particulate matter produced in the upper depths of trickling filters may be a factor in the lower removal rates observed in the lower depths of trickling filters. Suspended and colloidal matter may adhere to the biofilm surface reducing the active area for mass transport and exerting additional oxygen demand. Particulates may compete with the microorganisms for the reactants through adsorption, subsequently releasing the reactants to the effluent by desorption.

The importance of intermediate clarification between the carbonaceous oxidation and nitrification stages is evident. However, in winter climates the cooling effects of clarification should be considered in process design. Wall and Peterson (1986) have developed a model for winter heat loss from uncovered clarifiers that may be of use in this evaluation.

Ventilation effects

Proper ventilation of the media is necessary to maintain high dissolved oxygen concentrations in the bulk liquid phase. This is especially important if oxygen is the limiting species. Brown and Caldwell (1980) reported improved nitrification when forced draft ventilation was increased at the Stockton, California plant.

Most trickling filters rely on natural convection and whatever small benefit the wind may provide, in the case of uncovered filters, to cause air movement through the biofilter. The use of covers for trickling filters in cold climates is increasing; therefore, wind effects in cold climates are often absent. Convection currents may be either upward or downward depending on the relative temperatures of the air and the wastewater. The Recommended Standards for Sewage Works (1978) recommended that underdrains should flow not more than 1/2 full at peak flow to provide free air circulation.

The manufacturers of modern plastic media have made many advancements in configuration and specific surface that have increased detention time, air flow, and available contact surfaces. Forced convection is usually not considered necessary except for very tall plastic media towers and towers containing relatively small random media. The benefits of artificial ventilation were evident in the work of Wilderer et al. (1982) with small rock media. Figure 16 clearly demonstrates the oxygen limitation of nitrification in trickling filters and the improvement of nitrification with artificial ventilation.

Shock load attentuation

Cook and Herning (1978) reported that trickling filters have shock load attenuation capacities resulting from the harboring of "starved" bacteria at the lower depths. Discussion of their work by Greenfield and Moodie (1979) pointed out that the bacteria at lower depths were not necessarily starved, but that the bacterial response to shock loads could be explained by Monod kinetics. They showed that oversizing of trickling filters may not be a cost-effective means of providing shock load attenuation capacities. All trickling filters have shock load attenuation capacities except those obeying zero-order bulk liquid substrate kinetics (oxygen-limited) throughout the entire biofilm depth.

These observations have important implications. It can be concluded that shock attenuation capacities in nitrifying trickling filters may be provided by oversizing the biofilter so that nitrifier populations in the lower depths are not oxygen-limited and can respond according to Monod kinetics to shock loads. Alternatively, artificial ventilation can be provided so that oxygen-limited biofilter performance can be improved during shock loads. Recycle may be beneficial by increasing bulk liquid D.O. concentrations, by diluting any BOD shock load that may accompany the NH_4^+-N shock load, by increasing the wetted surface area, by shearing and flushing away less active biofilm, and by improving the mass transfer of reactants in the liquid phase.

Recycle may be detrimental by diluting the influent NH_4^+-N concentration so that oxygen-limited nitrification does not exist through the entire biofilter depth. Total NH_4^+-N uptake rates are higher for oxygen-limited conditions than for NH_4^+-N limitation conditions. Recycle also can be detrimental by reducing wastewater temperatures during winter operations.

Randtke and McCarty (1977) conducted 24-hour studies of nitrogen and organic loading variations at three activated sludge plants. They found that the primary effluent peak hourly flow, ammonia concentration, ammonia mass loading, and soluble COD mass loading to be 123-139 percent, 136-177 percent, 151-240 percent, and 139-173 percent of the 24-hour average, respectively. They found the secondary effluent peak hourly flow, ammonia concentration and ammonia mass loading to be 123-139 percent, 123-138 percent and 122-142 percent of the 24-hour average, respectively.

Randtke and McCarty (1977) concluded that peak nitrogen and organic substrate concentrations coincided with the peak hydraulic loads during the 24-hour diurnal variation observation period. Thus, maximum oxygen demand was being exerted at the time when hydraulic residence was at its minimum. Their comparison of secondary effluent versus primary effluent ammonia mass loading peaks provides evidence of the beneficial effects of flow equalization. Negligible change in ammonia concentration was observed in primary treatment.

Stenquist et al. (1978) presented data from several studies that showed that primary treatment had no effect on ammonia concentrations, but that it did reduce organic nitrogen concentrations somewhat. They presented peak hourly ammonia loading versus peak hourly hydraulic load correlations similar to Randtke and McCarty.

Since nitrification is approximately zero-order with respect to bulk liquid NH_4^+-N through the majority of the tower depth, significant NH_4^+-N may reach the lower end of the tower only during peak load hours for properly sized biofilter towers. Biofilters, especially oxygen-limited ones, are not ideal for handling shock loadings. Therefore, shock load attenuation is better provided by forced draft variability (flexibility). Digester supernatant should not be recycled during peak load hours because of its significant NH_4^+-N content. Digester supernatant should be recycled during nonpeak hours.

The data of Duddles and Richardson (1973), Sampayo (1981), Sampayo and Metcalf (1984), and Baxter and Woodman, Inc. (1973) indicated relatively stable biofilter nitrification treatment performance during normal diurnal loading variation. These biofilters were not oxygen limited in the lower media depths during nonpeak hours. Intervals between peak hour loadings were evidently short enough to maintain nitrifier populations capable of treating the peak load. Seasonal shock loading variability may be of more concern. While response to diurnal loading fluctuations appears to be quite rapid, response to seasonal shock loads may require a substantial acclimation period.

Inhibitory conditions

The hydrogen ion concentration has a strong influence on the rate of nitrification. Nitrification rates decrease significantly as the pH drops into the acidic range. Figure 12 demonstrated the effect of pH on the nitrification rate. The pH range of 8 to 9 is considered ideal for nitrification. It is important that sufficient alkalinity (either natural or added) be available to prevent the pH from falling into the acidic range.

Painter (1970) published a literature review of inorganic nitrogen metabolism in microorganisms. It included a list of toxicants and the concentrations at which toxic effects were observed for nitrification processes. Vismara (1982) also has reviewed a number of nitrification toxicants. He found that the thresholds for toxic effects from chloride and magnesium were 10 and 50 mg/L, respectively. The threshold for toxic effects from ammonium nitrogen ranged from 436 to 1000 mg/L and was pH dependent.

Media characteristics

Media usually fall into the following categories: 1) rock or slag, 2) wood lattice, 3) plastic random, 4) plastic vertical tubes, 5) corrugated plastic vertical-flow, and 6) corrugated plastic cross-flow. Plastic media have been specified for most new trickling filter construction in the last ten to twenty years, and have been employed in rehabilitating older rock trickling filters to improve their performance. Media configuration and increased specific surface areas are the most significant developments to happen in trickling filter technology in several decades. The new plastic media are light enough and strong enough to allow stacking to depths up to 10 m.

Porter and Smith (1979), Albertson and Davies (1984), Albertson and Eckenfelder (1984), Harrison and Daigger (1985), Richards (1984), Richards and Reinhart (1986), Parker and Merrill (1984), Parker and Richards (1985), Sarner (1984), and Drury et al. (1986) have studied the performance of the various types of media. Porter and Smith (1979) found that random media was more efficient than vertical-flow media and that vertical-flow media was more efficient than vertical tube media when performance was compared at similar hydraulic application rates per unit specific surface area. The majority of the investigators found that cross-flow media performed better than other types of media, including plastic vertical-flow media.

They have usually supported their conclusions based on a comparison of modified Velz equation, first-order k_{20} kinetic coefficient (treatability) values for carbonaceous BOD removal and on comparison of hydraulic residence times. The modified Velz equation is discussed in greater detail in the next section of this literature review. Hydraulic residence time has been described by the following empirical equation:

$$t = C\ a_s\ D/q^n \tag{15}$$

where

t = average hydraulic residence time, minutes.

q = cross sectional hydraulic loading rate, gpm/ft^2.

d = media depth, ft.

n = dimensionless constant dependent on media properties and wastewater distribution.

a_s = specific surface area, ft^2/ft^3.

C = constant, $(\text{gal/ft}^2)^n \cdot \text{min}^{1-n}$.

Adams et al. (1981) demonstrated the methodology appropriate for determination of k_{20} and n values. Liquid distribution at the top of the tower can affect the values observed. Values of $n < 0.3$ imply that retention time is independent of flow rate, while n values > 0.7 imply dependence of retention time on flow rate (Albertson and Eckenfelder, 1984).

Cross-flow media were found to have longer hydraulic residence times and higher k_{20} values than vertical-flow media (Harrison and Daigger, 1985, Sarner, 1984, Albertson and Eckenfelder, 1984, Drury et al., 1986, Parker and Merrill, 1984, Richards, 1984, Richards and Reinhart, 1986). Vertical media were found to have small n values indicating that the hydraulic residence time in vertical media is somewhat insensitive to hydraulic load (Harrison and Daigger, 1985, Richards, 1984, and Sarner, 1984). Cross-flow media n values were higher indicating that hydraulic residence times would be significantly longer at lower hydraulic loading rates (Harrison and Daigger, 1985, Richards, 1984, and Sarner, 1984). Rock and random media were found to have very high n values, explaining why they performed well at low hydraulic loading rates, but performed poorly at high hydraulic loading rates (Harrison and Daigger, 1985, Richards, 1984, and Sarner, 1984).

Over the normal hydraulic loading range cross-flow media have generally been shown to have longer hydraulic residence times than vertical media. Harrison and Daigger (1985) have shown that n values for clean plastic media are significantly higher than n values for media containing biofilm growth. Thus, hydraulic residence times in trickling filters with established biofilms are less sensitive to hydraulic loading. Balakrishnan and Eckenfelder (1969) found that biofilms could increase retention time by 200-500%, but that n values for clean media and for media containing biofilm were not significantly different.

Researchers have attributed the superior performance of cross-flow media compared to other media to: 1) improved distribution of the wastewater and better wetting properties at lower flow rates, 2) longer hydraulic retention times, and 3) better oxygen transfer characteristics. Richards (1984) and Richards and Reinhart (1986) showed that oxygen transfer efficiency alone could not explain the difference in performance between cross-flow and vertical media, but they acknowledged that it could play a significant role in treatment of high strength wastewaters.

Most researchers have recognized that the clean media specific surface area and the effective biofilm area are not the same entities.

Furthermore, they generally recognize that the effective biofilm area must vary with hydraulic loading rate. Unfortunately, most equations, models and curves available for predicting trickling filter performance use the assumption of a constant biofilm area equal to the clean media specific surface area.

This assumption can lead to erroneous conclusions relating to hydraulic retention time and the effects of dosing as previously discussed. In addition, it can lead to erroneous values for other constants in the design equations. This assumption has been defended by citing the lack of data and understanding in predicting the effective biofilm area with varying hydraulic loading rate.

Onda et al. (1968) reported the following equation to predict the effective surface area for air stripping towers:

$$\frac{a_w}{a_t} = 1 - \exp \left[-1.45 \left(\frac{\sigma c}{\sigma}\right)^{0.75} \left(\frac{L}{a_t \mu_L}\right)^{0.1} \left(\frac{L^2 a_t}{\rho_L{}^2 g}\right)^{-0.05} \left(\frac{L^2}{\rho_L \sigma a_t}\right)^{0.2}\right] \quad (16)$$

where: a_w = wetted specific surface area, m^2/m^3

a_t = total specific surface area, m^2/m^3

σ_c = critical surface tension of the packing material, kg/hr^2

σ = surface tension of the liquid, kg/hr^2

L = superficial mass velocity of liquid, $kg/hr \cdot m^2$ of tower cross section

μ_L = dynamic viscosity of the liquid, $kg/m \cdot hr$

g = gravitational acceleration m/hr^2

ρ_L = liquid density, kg/m^3

This equation has been shown to have an accuracy of ±20 percent for randomly packed towers. This investigator correlated the equation's performance for the air stripping of trichloroethylene on cross-flow plastic media with specific surface areas of 223-403 m^2/m^3. The observed k_La data of Amy and Cooper (1986) were plotted versus the predicted k_La_w. An R-squared value of 0.84 was found for the relationship. Figure 20 presents the ratio of the wetted specific surface area and the total specific surface area versus hydraulic loading rate and wastewater temperature as predicted from the Onda equation for two media with different specific surface areas.

The predicted wetted specific surface areas are in excellent agreement with the upper part of the range suggested by Hosono et al. (1980) and with the lower part of the range suggested by Gullicks and Cleasby (1986) based on the oxygen-limited work of Maier et al. (1967). Figure 20 clearly demonstrates that hydraulic loading rate has a great influence on the wetted specific surface area and that wastewater temperature has a lesser impact on the wetted specific surface area.

Mills and Dudukovic (1981) proposed the following equation to predict the external wetting efficiency for conditions typical of random media (< 0.004 m in diameter) trickle flow operations:

$$\eta = \tanh \left[1.09 \left(\frac{L}{a_t\mu_L}\right)^{0.28} \left(\frac{L^2 a_t}{\rho_L{}^2 g}\right)^{0.21} \left(\frac{L^2}{\rho_L \sigma a_t}\right)^{-0.16} \left(\frac{6(1-\varepsilon)}{\varepsilon}\right)^{0.03}\right] \quad (17)$$

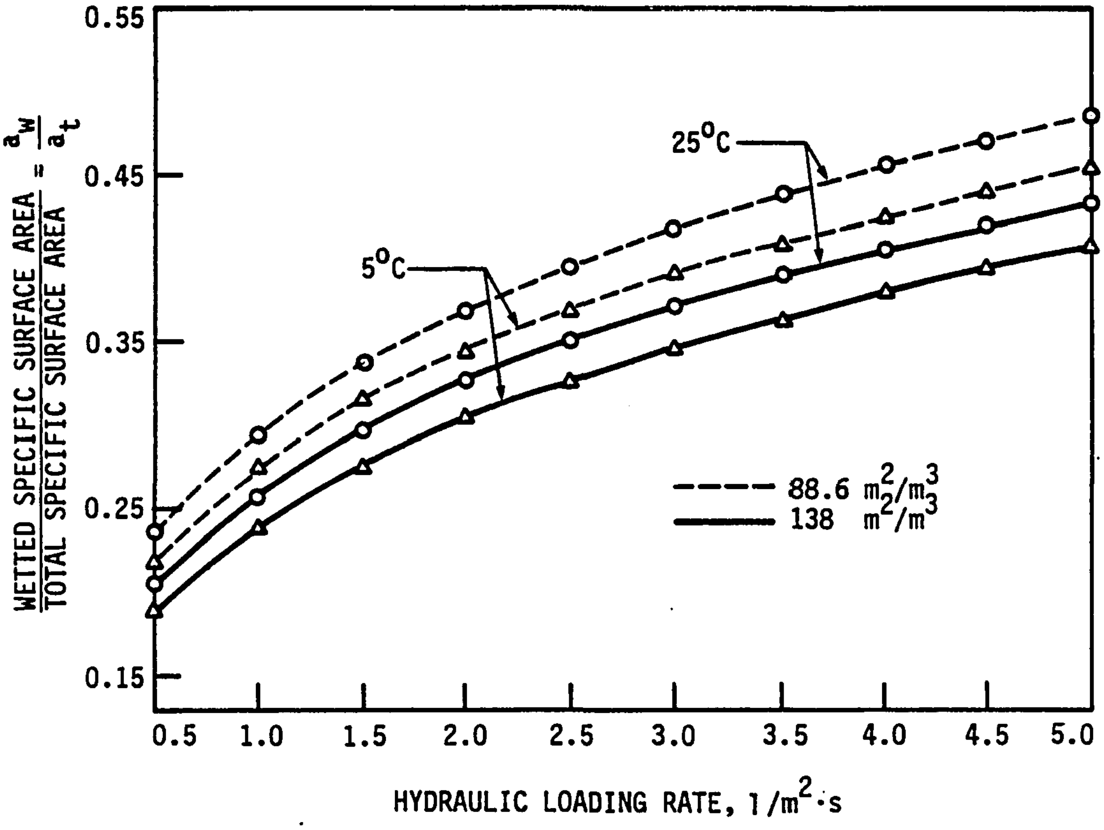

Figure 20. Wetted specific surface area based on Onda's correlations

where: ε = media bed porosity

η = external wetting efficiency $\approx a_w/a_t$

all other terms are the same as those in Eq. 16.

Crine (1986) reported that the Mills-Dudukovic equation is consistent with percolation theory analyses of trickle flow operations. Figure 21 shows that external wetting efficiencies predicted by equation 17 are approximately twice as great as Onda equation predictions. Media specific surface area had little effect on predicted wetting efficiencies. Maximum external wetting efficiencies of approximately 80% are predicted by equation 17 at normal trickling filter hydraulic loading rates.

The minimum liquid wetting velocity for which stable liquid film trickling over a solid surface does not exist can be predicted from percolation theory (Crine, 1986). At liquid velocities less than the minimum wetting velocity, isolated rivulet flow occurs. Crine (1986) reported the following relationship to predict the minimum liquid wetting rate:

$$\frac{a_w}{a_t} = \left(\frac{Re_L}{Re_M}\right)^{1 - a_w/a_t} \tag{18}$$

where: Re_L = Reynolds number at the liquid velocity applied.

Re_M = Reynolds number at the minimum liquid wetting velocity.

Albertson and Eckenfelder (1984) showed that biofilm thickness could affect the aerobic surface area. They demonstrated that a 4 mm thickness of biofilm would cause a 12 percent reduction of surface area

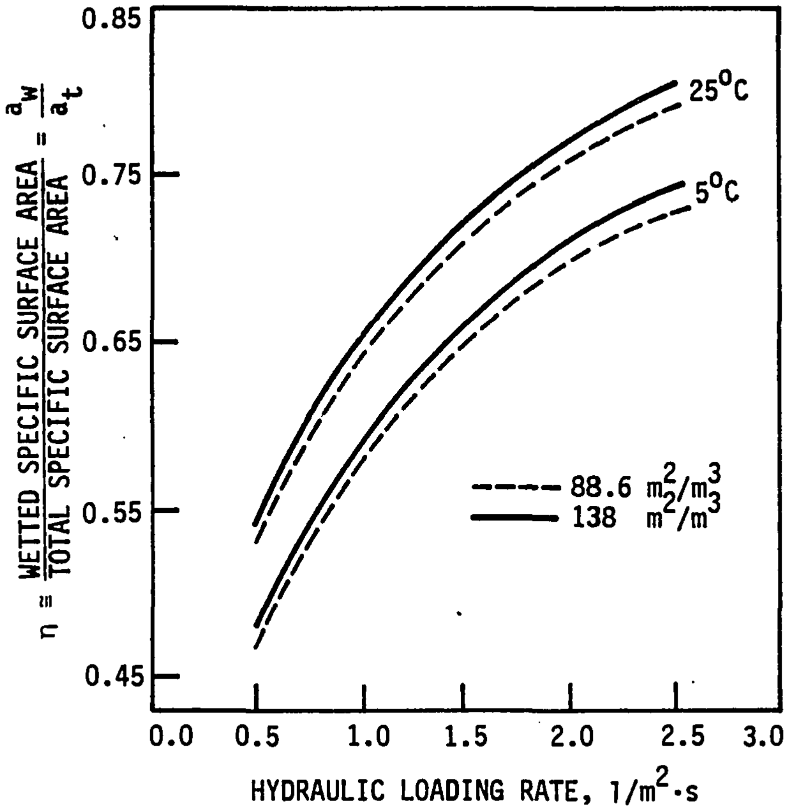

Figure 21. External wetting efficiency based on percolation theory

in cross-flow media with a total specific surface area of 98 m^2/m^3. Surface area loss due to biofilm growth is dependent on media configuration as well as biofilm thickness. Albertson and Eckenfelder (1984) predicted that media with the highest proportions of converging sheets (i.e., narrow opening, high sheet and mixing point densities) would lose more surface area than media with low proportions of converging sheets. Of course, excessive biofilm buildup at mixing points or sheet convergence points would result in even greater loss of effective surface area by partially or completely plugging access to a portion of the media sheets.

Trickling Filter Models

Velz (1948) and Germain (1966) established the use of first-order kinetics in the design of trickling filters for the removal of carbonaceous BOD. The Velz equation was modified by Schulze (1960) to include specific surface area and temperature effects. Total substrate concentrations were used in the original first-order models; however, current practice is to use soluble substrate concentrations (Albertson and Eckenfelder, 1984 and Harrison and Daigger, 1985). The Schulze equation can then be defined as follows:

$$S_e = S_i \exp\left[-k_{20}\, a_s\, D\, \theta^{(T-20)}/Q^n\right] \tag{19}$$

where: S_i = soluble substrate concentration in influent wastewater flow without recirculation, mg/l

S_e = soluble substrate concentration in settled effluent, mg/l

Q = Influent wastewater flow without recirculation, gpm/ft^2

D = media depth, ft.

θ = 1.035

T = wastewater temperature, °C

a_s = media specific surface area, ft^2/ft^3

n = dimensionless hydraulic rate constant

k_{20} = soluble substrate treatability coefficient @ 20°C, $(gpm/ft^2)^n$

The Schulze equation does not include recirculation. The modified Velz equation, which includes recirculation, has gained widespread acceptance in carbonaceous trickling filter design. The modified Velz equation is defined below:

$$S_e = S_b \exp [-k_{20}\ a_s\ D\ ^{(T-20)}/Q_T{}^n] \qquad (20)$$

where: S_e = soluble substrate concentration in settled effluent, mg/l

S_b = soluble substrate concentration applied = $(S_i + S_eR)/(R+1)$, mg/l

R = recycle ratio = recycle hydraulic load/influent (feed) hydraulic load

Q_T = total applied hydraulic load, gpm/ft^2

Other symbols were defined for equation 19.

The validity of first-order modeling of substrate removal in trickling filters is questionable. The k_{20} values used in the above equations are not independent of media depth as often assumed. Albertson and Eckenfelder (1984) and Albertson and Davies (1984) showed that

k_{20} values must be converted to a standard media depth. They recommended the following equation for this conversion:

$$k_{20} = k_D \, (D/20)^{0.5} \tag{21}$$

where:

k_{20} = the treatability coefficient for 20 ft. media depth.

k_D = the treatability coefficient for media depth, D.

Rittmann (1984) reported that the apparent first-order reaction coefficient was a function of the influent substrate concentration when detention time was held constant. An increase in the substrate concentration yielded a decrease in the apparent first-order reaction coefficient. The apparent first-order reaction coefficient was also dependent on the hydraulic load or detention time when the influent concentration was held constant. An increase in the detention time caused a decrease in the apparent first-order reaction coefficient.

Richards and Reinhart (1986) reported that the apparent first-order reaction coefficient was dependent on the media characteristics, including media configuration. Furthermore, k_{20} values for nitrification have not been studied extensively, and data scatter, even for carbonaceous BOD removal, has been quite significant due to the variability of wastewaters treated.

Detention time studies have been conducted on many of the new plastic media (Sarner, 1984, Harrison and Daigger, 1985, Albertson and Davies, 1984, Richards and Reinhart, 1986, and Parker and Merrill, 1984). These studies have helped to explain the differences in performance of the media and have established that the n values in the equations above depend not only on media configuration, media depth, hydraulic load, and initial distribution, but also on the nature of the biofilm established on the media (Harrison and Daigger, 1985).

Williamson and McCarty model

Williamson and McCarty (1976a and 1976b) set up iterative computer solutions to equate the flux of the limiting reactant through the liquid phase with the flux of the limiting reactant into the biofilm. They published their solutions in graphical form allowing the use of the model without computer assistance. Their model is based on Monod kinetics and is applicable to either substrate or oxygen diffusion limited cases.

The primary drawbacks to the model are the uncertainties associated with the Monod constants and coefficients, the biofilm density, and the liquid phase effective diffusion layer thickness and the time-consuming nature of the graphical iterative solution which must be applied at numerous depths in the trickling filter. The computer solution eliminates the time-consumption disadvantage of this model. Suidan (1986) published a similar dimensionless graphical solution for plug-flow, deep biofilm reactors.

Rittmann and McCarty models

Rittmann and McCarty (1978) proposed a variable order model based on Monod kinetics and using dimensionless variables. At low bulk liquid substrate concentrations (much less than the appropriate half velocity coefficient) the model is first-order with respect to the substrate concentration. At high bulk liquid substrate concentrations (much greater than the appropriate half velocity coefficient) the model is one-half order with respect to the substrate concentration. For other bulk liquid substrate concentrations, the kinetics range from one-half to first order.

Rittmann and McCarty (1980b) reported that organic materials may persist in low concentrations (S_{min}) because insufficient energy is available to sustain microorganisms. Steady-state biofilm thickness approached zero as the bulk liquid substrate concentration approached S_{min}. For bulk liquid concentrations of the limiting substrate between S_{min} and 3.2 mg/l, Rittmann and McCarty (1980a) recommended their steady-state biofilm kinetics model.

Rittmann and Dovantzis (1983) reported that dual substrate nitrification rate limitation would occur within the NH_4^+-N interfacial concentration range of 1 to 5 mg/l for an interfacial D.O. concentration of 2 mg/l. Available bulk liquid D.O. concentration data (Brown and Caldwell, 1980) suggest that higher D.O. concentrations exist. Therefore, NH_4^+-N will be the single limiting reactant only when the bulk liquid NH_4^+-N concentration approaches 1 mg/l; and oxygen will be the single limiting reactant for all NH_4^+-N bulk liquid concentrations greater than about 5 mg/l.

These models share many of the drawbacks of the Williamson and McCarty model relating to the uncertainty of constants and coefficients.

They are, however, readily amenable to simple computer or hand calculator solution. The models are not applicable to oxygen-limited cases which comprise the majority of fixed-film nitrification applications.

Harremoes zero-order model

Harremoes (1982) developed a simplified mixed microbial film nitrification model using zero-order kinetics in the biofilm for both the carbon oxidizing microbes and the nitrifiers. The population of nitrifiers was assumed to increase exponentially with increasing depth into the biofilm, giving rise to a nonuniform ammonia removal per unit volume of biofilm. Nitrifiers have a small growth rate when compared to the growth rate of heterotrophs which oxidize carbon. Therefore, nitrifiers are quickly submerged beyond the penetration depth of oxygen in biofilms growing fast on carbonaceous substrate.

Harremoes showed that nitrification in fixed-film systems is nearly always oxygen flux-limited. Nitrification in fixed-films was represented by two potential substrate profile cases: Case 3, in which only oxygen partially penetrated the biofilm, and Case 6, in which only ammonia fully penetrated the biofilm. For these cases, Harremoes showed that the removal rate of nitrogen per unit surface area can be predicted from the following set of equations. Appropriate parameter estimates have been included from a variety of sources.

Case 3 $\quad B_o < B_s$

$$(1 - B_o)\, e^{B_o} = 1 - B_o^{*2} \left(1 - \frac{B_o^2}{B_o'^2}\right) \qquad (22)$$

Case 6 $B_o > B_s$

$$(1 - B_o)\, e^{B_o} = 1 - B_o^{*2}\,(1 - C_s^2) \tag{23}$$

r_{an} = ammonium removal rate per unit surface area

$$= (e^{B_o} - 1)\,\left(\frac{X^* v_f}{Y_n}\right) \tag{24}$$

where:

$$B_s = \frac{\mu L_s}{v_f} \qquad B_o = \frac{\mu L_o}{v_f} \qquad B_o^* = \left(\frac{Y_n}{f_n}\,\frac{\mu D_o S_o^*}{X^*\, v_f^2}\right)^{\frac{1}{2}}$$

$$B_o' = \left(\frac{2D_o S_o^* \mu^2}{f_s K_{sf} v_f^2}\right)^{\frac{1}{2}} \qquad L_s = \left(\frac{2D_s S_s^*}{K_{sf}}\right)^{\frac{1}{2}}$$

$$C_s^2 = \frac{f_s D_s S_s^*}{D_o S_o^*} \qquad v_f^2 = \left(\frac{Y_s K_{sf} L_s}{Y}\right)^2$$

S_s^* = bulk liquid organic carbon concentration, g soluble BOD/m^3

S_o^* = bulk liquid dissolved oxygen concentration, g/m^3

D_o = diffusivity of oxygen, 15×10^{-10} m^2/s, 67% (range 35-80%) D_o in water Chen and Bungay (1981)

D_s = diffusivity of organic matter, 5.8×10^{-10} m^2/s, glucose Maier et al. (1967)

f_s = stoichiometric ratio of oxygen to BOD, 0.5 g O_2/g BOD Harremoes (1982)

f_n = stoichiometric ratio of oxygen to NH_4^+-N, 4.24 g O_2/gN Parker et al. (1975)

K_{sf} = zero-order specific rate of organic substrate oxidation in the biofilm, g BOD/m³ • s

γ = biofilm density, 4×10^4 to 5×10^4 g VSS/m³ Williamson and McCarty (1976a and 1976b)

$\frac{K_{sf}}{\gamma}$ = k_s = specific rate of organic substrate uptake in biofilm, 1.5×10^{-4} g BOD/g VSS • s, Williamson and McCarty (1976a and 1976b)

μ = nitrifier growth rate, $s^{-1} = k_n Y_n$

k_n = specific rate of NH_4^+-N uptake in biofilm, 2.3×10^{-5} g N/g VSS • s, Williamson and McCarty (1976a and 1976b)

Y_n = yield coefficient for nitrifiers, 0.166 g VSS/gN, Parker et al. (1975)

Y_s = yield coefficient for heterotrophs, 0.5 g VSS/g BOD Parker et al. (1975)

X^* = specific nitrifier concentration at the biofilm surface, fraction of γ, say 5000 g VSS/m³

L_o = penetration of oxygen into biofilm

L_s = penetration of organic substrate into biofilm

For the most simplified condition when no organic carbon exists, $S_s^* = 0$, Harremoes showed that the rate of removal of nitrogen per unit area can be expressed in the form of a half-order solution (with respect to D.O. bulk liquid concentration) as follows:

$$r_{an} = 2^{0.5} B_o^* \left(\frac{v_f X^*}{Y_n}\right) = \left(\frac{2 D_o S_o^* X^*}{f_n Y_n}\right)^{0.5} \qquad (25)$$

Assuming a constant D.O. bulk liquid concentration and constant specific nitrifier concentration at the biofilm surface at all depths in the tower, the above equation implies zero-order NH_4^+-N response with tower depth. Harremoes found no data in the literature that could be used to verify his model, and he strongly urged research of the type reported in this dissertation.

Strand's combined carbon and ammonia oxidation model

Strand (1986) proposed a mathematical model for mixed microbial biofilms based on Monod kinetics and Fickian diffusion for organic carbon uptake and based on zero-order kinetics for oxygen and nitrogen uptake within the biofilm. The computer solution of the approximation of the nonlinear equation for organic carbon uptake provided definition of the organic carbon profile from the biofilm-water interface into the biofilm depths. Nitrification was assumed to begin at the distance relative to the biofilm-water interface where the heterotrophic and nitrifying organism growth rates were equal. Strand presented the model in graphical form making it simple to use.

The primary drawback to this model was its dependence on parameter values from the literature which exhibited wide variation in the reported ranges of the parameter values. The model adequately predicted the ammonium flux for rotating biological contactor data from four sources (Stratta and Long, 1981, Mueller et al., 1980, Watanabe et al., 1980, and Weng and Molof, 1974).

First-order media configuration model

Logan et al. (1986) incorporated media configuration differences directly into a model based on first-order microbial kinetics for substrate-limited trickling filters. Substrate removal differences for different media were due only to differences in media geometries rather than implying changes in microbial kinetics for different media. The finite difference model adequately predicted soluble BOD removal based on comparison with observed data from several studies.

The model can be adapted to use in oxygen-limited situations. In fact, even without incorporating the modifications necessary for oxygen-limited applications, the soluble BOD removal predicted by the model was in good agreement with oxygen-limited data reported by Hutchinson (1975).

The importance of liquid phase mass transfer in trickling filter performance was demonstrated by the successful performance of this model. Cross-flow media were shown to be superior to vertical-flow media because cross-flow media provided more frequent disruption (intermittent mixing) of the liquid film (and, therefore, the boundary layer of highest mass transfer resistance adjacent to the biofilm).

EXPERIMENTAL

Materials and Equipment

The trickling filter pilot plant used in this study was located at the Ames Water Pollution Control Plant (WPCP). A schematic diagram of the pilot-scale, separate-stage, trickling filter plant is shown in Figure 22. The pilot plant influent was the Ames WPCP secondary clarifier effluent (final effluent). Subsequent to June 16, 1986 this influent wastewater was pretreated to control carbonaceous oxygen demand and suspended solids loadings to the nitrification biofilter. The nitrification biofilter performance prior to June 16 may have been slightly impaired by carbonaceous oxygen demand and solids carryover from the Ames WPCP final clarifiers.

Pretreatment process

Ames WPCP secondary clarifier effluent was distributed continuously at 1.6 to 1.9 $L/m^2 \cdot s$ to the top of a 2.44 m high x 0.61 m x 0.61 m pretreatment biofilter containing 45-degree, cross-flow plastic media with a specific surface area of 98 m^2/m^3. Carbonaceous oxygen demand was reduced in this step. Wastewater samples were collected at the top, 1.22 m depth, and 2.44 m depth of the pretreatment biofilter. Clarification at approximately 40,740 $L/m^2 \cdot d$ followed the pretreatment tower to reduce suspended solids loadings on the subsequent separate-stage, pilot-scale, nitrifying biofilter.

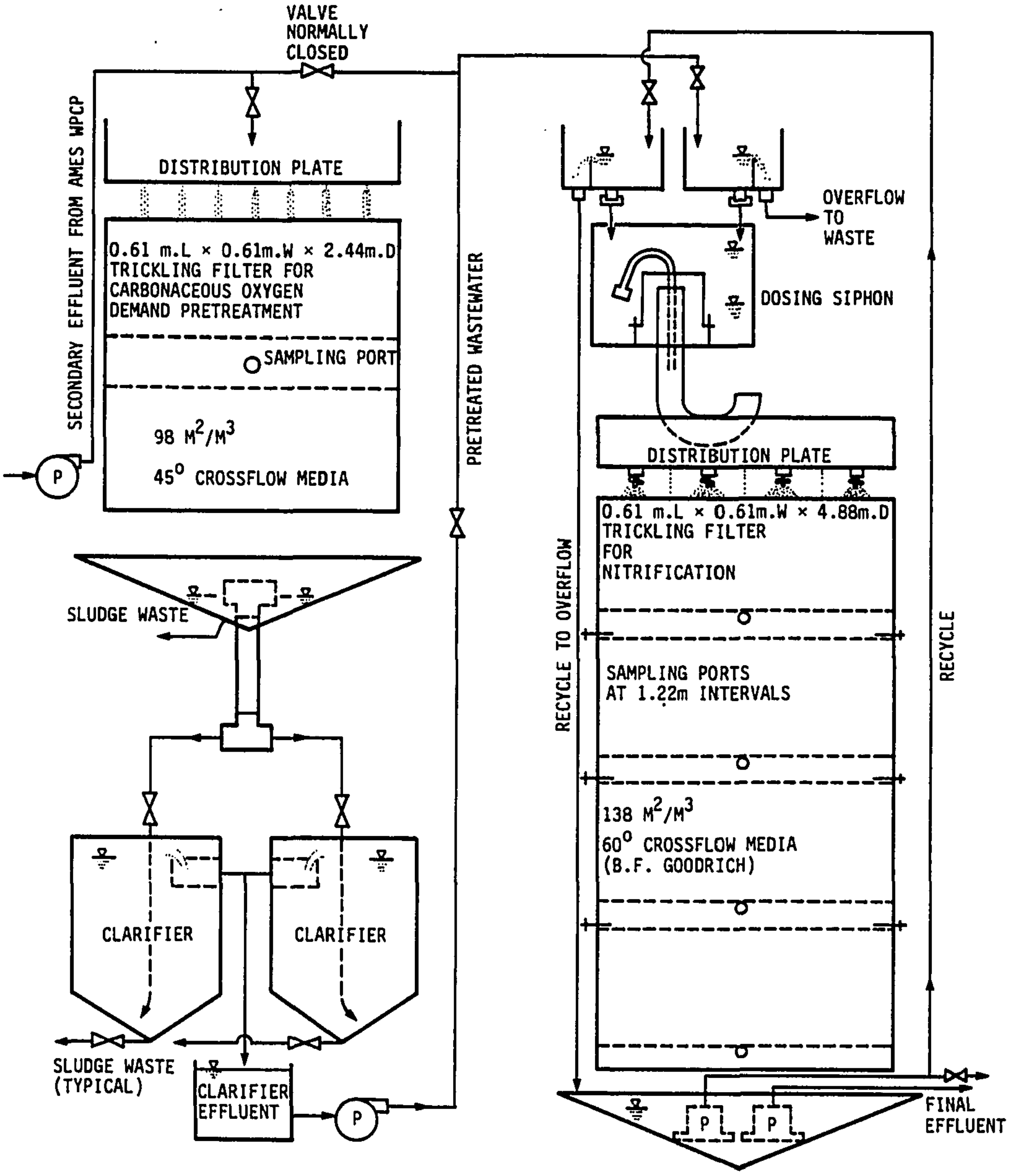

Figure 22. Ames WPCP pilot-scale separate-stage nitrifying biofilter schematic

Separate-stage nitrifying biofilter

Subsequent to June 16, 1986, the pretreatment process effluent was pumped to a constant head tank above the nitrifying biofilter. Prior to that, secondary effluent had been used as the nitrifying biofilter influent. When recycle was in use, nitrifying biofilter effluent was pumped to a separate constant head tank above the nitrifying biofilter. Separate streams of pretreated wastewater and recycled nitrifying biofilter effluent flowed at constant, preset rates into a plexiglas dosing siphon which measured 0.30 m x 0.30 m in cross section.

The dosing siphon had a 0.10 m diameter x 0.10 m high bell and 0.05 m diameter discharge piping. The siphon breaker consisted of a weighted air intake mounted on a spring-stiffened, flexible tube. This allowed the siphon breaker to bounce when the siphon break occurred, which provided stable dosing cycles and reduced fouling of the air intake by biomass accumulation.

The dosing siphon allowed wastewater to be applied to the nitrifying biofilter on an intermittent basis rather than as continuous dosing. The operation of dosing siphons was discussed in detail by Babbitt and Baumann (1958). The cycle time and dosing volume of the dosing siphon were determined by the influent flow rate, the height of the siphon breaker, and the height of the discharge leg of the siphon trap.

During some data collection periods, the NH_4^+-N concentrations in the wastewater were supplemented to maintain bulk liquid concentrations above 4 mg/L throughout the nitrifying biofilter depth. A chemical feed pump, operated at constant flow rates, was used to add concentrated

NH_4Cl solution directly to the wastewater stream as it entered the dosing siphon. Turbulence from the stream(s) of wastewater entering the siphon tank and from the siphon tank discharge cycle provided good mixing of the NH_4Cl and wastewater.

The discharge from the dosing siphon occurred in a short period of time (approximately 8 to 20 seconds depending on the influent flow rate and preset dosing volume). The discharge spilled onto a 0.61 m x 0.61 m plexiglas distribution plate with 0.07 m high sidewalls. The distribution plate had sixteen, equally-spaced 0.0095 m diameter orifices and thirty-three 0.0064 m diameter orifices located such that the distance between orifices was 0.076 m.

The total area of the 0.0064 m orifices equalled the total area of the 0.0095 m orifices. The 0.0095 m orifices were fitted with target nozzles to spread the wastewater discharged by the orifices over the media surface below. This arrangement gave very satisfactory distribution of wastewater over the media. Total discharge time (dosing siphon plus distribution plate) was 15 to 30 seconds, depending on the influent flow rate and preset dosing volume.

The dosing siphon and distribution plate were very reliable. Maintenance was required only on a weekly to bi-weekly basis to clean the biomass accumulation from the dosing siphon bell and the distribution plate orifices. Malfunctions and clogging were not observed with this weekly to bi-weekly cleaning schedule.

The nitrifying biofilter consisted of four welded steel sections, each measuring 0.61 m x 0.61 m x 1.22 m tall, stacked end to end for a total tower height of 4.88 m. The nitrifying biofilter was filled with B. F. Goodrich 60-degree, cross-flow media with a specific surface area of 138 m^2/m^3. Short circuiting of wastewater flow along the tower walls was prevented and redistribution was promoted by securely wrapping each media section with plastic sheeting, by rotating the media orientation 90° at 0.61 m depth intervals, and by providing sidewall baffles or skirts at 1.22 m depth intervals to redistribute any sidewall flow back onto the media.

Wastewater samples were collected at the dosing siphon discharge, at 1.22 m, 2.44 m, 3.66 m, and 4.88 m depths, and, in some cases, following a 30 minute simulated clarification.

Pilot Plant Operational Procedures

Start-up operations

Funding for the project was obtained from the city of Ames in late October, 1985. Construction of the uninsulated building to house the pilot plant was completed in late November, and the media arrived in late December. The plant was assembled and hydraulically functional (except for the pretreatment process) on January 21, 1986.

The nitrifying microorganism population in the biofilter was established in cold temperatures. Antonie (1976) discussed the difficulties associated with cold climate RBC nitrification start-up. Heaters were used to maintain building interior ambient temperatures of 7° to 12° C.

Recycle of the biofilter effluent was employed, and the effluent collection tank at the base of the biofilter was heated with a livestock tank heater so that the temperature of the recycled wastewater was raised from approximately 6°C to final temperatures of 8° to 11°C. Recyle accounted for 50 to 80 percent of the total hydraulic load during the start-up operations. Dosing cycle length was 40 to 80 seconds during the start-up operations. The average total hydraulic loading rate was maintained between 0.45 $1/m^2 \cdot s$ and 0.56 $1/m^2 \cdot s$.

The key to the successful cold weather start-up was the opportunity to seed the biofilter influent with effluent from a full-scale nitrifying biofilter located in Huxley, Iowa. A small sampling pump was used to introduce small amounts of nitrified effluent into the dosing siphon tank at constant time intervals for about six to eight hours per day from February 24 to March 1, 1986.

Prior to the seeding operations, nitrification in the biofilter was detectable, but the rate of nitrification was low and was not improving rapidly. Significant improvement in the rate of nitrification was measurable in the biofilter after only a few days following the initial seeding.

The hydraulic loading was then adjusted to the desired average hydraulic loading and the desired recycle ratio for the first data collection period. The system was allowed to remain at this hydraulic loading condition for two weeks with occasional sample collection and testing to establish the approach to "pseudo-steady state". The first "pseudo-steady state" data collection was conducted after March 13, 1986.

Post-start-up operations

When hydraulic loading and/or influent NH_4^+-N concentration (supplementation instituted) conditions were changed for subsequent data collection periods, an acclimation period of 2-4 weeks was allowed with occasional sampling and testing to establish the approach to the new "pseudo-steady state" condition. The chronology of operating procedures, conditions, and changes and equipment malfunctions is summarized in Table 6.

Table 7 lists the data collection periods, the hydraulic loading conditions in effect for each, the wastewater temperature for each, and the range of influent NH_4^+-N and TKN concentrations for each.

Hydraulic residence tests

Hydraulic residence tests were conducted on two occasions for continuously and intermittently-dosed wastewater applications at average hydraulic loading rates of 1.2 $l/m^2 \cdot s$. Because of the cyclic nature of the hydraulic loading provided by the dosing siphon, special procedures were used to determine the average hydraulic residence times. The adequacy of flow distribution within the biofilter media was determined prior to hydraulic residence testing.

The water level in the dosing siphon was monitored on a continuous basis using an ISCO 1870 flow meter in the level mode. The chart time was synchronized with the operator's watch. The cyclic rise and fall of the water level in the dosing siphon was recorded relative to real time. The volume of influent wastewater per cycle, V_{APP}, was equal to

Table 6. Chronology of nitrifying biofilter operating procedures, conditions, and changes and equipment malfunctions

Date	NH_4^+-N Supplementation With NH_4Cl	Source of Influent to Nitrifying Biofilters	Total Hydr. Loading Rate $l/m^2 \cdot s$
1/21/86	No	Ames WPCP Secondary Effluent	0.45-0.56
2/24/86	No	"	"
3/1/86	No	"	"
3/10/86-3/17/86	No	"	0.47
3/17/86-3/22/86	No	"	0.49-0.52
3/23/86	No	"	"
3/24/86	No	"	0.58
3/25/86	No	"	"
3/26/86-4/1/86	No	"	0.58
4/1/86-4/18/86	Yes	"	0.56-0.59
4/18/86-6/16/86	No	"	0.58
6/16/86	No	Pretreated Secondary Effluent	0.58
6/18/86	No	"	0.58
6/18/86-7/1/86	No	"	"
7/1/86-7/2/86	No	???	"
7/3/86-7/7/86	No	Pretreated Secondary Effluent	<0.5

Recycle % of Total Flow	Intermittent Dosing Cycle and Distribution Time/Cycle	Other Information
50-80	40-80s 23-35 s/cycle	Nitrification first detected 2/20/86
"	"	Seeding with Huxley biofilter effluent
"	"	Ended seeding
58	71-79s 25-30 s/cycle	
30-32	64-68s 25 s/cycle	
"	"	Feed pump circuit breaker tripped
26	60s 18 s/cycle	
"	"	Feed pump circuit breaker tripped
26	59-61s 18 s/cycle	
24-29	53-66s 18 s/cycle	
0	55s 18 s/cycle	
0	55s 18 s/cycle	New pretreatment tower on-line
0	55s 18 s/cycle	Feed pump lost prime
0	"	
0	"	Skunk River flooded
0	?	Skunk River receded, feed pump suction drew some air

Table 6. (Continued)

Date	NH_4^+-N Supplementation With NH_4Cl	Source of Influent to Nitrifying Biofilters	Total Hydr. Loading Rate $l/m^2 \cdot s$
7/7/86-7/21/86	No	Pretreated Secondary Effluent	0.59
7/21/86-7/31/86	Yes	"	0.56-0.59
8/1/86	No	"	"
8/10/86	No	"	"
8/11/86-8/30/86	No	"	"
8/30/86-10/28/86	No	"	1.1-1.2
10/28/86-11/13/86	No	"	1.1-1.2
11/13/86-11/19/86	No	"	1.1→0.8
11/19/86-12/4/86	No	"	0.67-0.80
12/4/86-12/19/86	No	"	1.1-1.2
12/19/86-1/12/87	No	"	1.1-1.2
1/12/87-1/15/87	No	"	No flow for 1-3 days
1/15/87-1/27/87	No	"	1.2-1.3
1/27/87-2/13/87	No	"	0.62

Recycle % of Total Flow	Intermittent Dosing Cycle and Distribution Time/Cycle	Other Information
0	58s 18 s/cycle	
0	58-60s 18 s/cycle	
0	"	
0	"	Pump overheated, no flow to tower
"	"	
0	30-35s 18 s/cycle	
27-32	30-34s 18 s/cycle	
32→44	34→49s 20 s/cycle	Pump began losing efficiency
0	41-57s 15-25 s/cycle	
38	34-36s 18 s/cycle	
38	Not intermittent	
		Feed Pump Quit
0	Not intermittent	
0	Not intermittent	

Table 7. Summary of data collection periods

Collection Period	Avg. Hydraulic Loading Rate, $l/m^2 \cdot s$ (% Recycle)	Dosing Cycle sec	Distribution Time, sec	Average Dosed Hydraulic Loading, $l/m^2 \cdot s$	Influent NH_4^+-N mg/l	Influent TKN mg/l	Wastewater Temp., °C
3/10/86-3/17/86	0.46-0.47 (58)	71-79	25-30	1.1-1.3	1.4-5.6	5-11	9-12
3/19/86-3/22/86	0.49-0.52 (31)	64-68	25	1.3	2.6-8.0	10-11	6-12
3/26/86-4/18/86	0.56-0.59 (24-29)	53-66	15-20	1.8-2.1	7-25	11-28	11-16
7/14/86-7/31/86	0.56-0.59 (0)	58-60	15-20	1.8-2.1	1-21	20	21-25
11/11/86-11/13/86	1.13-1.27 (27-32)	31-34	15-20	2.0-2.5	12-14	15-19	12-15
11/19/86	0.79 (44)	49	20	1.9	16	38	13-15
11/21/86-12/4/86	0.67-0.80 (0)	41-56	15-25	1.6-2.0	6-17	13-21	12-15
12/15/86-12/19/86	1.15-1.17 (38)	34-36	15-20	2.0-2.5	6-16	13-16	13-15
1/19/87-1/27/87	1.21-1.28 (0)	Not Intermittent			7-16	11-21	11-12
2/12/87-2/13/87	0.62 (0)	Not Intermittent			13	17	13-16

the flow rate into the dosing siphon tank multiplied by the time interval between cyclic discharges.

A collector of known cross-section (9.0 cm diameter) was used to collect effluent from the media at the 4.88 m depth. The collected effluent drained directly into a 1000 mL graduated cylinder. The cumulative volume of effluent collected was recorded at time intervals of six to ten seconds. The effluent of three to four dosing siphon tank cycles was collected in a single 1000 mL cylinder.

Effluent collection with this equipment indicated uniform wastewater distribution in the media. The average rate of effluent collection was plotted versus real time. The volume of effluent collected, V_{COLL}, for a single dosing siphon tank discharge was determined as the area under the effluent collection rate versus real time curve. Comparison of V_{COLL} to V_{APP} confirmed that the superficial velocities at various points beneath the tower were within ten to twenty percent of the theoretically applied superficial velocity.

When intermittent dosing was in use, a 500 ml volume of a known concentration of NH_4Cl brine (tracer) was introduced onto the distribution plate immediately prior to discharge of the dosing siphon tank, and the time was recorded. This volume allowed fairly uniform spread of the tracer over the distribution plate and onto the media immediately before the dosing siphon tank discharge occurred. Introduction of the tracer in other locations or by other methods was found to be unsatisfactory for intermittent dosing conditions. When continuous dosing was in use, the tracer was introduced directly into the dosing siphon discharge pipe.

Biofilter effluent was collected at twenty to thirty second intervals for eight to ten minutes following tracer introduction. Each of the samples was analyzed for NH_4^+ and Cl^-. The NH_4^+ and CL^- concentrations were plotted versus real time. The cumulative recovered mass was determined with time from these plots, and the average hydraulic residence time was determined to be the time required to recover 50% of the chloride tracer mass introduced.

Since the biofilter was operated in an oxygen-limited mode throughout its entire depth (i.e., constant total NH_4^+ mass removal across the tower depth, independent of the bulk liquid NH_4^+-N concentration), the NH_4^+ tracer was used to determine the average NH_4^+ contact time. For this condition, NH_4^+-N loss due to nitrification did not affect the NH_4^+-N contact time calculation. The average NH_4^+ contact time was defined as the time required to recover 50% of the NH_4^+ tracer mass introduced.

Sample collection, preservation, and analysis

The sampling ports on the nitrification biofilter were constructed such that the main wastewater access slots at any two sampling depths were not vertically aligned. Thus, flow collected by an upper sampling port did not reduce the hydraulic loading rate for wastewater entering sampling ports at greater depths. Figure 23 demonstrates the staggered orientation of the sampling port access slots.

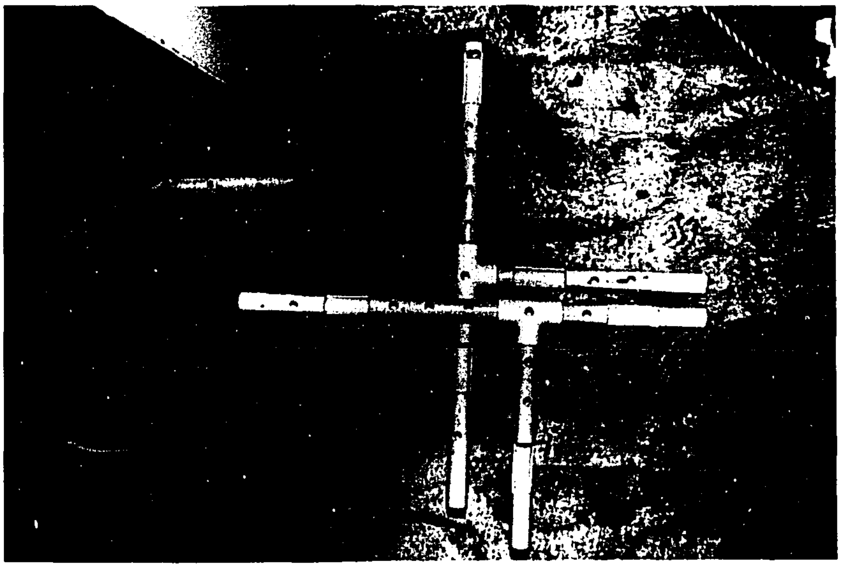

Figure 23. Nitrifying biofilter sampling port construction

Samples were collected simultaneously at all sampling points during any given profile sampling of the nitrifying biofilter. Samples were usually collected at various depths in the pretreatment biofilter simultaneously to allow some comparison of the two types of media in use.

Prior to sample collection, the sampling ports were flushed clean in the following manner. The sampling ports were opened and closed many times over a ten minute period to flush accumulated solids out of the sampling ports. The sampling ports were then left open for an additional ten minutes to assure that they were flushed clean of any stagnant water and solids. Clean, five-liter collection buckets were attached to the sampling ports to simultaneously collect discharge from the ports for a period of time ranging from 15 to 45 minutes. The sample collection times at all sampling ports were essentially equal (± 2 to 3 minutes).

When complete biofilter profile data were not deemed necessary or practical, discrete samples were collected at constant time intervals at the nitrifying biofilter dosing siphon tank and the biofilter effluent using ISCO 2100 automatic samplers. A composited sample was collected simultaneously at the eight feet depth using an N-CON automatic sampler set at three equal volume samples per hour.

Samples were collected at one to eight hour intervals during data collection periods depending on sampling objectives and operator convenience. Upon collection, the samples were transferred to clean sample bottles when necessary and were preserved and analyzed in accordance with Table 8. When composited samples were required, the discrete

Table 8. Sample preservation and analytical methods

Analytical Parameters	Preservation Methods	Analytical Method Used
pH	Determined immediately in field	Method #423 in Standard Methods[a]
Temperature	Determined immediately in field	
D.O.	Determined immediately in field	Hach Chemical Company version of the azide modification of the Winkler Method #421 B. in Standard Methods[a], for 60 mL sample size
NH_4^+-L	4°C, H_2SO_4 to pH < 2[b]	Ammonia selective electrode method #417 E. in Standard Methods[a]
$NO_2^- + NO_3^-$-N	4°C, H_2SO_4 to pH < 2[b]	Automated cadmium reduction method #418 F. in Standard Methods[a]
TKN	4°C, H_2SO_4 to pH < 2[b]	Colorimetric, semiautomated block digester AA II, EPA Method 351.2 (semiautomated phenate method)
Filterable TKN	0.45µ filtration, 4°C, H_2SO_4 to pH < 2	
COD	4°C, H_2SO_4 to pH < 2[b]	Dichromate reflux method #508 in Standard Methods[a]

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[a] Standard Methods for the Examination of Water and Wastewater. 16th ed. Washington, D.C. American Public Health Association, 1985.

[b] Samples were not acidified until after filterable TKN, filterable COD, SS, VSS and alkalinity liquid fractions were removed for analyses when applicable.

Table 8. (Continued)

Analytical Parameters	Preservation Methods	Analytical Method Used
Filterable COD	0.45µ filtration, 4°C, H_2SO_4 to pH < 2	
SS	4°C	Total nonfilterable residue dried at 103-105 C #209 D. in Standard Methods[a]
VSS	4°C	Volatile and fixed matter in nonfilterable residue and in solid and semisolid samples #209 G. in Standard Methods[a]
Alkalinity	4°C	Method #403 in Standard Methods[a]

samples taken at any given sampling point were combined on a flow-proportional basis to account for sampling interval variations, properly preserved and analyzed.

The significant analytical parameters in this study were the NH_4^+-N, TKN, filterable TKN, NO_2^- + NO_3^--N, COD, filterable COD, pH, temperature, SS, VSS, alkalinity, and DO of the bulk liquid. The pH, temperature, DO, and NH_4^+-N analyses were performed by the operator. The remaining parameter analyses were performed by the Engineering Research Institute laboratory personnel. The analytical methods used for the analytical parameters are summarized in Table 8.

The analytical schedule for samples was generally related to sampling point location as shown in Table 9. However, the operator exercised discretion in deviation from this schedule when he felt that the understanding of process variables and biofilter performance were likely to be enhanced or when analytical costs and operator convenience were considerations.

Characteristics of Pilot Plant Influent

The values of significant parameters in composited samples of the Ames WPCP secondary clarifier (final) effluent were determined three times per week during the pilot study. These analyses were performed and reported by the Ames WPCP personnel.

The properties of the wastewater influent to the nitrifying biofilter portion of the pilot plant were usually different from those of the Ames WPCP secondary clarifier effluent because of the pretreatment portion of the pilot plant, NH_4^+-N supplementation, and recycle.

Table 9. Sampling point analytical schedule

Sampling Point	Analyses Normally Performed
Pretreatment Biofilter	
Influent	COD, TKN, NH_4^+-N, NO_3^--N + NO_2^--N
4' Depth	NH_4^+-N
Effluent	COD, TKN, NH_4^+-N, NO_3^--N + NO_2^--N
Pilot-Scale Nitrifying Biofilter [a]	
Influent	pH, temperature, D.O., COD, filterable COD, TKN, filterable TKN, NH_4^+-N, NO_3^--N + NO_2^--N, SS, VSS, alkalinity
4' Depth	pH, D.O., COD, TKN, NH_4^+-N, NO_3^--N + NO_2^--N
8' Depth	pH, temperature, D.O., TKN, NH_4^+-N, NO_3^--N + NO_2^--N
12' Depth	pH, D.O., TKN, NH_4^+-N, NO_3^--N + NO_2^--N
16' Depth	pH, temperature, D.O., COD, filterable COD, TKN, filterable TKN, NH_4^+-N, NO_3^--N + NO_2^--N, SS, VSS, alkalinity
Settled Effluent (½ hour -1 hour in 5 gallon bucket)	TKN, NH_4^+-N, SS, VSS

[a] pH and D.O. measurements were made during some, but not all, sample collection periods.

Detailed reporting of the secondary effluent analytical parameters is, therefore, not appropriate in this dissertation. Pertinent secondary effluent DO and BOD_5 concentrations reported by the Ames WPCP personnel during the study period are included in the pretreatment tower data section in the Appendix.

Huxley, Iowa Full-Scale Plant Sampling

The city of Huxley operates a new 2.4×10^6 l/d average design flow separate-stage trickling filter plant, which began operation in May, 1985. The minimum initial wastewater flow was expected to be about 5.4×10^5 l/d. The minimum design flow was 1.3×10^6 l/d. The covered nitrifying biofilter is 7.62 m in diameter and 4.27 m deep. It is filled with 98 m^2/m^3 cross-flow media. The rotary distributors are rated for maximum and minimum flow rates of 79 L/s and 28 L/s, respectively. A 16 L/s recirculation capacity is available.

Approval was obtained to sample the nitrifying biofilter influent and effluent during the months of January, February, and March, 1986. The samples were analyzed for NH_4^+-N and temperature, and occasionally for TKN, COD, SS, and pH. The samples were collected at preset, constant time intervals using ISCO 2100 automatic samplers. All samples were preserved immediately by the cold ambient temperatures and by acidification for TKN, NH_4^+-N, and COD analyses.

The low flow conditions and low NH_4^+-N plant loadings yielded little useful oxygen-limited data. Most influent NH_4^+-N concentrations were very low. In addition, plant records were not always sufficient to evaluate the use of recycle. Ammonium-limited data were obtained.

Only the oxygen-limited nitrification data will be presented in subsequent presentations.

RESULTS AND ANALYSIS

This nitrifying biofilter study was noteworthy for the following reasons:

1. It involved successful start-up in cold temperatures.
2. It involved a comparison of two types of wastewater application, i.e., intermittent dosing and continuous dosing, at identical average hydraulic loading rates.
3. Bulk liquid sampling was performed at many tower depths, and chemical parameter concentration profiles along the tower depth were constructed.
4. Bulk liquid chemical parameters monitored included D.O., NH_4^+-N, NO_2^- + NO_3^--N, TKN, filterable TKN, COD, filterable COD, pH, SS, VSS, and alkalinity.
5. 60 degree cross-flow structured media with a specific surface area of 138 sq. m/cu. m and 45 degree cross-flow structured media with a specific surface area of 98 sq. m/cu. m were used in the nitrifying biofilter and the pretreatment biofilter, respectively.
6. Nitrification performance at bulk liquid NH_4^+-N concentrations greater than 3 to 4 mg/l throughout the tower depth was emphasized.
7. The project was performed with equipment and operational budgets of $2,000 and $6,000, respectively, and with a one-person staff.

Typical results for the variety of hydraulic and mass loadings studied will be presented. Observations of conditions which may have influenced the nitrification performance will be discussed. The experimental and calculated data for this investigation have been included in the appendix.

It was desirable to evaluate the data at a common wastewater temperature. The common temperature selected was 10°C. Nitrification rates observed at temperatures other than 10°C were converted to a 10°C basis by the use of the Nernst-Einstein equation presented in the Review of Literature section. The effects of temperature-related viscosity changes on the hydraulic residence time were not considered for two reasons. First, hydraulic flow patterns over the surface of structured, plastic media would not be the same as flow patterns over flat, inclined planes like those used in the studies evaluated in the Review of Literature section. Second, biofilm growth on the plastic media would alter the viscosity effects.

Oxygen flux-limited nitrification rates approaching 8×10^{-4} to 10×10^{-4} kg N/d/sq. m of specific surface area were expected at 10°C. This prediction was based on conversion of the 11.7×10^{-4} kg N/d/sq. m oxygen flux-limited, average nitrification rate, reported by Gullicks and Cleasby (1986), to 10°C by the use of the Nernst-Einstein equation.

Pretreatment Biofilter Performance

Analytical parameter concentrations versus depth in the pretreatment tower are presented in Table 10. The pretreatment tower was 2.44 m tall and was filled with 45 degree cross-flow media with a specific surface area of 98 sq. m/cu. m. Wastewater flow to the pretreatment tower consisted entirely of secondary effluent from the final clarifiers

Table 10. Analytical parameter concentrations versus depth in the pretreatment tower. 45° cross-flow media with a specific surface area of 98 m^2/m^3. No recycle

Date	Avg. Hyd. Load $l/m^2 \cdot s$	Water Temp. °C	Depth in Tower, m	NH_4^+-N mg/l	TKN mg/l	NO_2^-+ NO_3^--N mg/l	TKN <0.45μ mg/l	COD mg/l	COD <0.45μ mg/l	Alk mg/l as $CaCO_3$	SS mg/l
7/31/86	1.90	22.5	0	8.6							
			1.22	7.4							
			2.44	6.3							
11/11/86	1.72	16.3	0	19.7	22.3			92			
			1.22	18.9							
			2.44	17.1	23.4	6.4		133			
11/12/86	1.72	13.2	0	17.2	20.4			181			
			1.22	17.1	19.9			116			
			2.44	15.9	19.4	5.5		130			
11/13/86	1.70	15.8	0	14.2	20.6			121			
			1.22	14.9	21.9		16.8		47		
			2.44	16.2	22.8	5.5		109			
11/19/86	1.66	15.5	0	19.0	27.1			84			
			1.22	19.0	26.2						
			2.44	17.0	23.9			72			

Table 10. (Continued)

Date	Avg. Hyd. Load l/m^2 • s	Water Temp. °C	Depth in Tower, m	NH_4^+-N mg/l	TKN mg/l	NO_2^-+ NO_3^--N mg/l	TKN <0.45µ mg/l	COD mg/l	COD <0.45µ mg/l	Alk mg/l as $CaCO_3$	SS mg/l
11/21/86	1.63	14.8	0	11.7	20.2			80			
			2.44	11.7	21.0		13.5	76	33		
11/25/86	1.64	15.2	0	14.8	19.3			138			
			1.22	15.1							
			2.44	12.1	16.4		13.6	65	25		
11/30/86	1.79	13.2	0	11.7	15.8			106			
			2.44	10.1	12.1		10.9	79	60		
12/1/86	1.81	14.8	0	14.9	20.0	4.0		102			
			2.44	11.9	16.1	9.1	15.4	127	49		
12/3/86	1.78	13.0	0	17.6	22.2	6.0					
			2.44	15.1	18.4	9.4	17.0	109	34	200	
1/19/87	1.77	12.9	0	18.8	22.8			119			
			2.44	16.5	21.3		18.0	69	42	155	54
1/25/87	1.75	12.5	0	14.2	22.2			166			
			2.44	12.0	19.0		16.0	140	66	161	57

Table 10 (Continued)

Date	Avg. Hyd. Load l/m² • s	Water Temp. °C	Depth in Tower, m	NH_4^+-N mg/l	TKN mg/l	NO_2^- + NO_3^--N mg/l	TKN <0.45µ mg/l	COD mg/l	COD <0.45µ mg/l	Alk mg/l as $CaCO_3$	SS mg/l
1/25/87	1.75	12	0	11.9	19.0	4.0	13.7	157	48		
			2.44	9.8	14.6	8.5	11.8	75	47	157	48
1/27/87	1.76	12	0	11.7	20.0	4.4	14.5	164	56		
			2.44	9.4	15.5	7.7	12.3	108	41	159	42

at the Ames WPCP. Recycle was not used. Wastewater was dosed continuously at hydraulic loading rates ranging from 1.4 to 1.9 l/sq. m • s.

The pretreatment tower was put into operation on June 16, 1986. The pretreatment tower was constructed to provide carbonaceous oxygen demand reduction ahead of the pilot-scale nitrifying biofilter. Nitrification was apparent in the pretreatment tower by July 14, 1986. Near steady-state nitrification was observed by July 30, only six to seven weeks after start-up. The pretreatment tower nitrification performance was monitored simultaneously with the performance of the pilot-scale nitrifying biofilter through January 27, 1987.

Figure 24 demonstrates that the rate of nitrification, converted to a common 10°C basis by the use of the Nernst-Einstein equation, in the pretreatment tower was independent of influent bulk liquid NH_4^+-N concentration at NH_4^+-N concentrations greater than 6 mg/l, and was, therefore, flux-limited by oxygen. At influent NH_4^+-N concentrations less than 6 mg/l, the concentration of NH_4^+-N in the tower effluent was less than 4 mg/l, and nitrification was flux-limited by substrate.

As expected with biological fixed-film processes, there was substantial data scatter. The data scatter was due primarily to relatively poorer performance of the top section of the pretreatment tower when compared to the performance of the lower section of the tower. It would be easy to assume that carbonaceous oxygen demand carryover from the secondary clarifiers was responsible for the poor performance of the top tower section; however, this was not the case. It will be shown that depleted D.O. concentrations in the secondary effluent had stronger

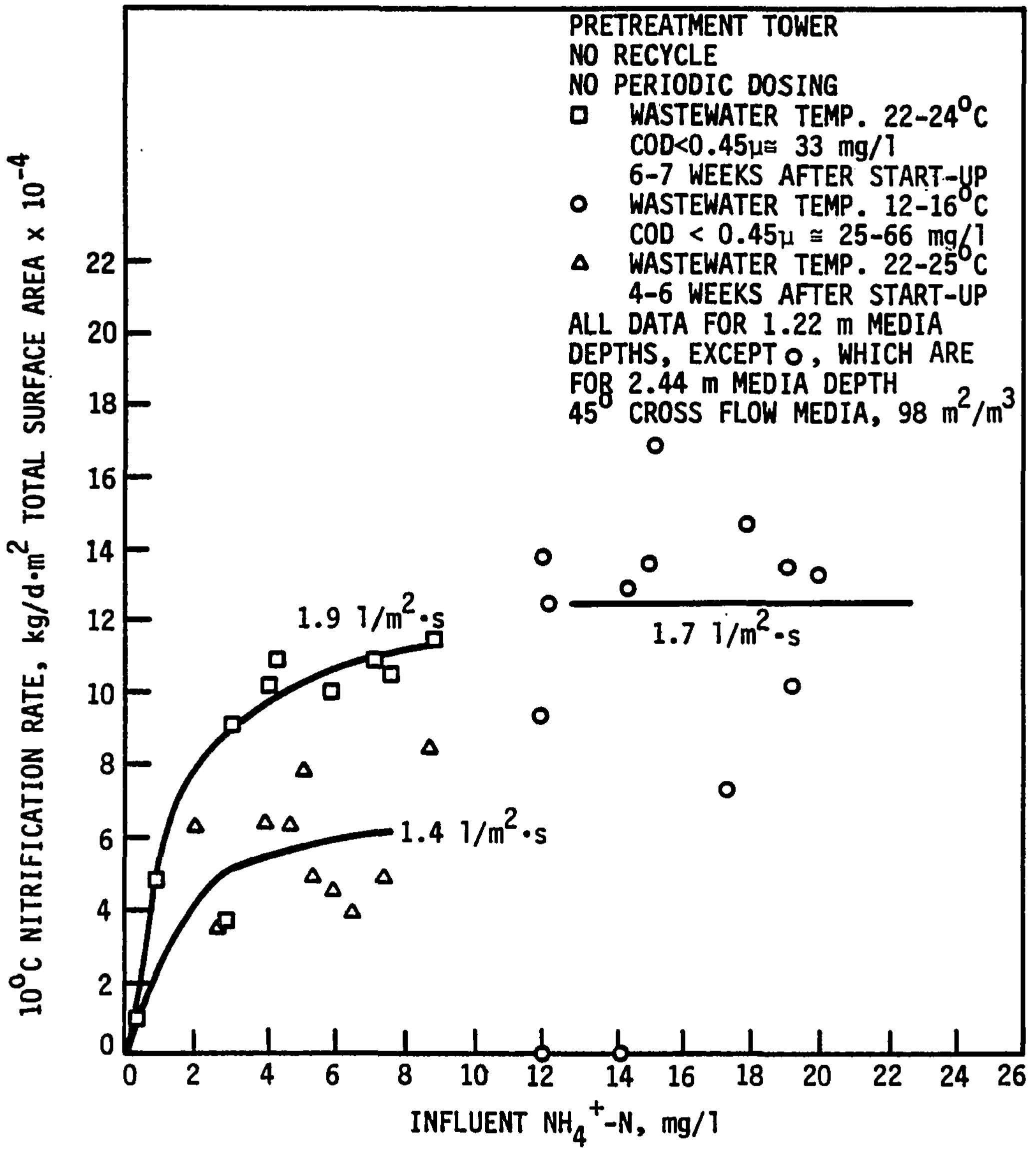

Figure 24. Pretreatment tower nitrification rate versus influent NH_4^+-N

influence on the low or nonexistent nitrification rate in the top section.

Pilot-Scale Nitrifying Biofilter Performance

The nitrifying biofilter consisted of four sections, each 1.22 m tall, stacked end to end for a total height of 4.88 m. The tower was filled with 60 degree cross-flow media with a specific surface area of 138 sq. m/cu. m. Prior to June 16, 1986, secondary effluent from the Ames WPCP was distributed directly to the top of the nitrifying biofilter, with varying amounts of recycled nitrifying biofilter effluent. Subsequent to June 16, 1986, secondary effluent from the Ames WPCP was pretreated to assure good carbonaceous oxygen demand removal before it was distributed onto the nitrifying biofilter media, again with varying amounts of recycled nitrifying biofilter effluent.

Intermittent dosing was used during most of the study, however, some data were collected for continuous dosing conditions. When intermittent dosing was used, the periodic dosing cycle length ranged from 30 to 70 seconds, depending on the average total hydraulic loading rate and the dosing siphon control elected by the operator. The cyclic flow volume was distributed in 15 to 25 seconds of the cycle, depending on the same dosing siphon operational conditions.

0.46-0.51 l/sq. m • s average hydraulic load

The rate of nitrification, converted to a common 10°C basis by the use of the Nernst-Einstein equation, was plotted versus influent NH_4^+-N concentration for average hydraulic loading rates of 0.46-0.51

1/sq. m • s in Figure 25. The rates of nitrification at NH_4^+-N concentrations greater than 4 mg/l were generally lower than expected. However, some data indicate that the anticipated rates of nitrification discussed previously in this section for NH_4^+-N concentrations greater than 4 mg/l can be achieved when influent liquid conditions and the tower environment are suitable.

Recycle, expressed as percent of total flow, did not appear to affect nitrification performance; however, recycle modifies factors such as bulk liquid D.O., carbonaceous oxygen demand, toxicity, etc. Thus, for example, the net influent bulk liquid D.O. is not necessarily higher when a greater percentage of recycle is used; but, were recirculation not in effect the D.O. of the bulk liquid would definitely be lower. This would explain why tower performances with recirculation rates of 31 and 59 percent of the total flow were similar.

0.55-0.59 1/sq. m • s average hydraulic load

Analytical parameter bulk liquid concentrations versus depth in the nitrifying biofilter are shown in Figures 26-28 for average total hydraulic loading rates of 0.57 to 0.58 1/sq. m • s and various recycle and wastewater temperature conditions. Figures 26 and 27 represent cold climate data, while Figure 28 demonstrates the enhanced performance at warmer wastewater temperatures. Nitrification performance at the lower temperatures was somewhat lower than would be expected if all influent conditions, except temperature, were equal. However, wastewater

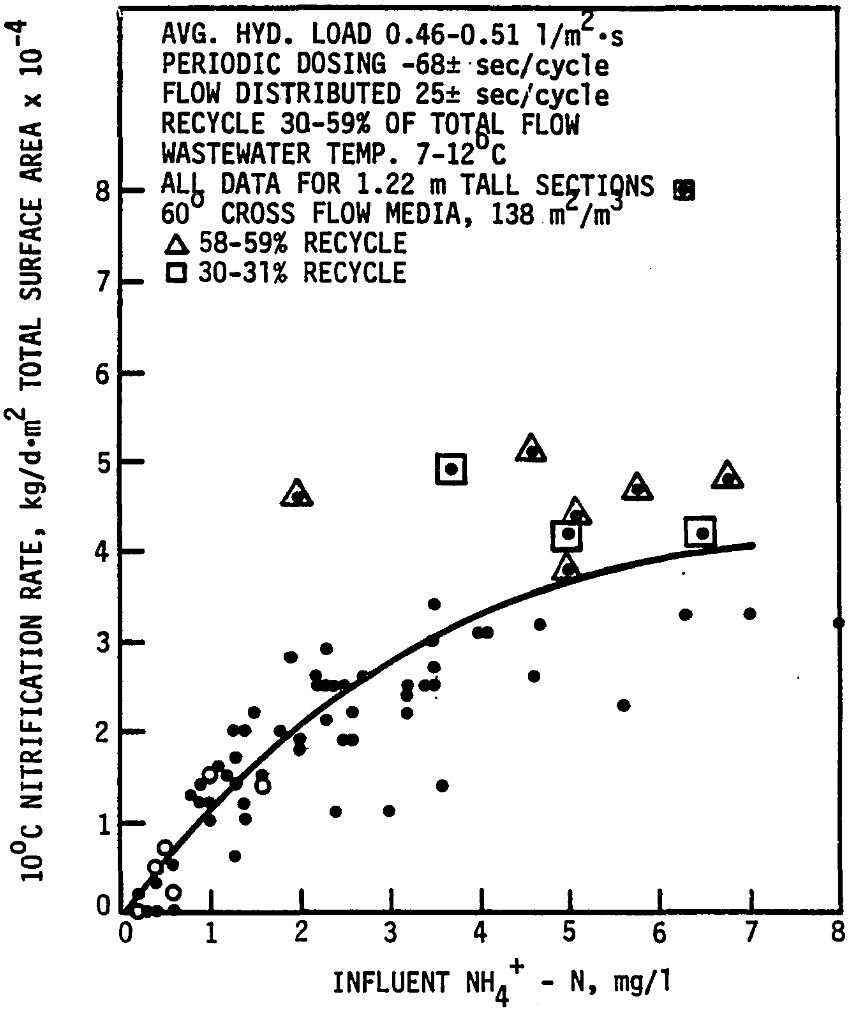

Figure 25. Nitrification rate versus influent NH_4^+-N concentration for average total hydraulic loading rates of 0.46-0.51 l/m² • s. All data points were for recycle conditions of either 30-31% or 58-59% of the total flow. For nitrification rates greater than 3.5×10^{-4} kg/d • m², the % recycle has been indicated by symbols

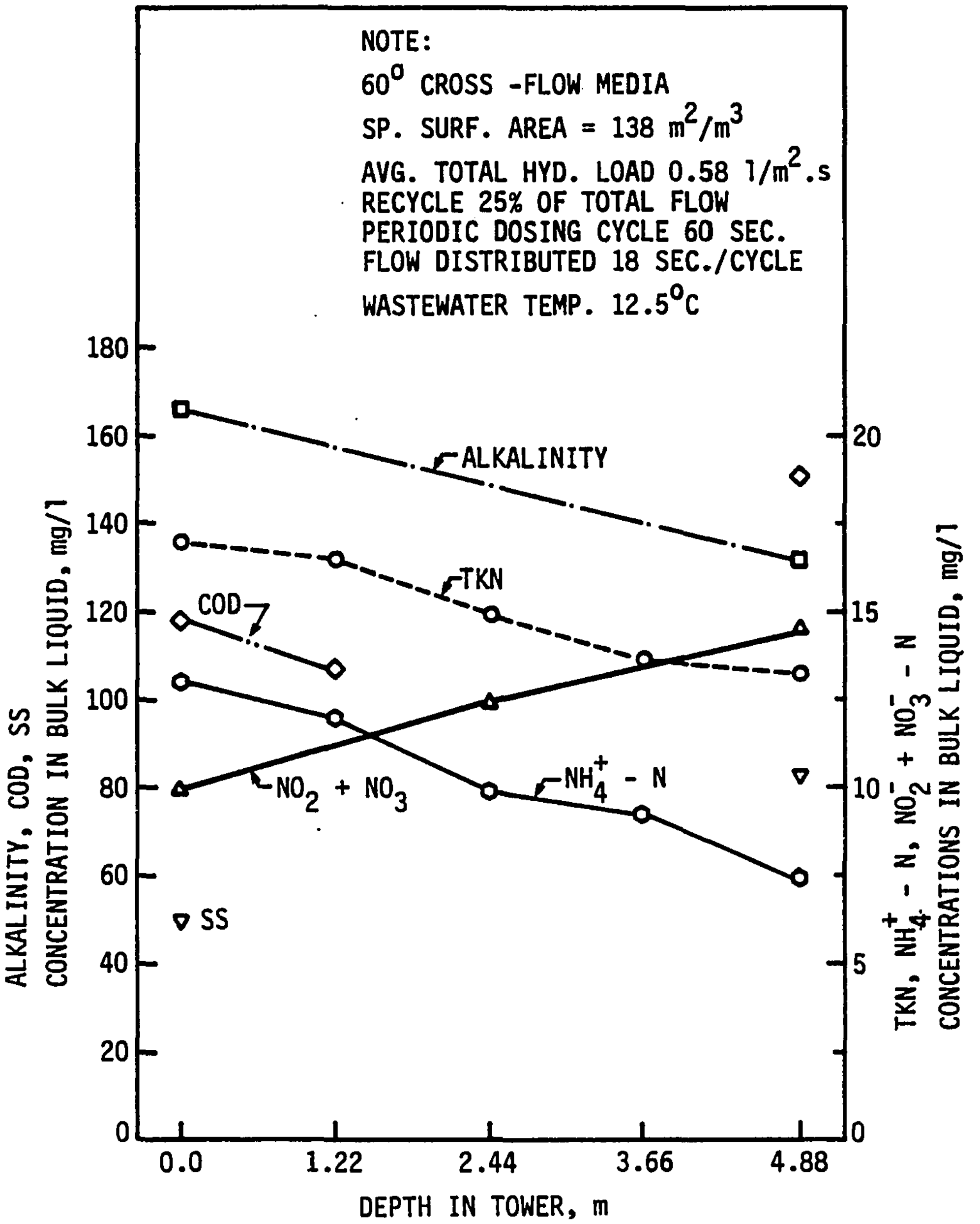

Figure 26. Analytical parameter concentrations versus depth in tower, 4/3/86

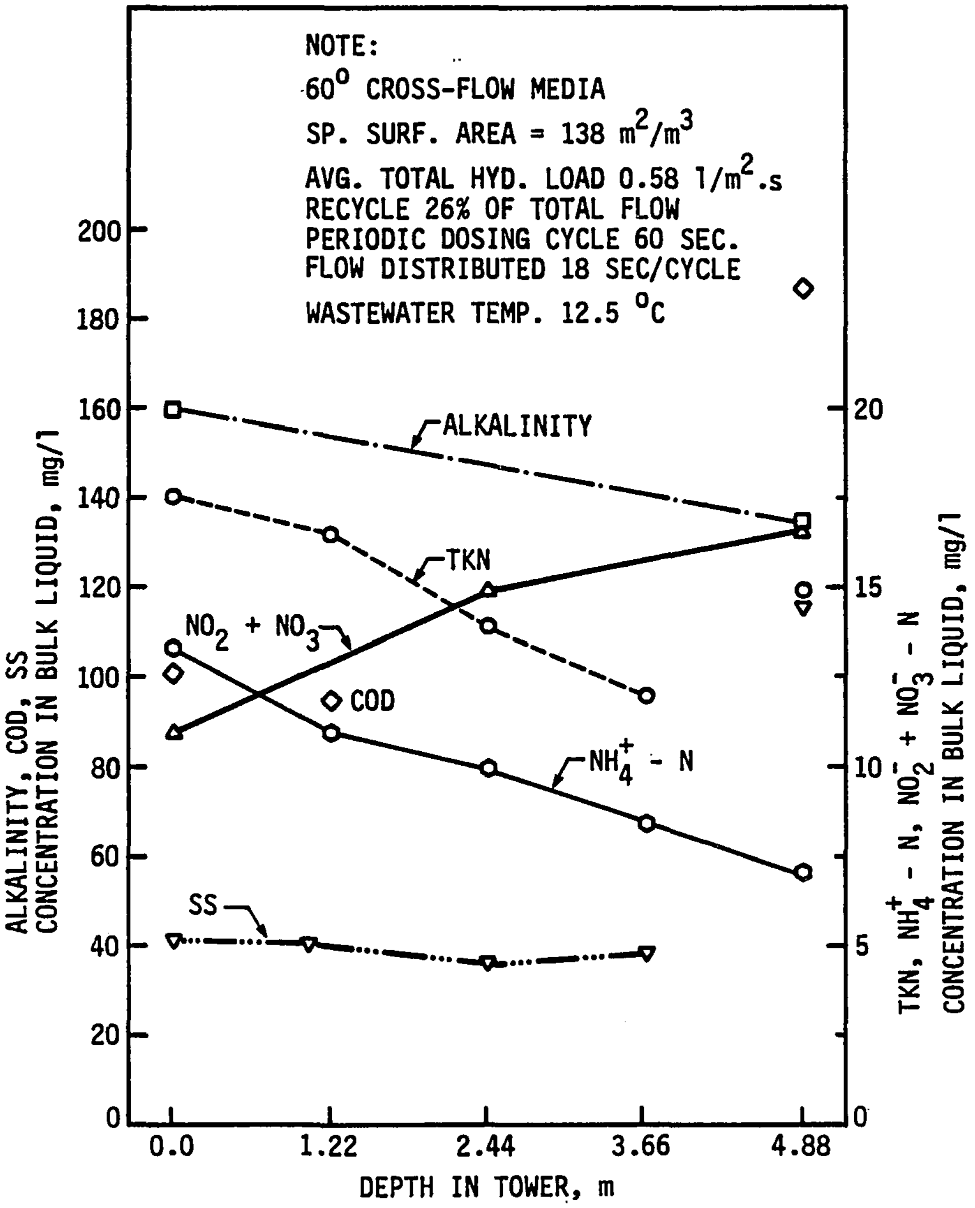

Figure 27. Analytical parameter concentrations versus depth in tower, 4/10/86

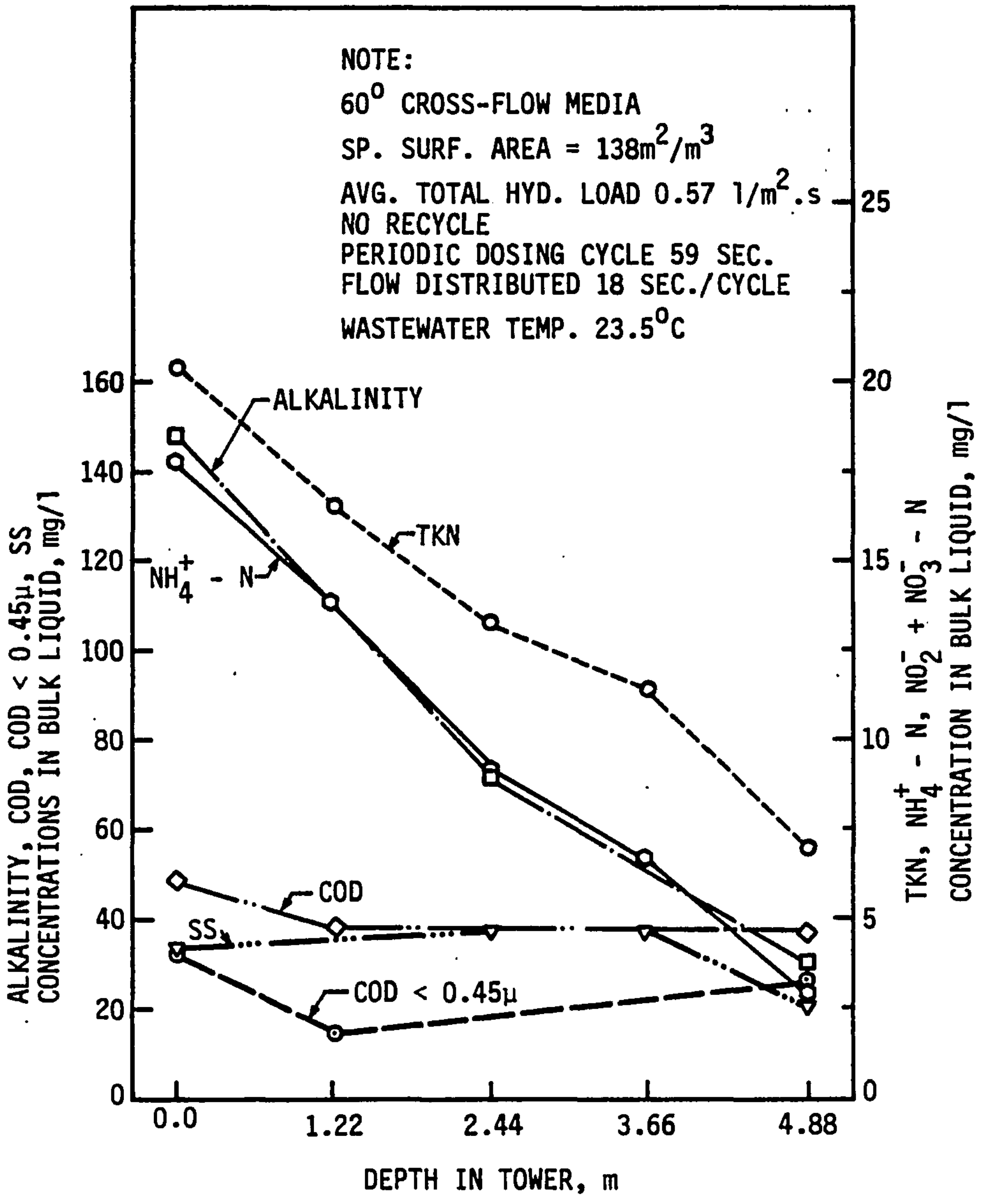

Figure 28. Analytical parameter concentrations versus depth in tower, 7/30/86 - 7/31/86

conditions at colder temperatures will be shown to be less satisfactory for nitrification.

All sections of the biofilter did not perform equally well at any given time. During this study, the 2.44 to 3.66 m tower section often performed poorly when compared to the sections immediately above and below it. Similarly, the top section often performed poorly relative to the section immediately below it. However, Figures 26 and 27 show that the poorer performance of these sections was transient and that other sections also exhibited this phenomenon on different occasions.

The performance of individual tower sections was probably affected by variation of influent bulk liquid characteristics and by partial plugging of the media. Partial plugging of the media would affect liquid distribution and the flow of air through a given section of media. Partial plugging in a tower section would probably not affect the performance of other sections of the tower because both air and water flow would be redistributed in adjacent tower media sections. Partial plugging which occurred at the middle of a tower section, where individual 0.61 m structured media units were stacked could affect both water and air flow in the 0.61 m high units above and below the plugging point.

Figures 29 and 30 show the rate of nitrification, converted to a common 10°C basis by the Nernst-Einstein equation, versus influent bulk liquid NH_4^+-N concentration for average total hydraulic loads ranging from 0.55 to 0.59 l/sq. m • s. The rate of nitrification was observed to be independent of influent NH_4^+-N bulk liquid concentration at

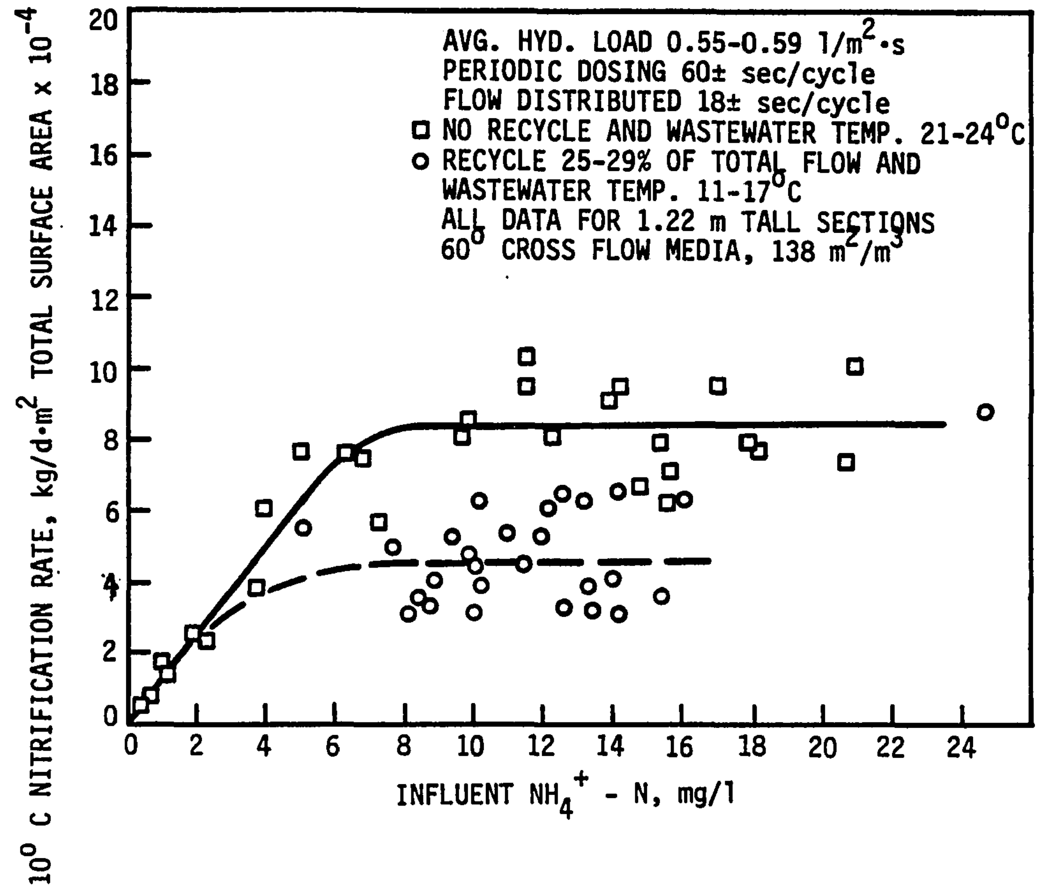

Figure 29. Nitrification rate versus influent NH_4^+-N concentration for average total hydraulic loading rates of 0.55-0.59 l/m² • s. Some data, usually for the 0-1.2m and 2.4-3.7m depth sections, with nitrification rates less than 50% of the nitrification rates in adjacent tower sections were deleted

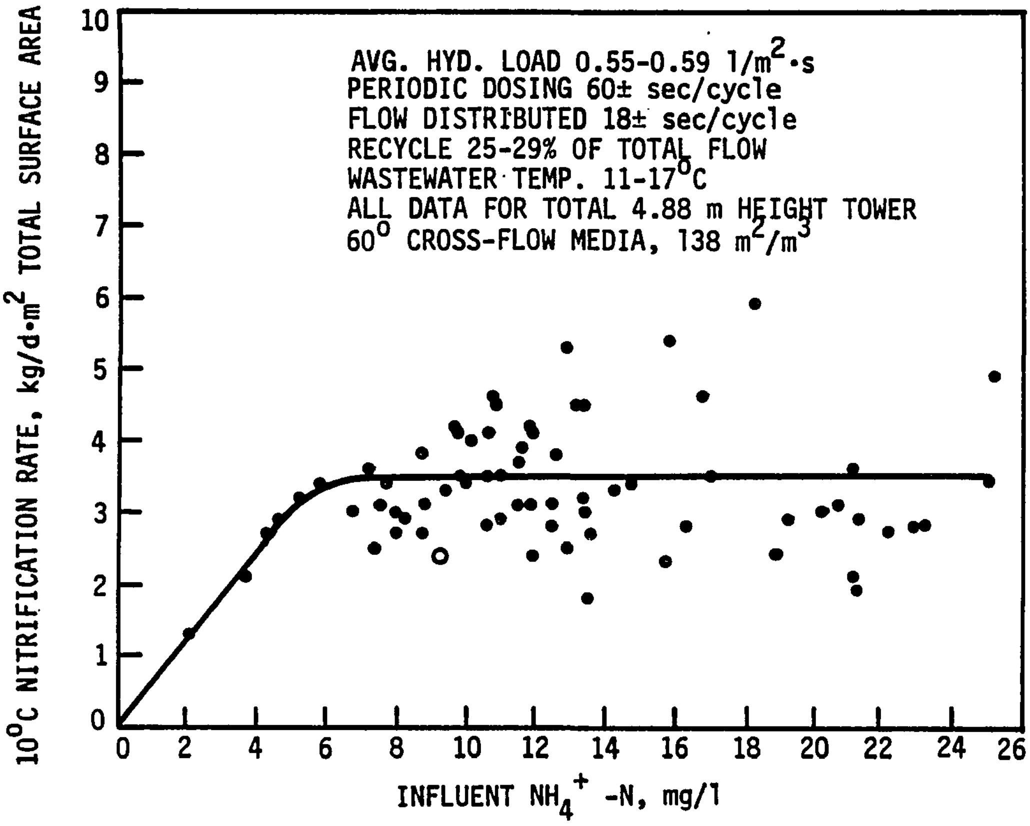

Figure 30. 4.88 m biofilter average nitrification rates versus influent NH_4^+-N concentrations for average total hydraulic loading rates of 0.55-0.59 l/m² • s

NH_4^+-N concentrations greater than 5 to 8 mg/l. Thus, oxygen or some reactant other than NH_4^+-N is the rate-limiting reactant above those concentrations.

Influent bulk liquid characteristics were significantly different during the cold weather data collection period than they were during the warm weather data collection period. The average bulk liquid percent of D.O. saturation was lower in the cold weather period. The average bulk liquid COD concentration was higher in the cold weather period. Thus, cold weather performance was lower than warm weather performance, even when converted to the same 10°C temperature basis.

Data scatter was substantial, but understandable, in view of the D.O. and COD variability. However, it was apparent that nitrification rates could approach those expected (8×10^{-4} to 10×10^{-4} kg/d • sq. m of total surface area as developed previously in this section) if influent liquid conditions and the tower environment were suitable. In general, the data presented in Figure 30 reflect the lower performance of the top section of the tower, and, in many cases, the 2.44 to 3.66 m depth tower section, as well.

1.13-1.29 and 0.67-0.8 l/sq. m • s average hydraulic loads

Figures 31 and 32 show profiles of analytical parameter concentrations versus tower depth for average total hydraulic loading rates of approximately 1.2 l/sq. m • s and wastewater temperatures of 11 to 13°C. These figures are significant in that they demonstrate denitrification in the upper section of the tower, as evidenced by the disappearance of

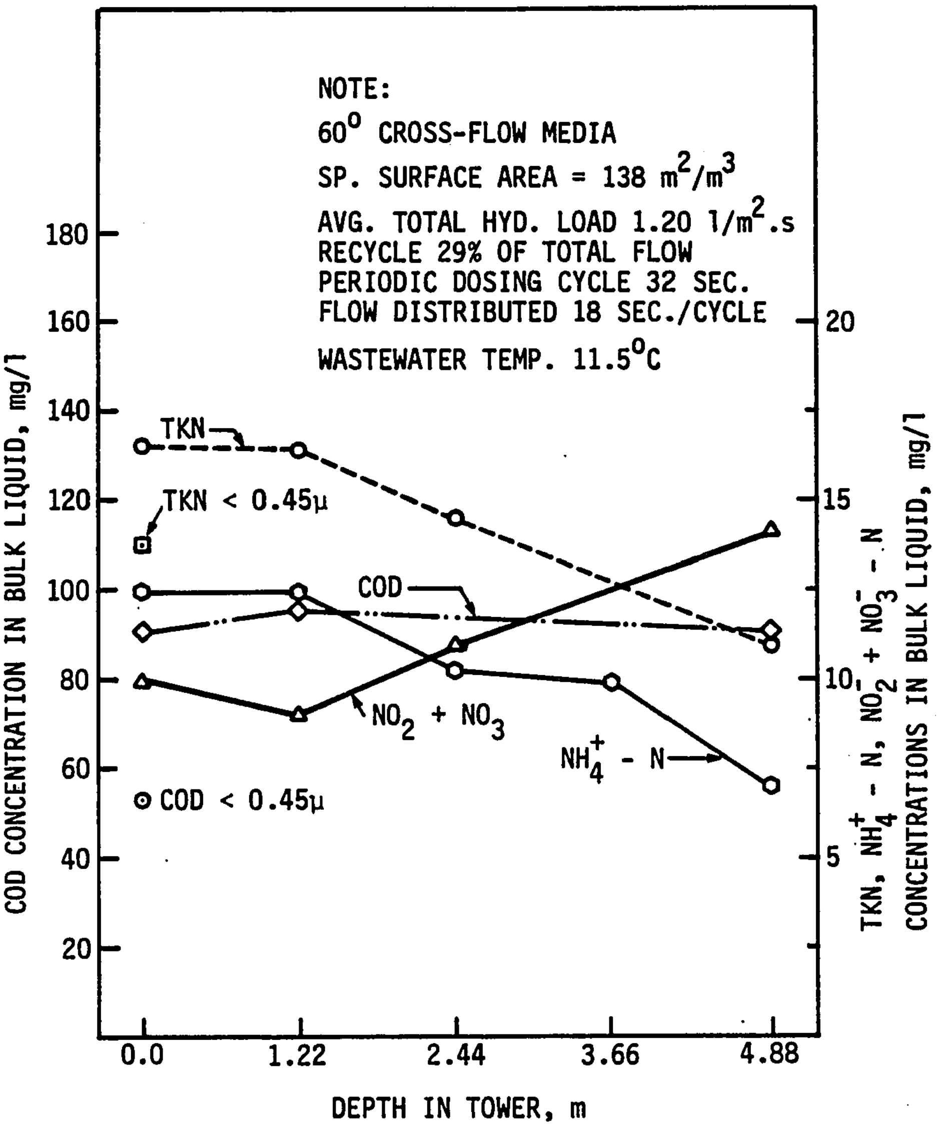

Figure 31. Analytical parameter concentrations versus depth in tower, 11/12/86

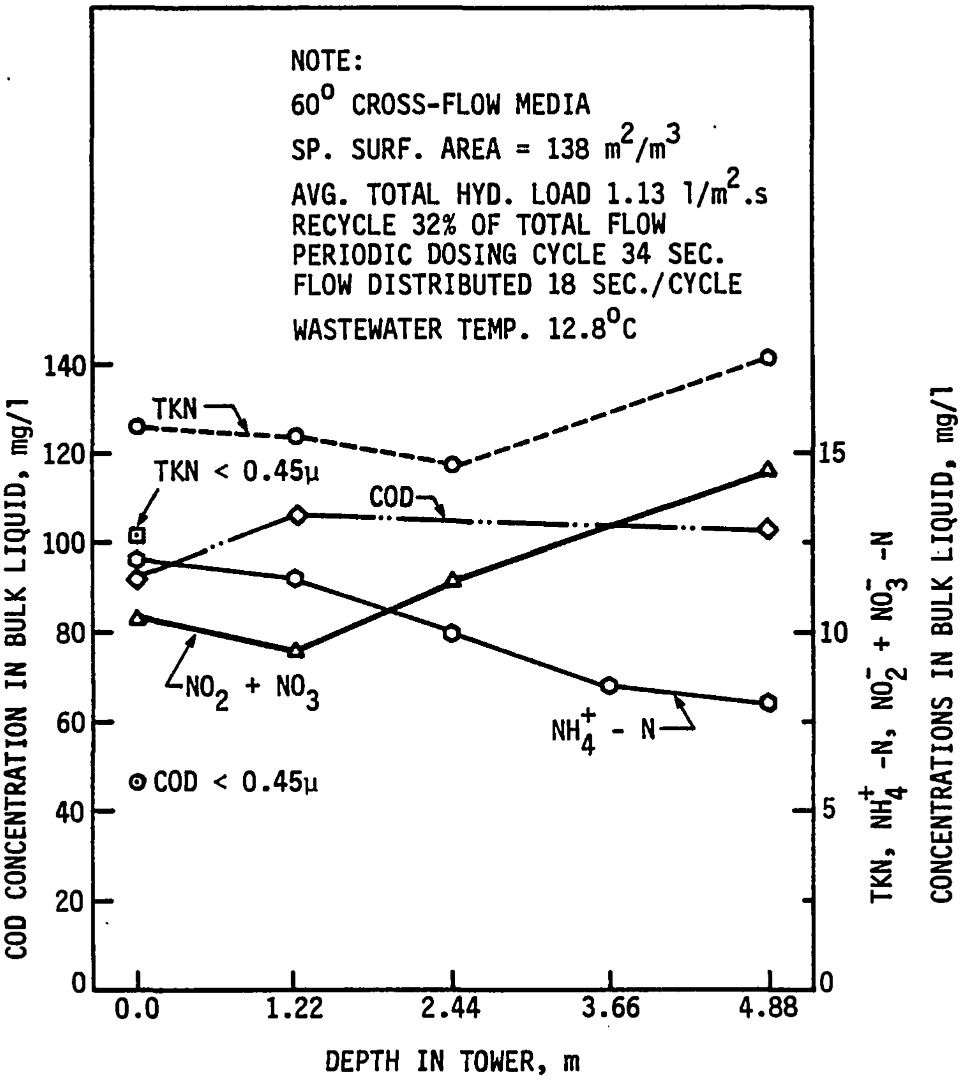

Figure 32. Analytical parameter concentrations versus depth in tower, 11/13/86

$NO_2^- + NO_3^-$-N. Thus, D.O. in the bulk liquid appears to have been inadequate for nitrification in the top tower section and possibly in short supply in the other tower sections as well. Wanner and Gujer (1984) predicted correctly that denitrification could occur in the upper sections of combined carbon oxidation-nitrification trickling filters when recycle was instituted. Apparently, denitrification is possible in the nitrifying biofilter stage of separate-stage systems, as well, when $NO_2^- + NO_3^-$-N concentrations are high enough.

Wanner and Gujer (1984) predicted that soluble COD concentrations greater than 27 mg/l would exclude nitrifiers from the biofilm because of competition with heterotrophs. While the filterable fraction of COD in the influent to the tower exceeded 27 mg/l, the apparent nitrification and negligible change in total COD through the tower depth suggests that the prediction of Wanner and Gujer is not correct.

Figure 33 contains analytical parameter concentration versus tower depth data for an average total hydraulic load of 1.28 l/sq. m • s, but without intermittent dosing. At first glance, this figure could easily be misinterpreted. It would appear that intermittent dosing provided slightly better nitrification than continuous dosing. However, D.O. deficiency may be the real reason for the nearly identical performance of the intermittently-dosed (Figures 31 and 32) and continuously-dosed (Figure 33) towers. Recycle, which was in use in Figures 31 and 32, would have the effect of increasing D.O. in the bulk liquid, and may be responsible for the equivalent performance of the two dosing methods.

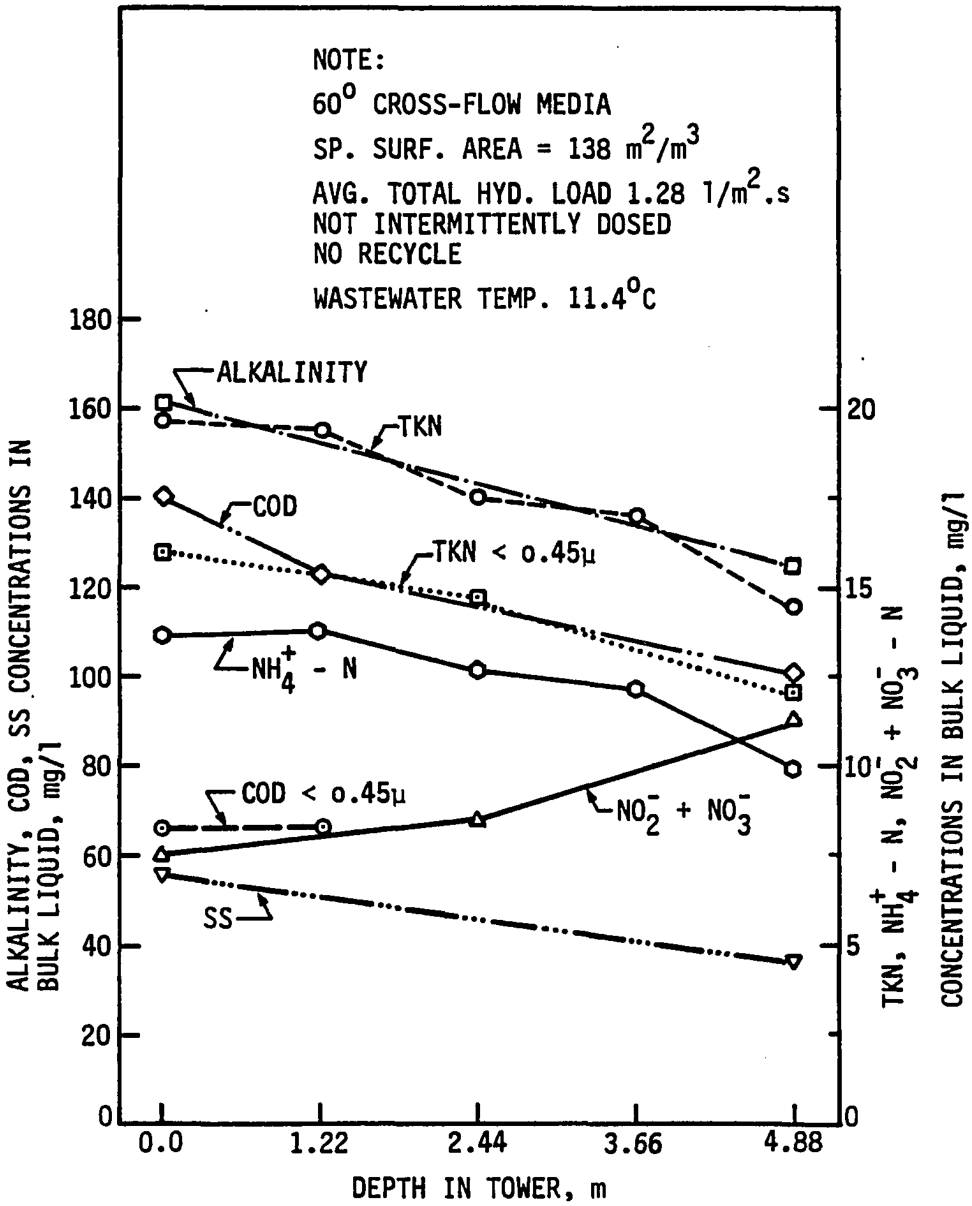

Figure 33. Analytical parameter concentrations versus depth in tower, 1/25/87

Nitrification was evident in Figure 33 even at filterable COD concentrations of 66 mg/l. This indicated that the 27 mg/l nitrifier extinction COD threshold predicted by Wanner and Gujer (1984) is incorrect. However, some competition between heterotrophs and nitrifiers was suggested by the total COD decrease with increased tower depth. Competition between heterotrophs and nitrifiers was not apparent in Figures 31 and 32.

Nitrification rate versus influent NH_4^+-N bulk liquid concentration data for average total hydraulic loading rates of 1.13 to 1.27 l/sq. m • s are shown in Figure 34. The data collected from 11/11/86 to 11/13/86 represented tower performance approximately one to two weeks after the onset of cold weather. The higher rates of nitrification (circled data points) approached, and in some cases, exceeded the expected values (8×10^{-4} to 10×10^{-4} kg/d • m^2) for cold weather performance.

A gradual decline in nitrification performance in the tower was noted with time, as evidenced by the data for 12/15/86 to 12/19/86, and corresponded to a gradual decline in secondary effluent D.O. concentrations. The decline of the D.O. concentrations in the Ames WPCP final clarifier effluent is documented in their records.

The pump supplying pretreated secondary effluent began to lose efficiency subsequent to 11/13/86. The total hydraulic loading had dropped from 1.2 down to 0.8 l/sq. m • s by 11/19/86. Analytical parameter bulk liquid concentrations versus depth in the tower on 11/19/86 are shown in Figure 35. Recirculation, expressed as a percent of the

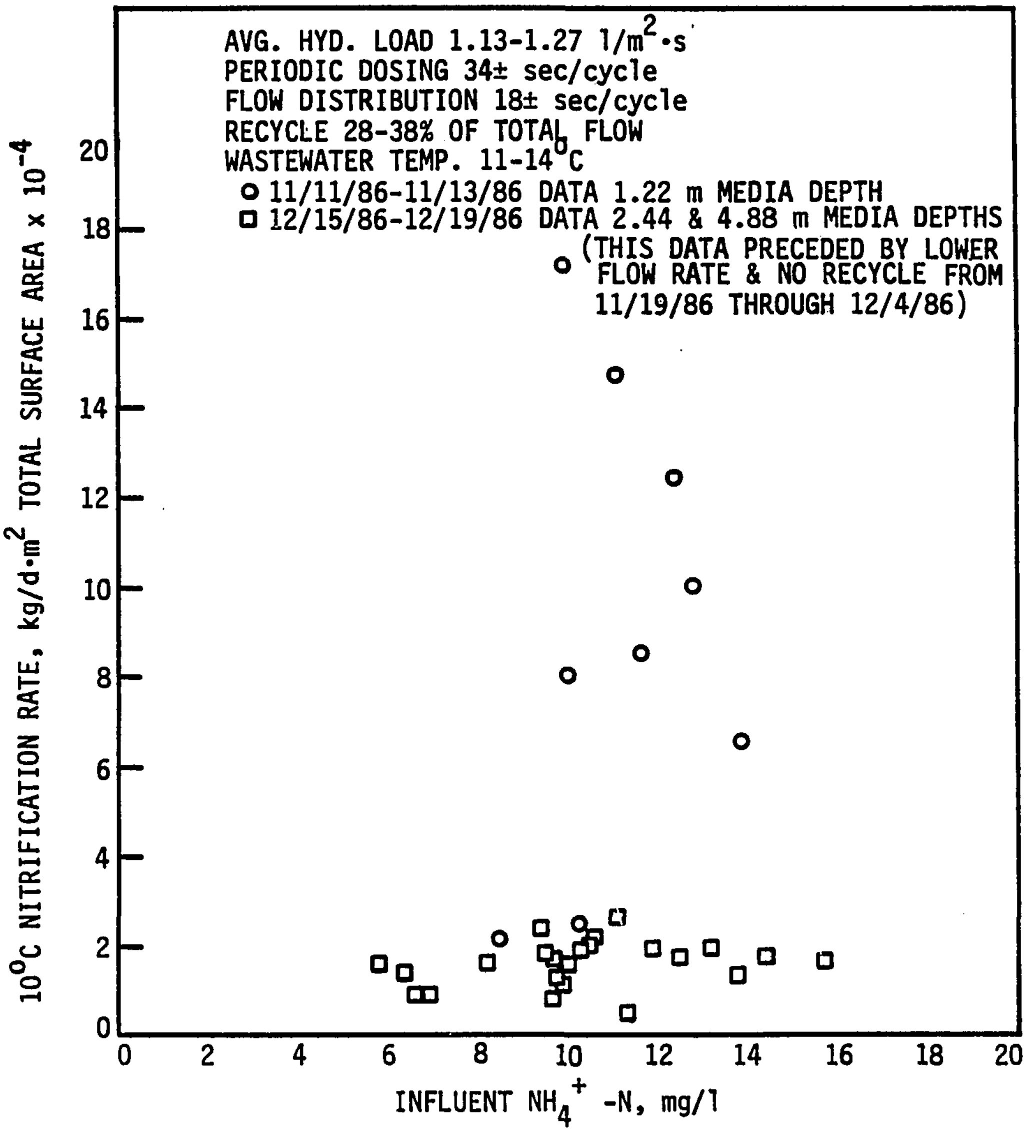

Figure 34. Nitrification rate versus influent NH_4^+-N concentration for average total hydraulic loading rates of 1.13–1.27 l/m²· s in nitrifying biofilter, 60° cross-flow media, 138 m²/m³

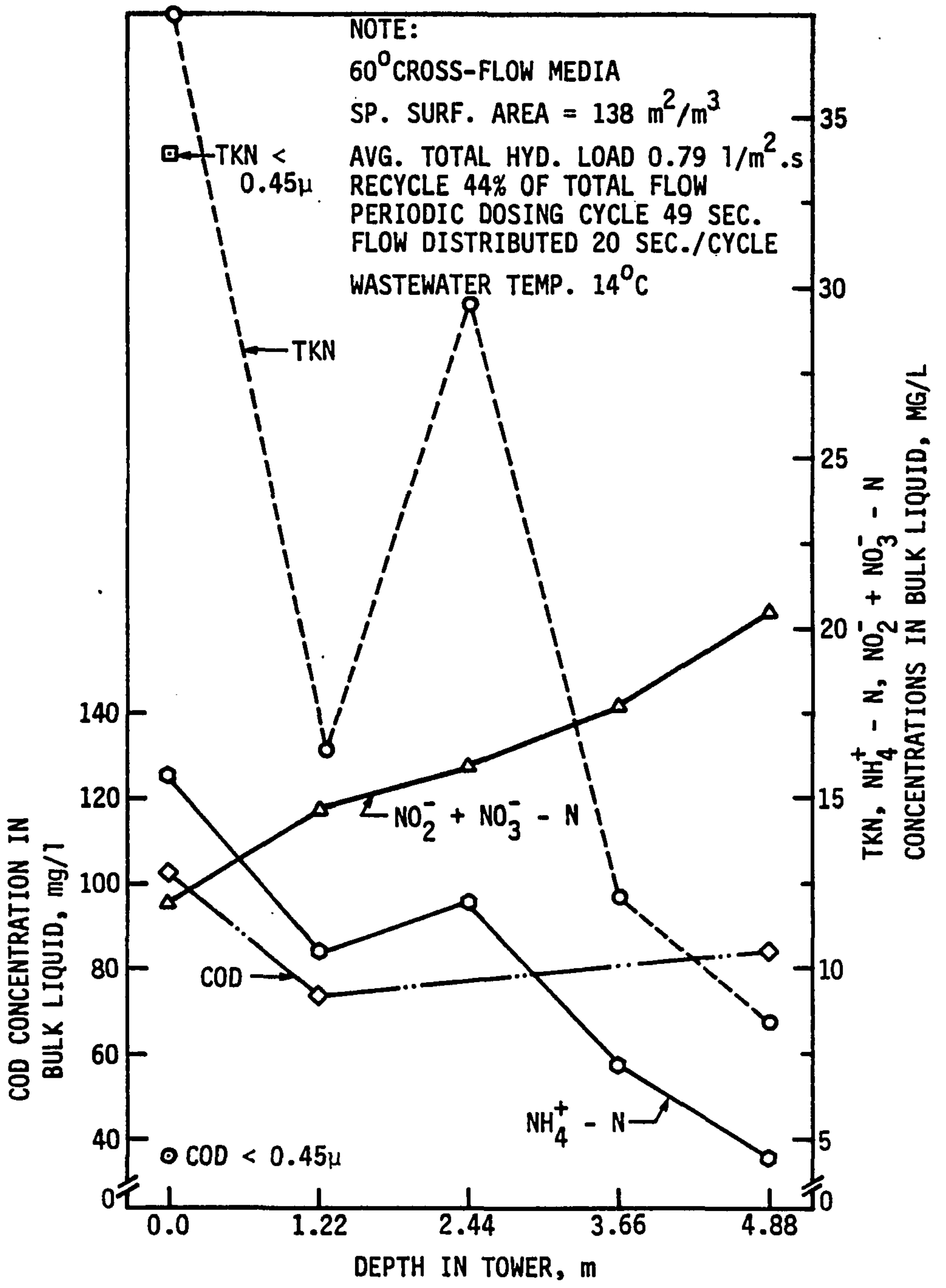

Figure 35. Analytical parameter concentrations versus depth in tower, 11/19/86

total flow, was 44% on 11/19/86, while recirculation on 11/13/86 was only 32%. A dramatic increase in nitrification performance occurred, as shown by comparison of Figures 32 and 35.

Again, nitrification was noted at filterable COD concentrations greater than the nitrifier elimination threshold of Wanner and Gujer (1984). Another noteworthy observation from Figure 35 is that sloughing from the 1.22 to 2.44 m tower section was documented. Two related phenomena were noted. First, the increase in TKN, as expected with an increase in solids due to sloughing, was accompanied by an increase in NH_4^+-N. This may be an indication of adsorption of NH_4^+-N onto the solids. The degree of adsorption did not appear to be high. Second, the solids associated with the sloughing from the 1.22 to 2.44 m tower section appeared to be retained in the 2.44 to 3.66 m tower section based on the TKN data.

Further evidence of adsorption of NH_4^+-N by solids in the biofilter process was observed in comparisons of the NH_4^+-N concentrations of unsettled biofilter effluent samples versus biofilter samples that had been settled for 30 to 60 minutes. The NH_4^+-N concentrations in the unsettled biofilter effluent samples were typically 0.3 to 0.6 mg/l higher than those in the settled samples.

Subsequent to 11/19/86, recirculation was discontinued. A plot of nitrification rate versus NH_4^+-N bulk liquid concentration for average total hydraulic loads of 0.7-0.8 l/sq. m • s is presented in Figure 36. Analytical parameter concentrations versus depth in the tower are shown in Figures 37 and 38 for two dates following the discontinuation of

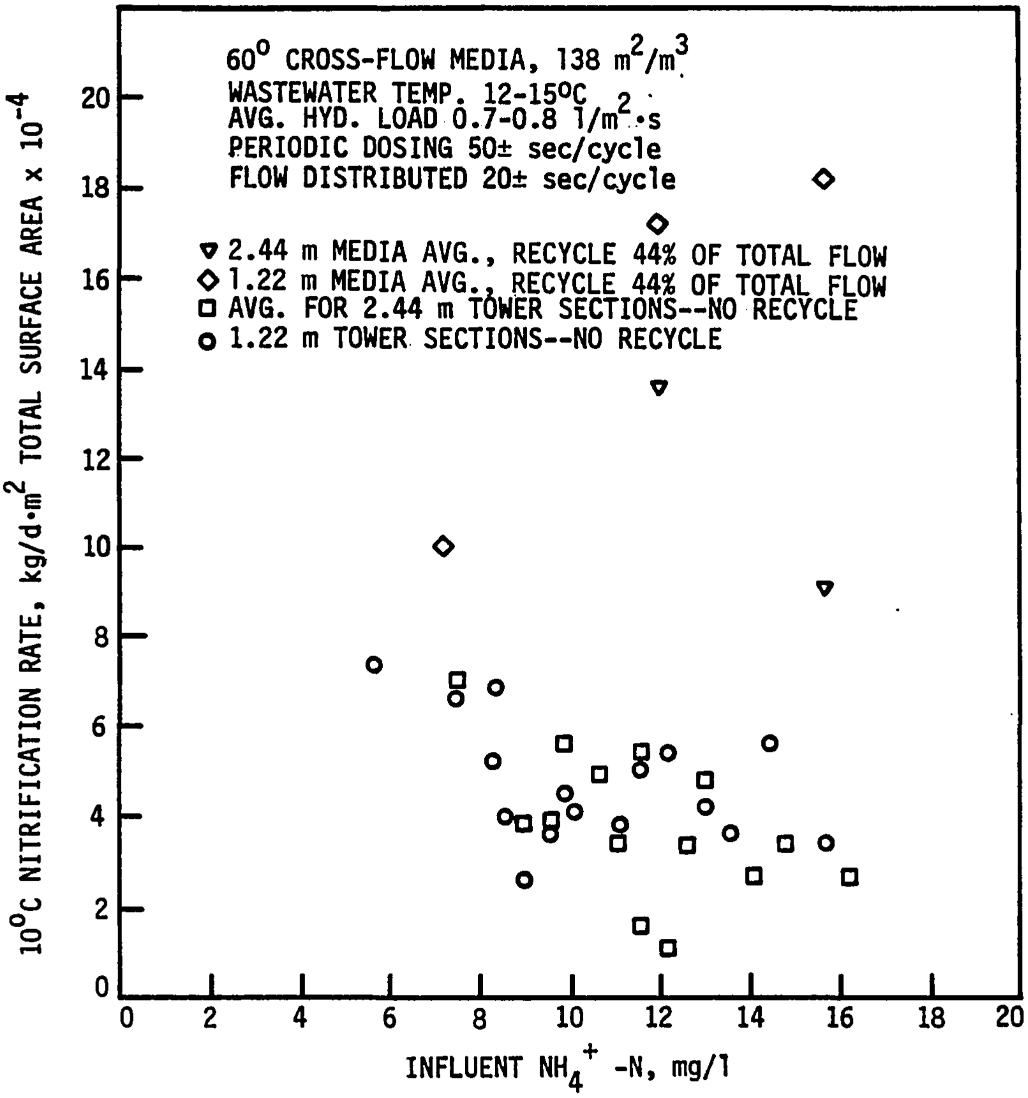

Figure 36. Nitrification rate versus influent NH_4^+-N concentration for average total hydraulic loading rates of 0.7-0.8 l/m²• s

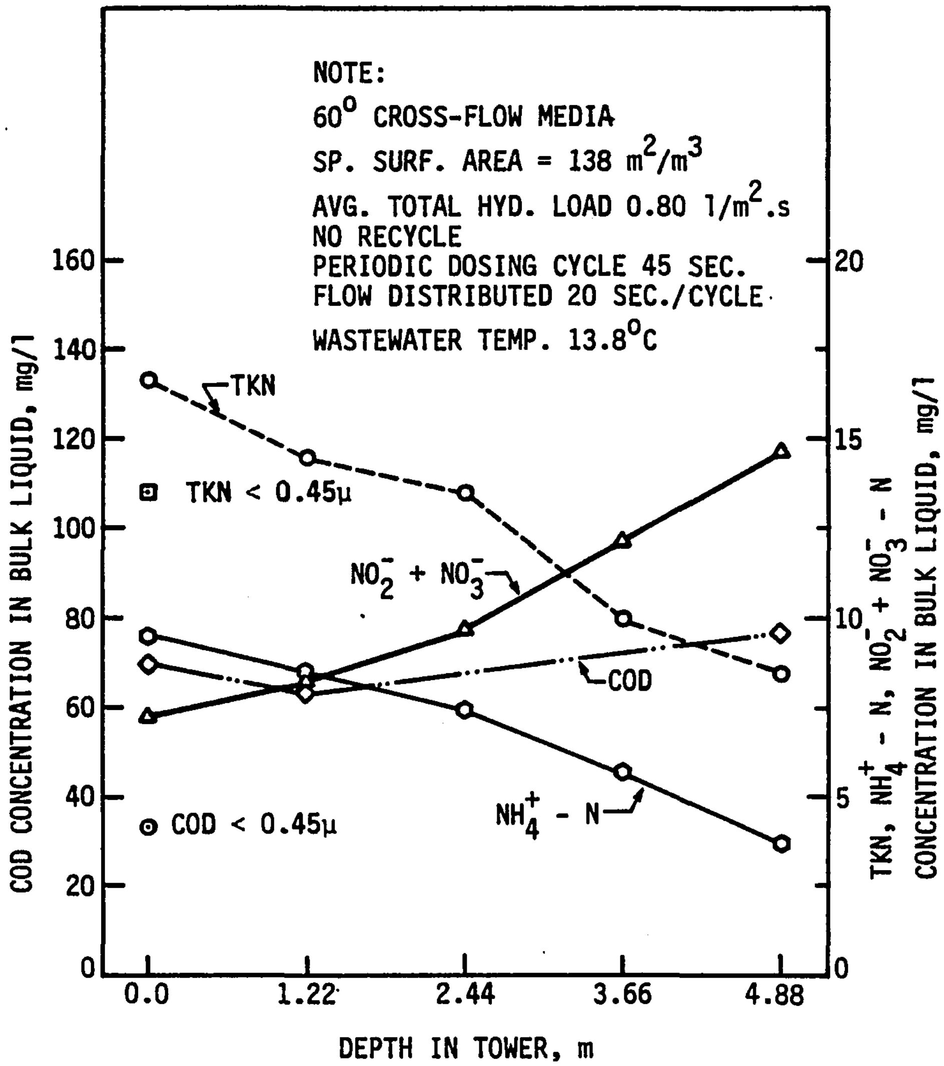

Figure 37. Analytical parameter concentrations versus depth in tower, 11/21/86

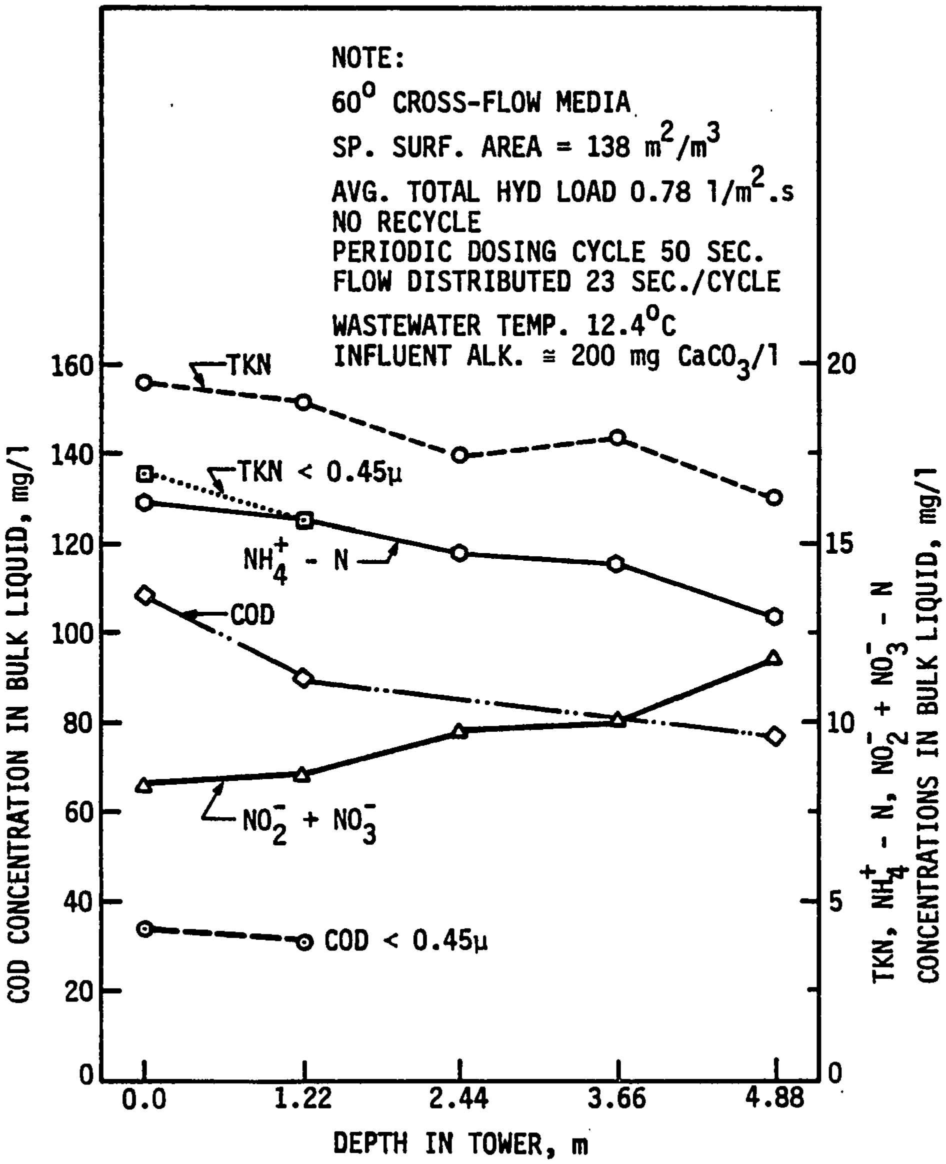

Figure 38. Analytical parameter concentrations versus depth in tower, 12/3/86

recirculation. These figures demonstrate that a rapid decrease in nitrification performance, corresponding to the discontinuation of recirculation, occurred. Figure 36 also shows that the rate of nitrification was independent of bulk liquid NH_4^+-N concentrations greater than 5.6 mg/l.

Figures 37 and 38 show that the nitrifier-elimination soluble COD threshold is greater than the 27 mg/l proposed by Wanner and Gujer (1984). The figures demonstrate that the total COD exhibited some fluctuation in concentration with increasing depth in the tower, but that the COD fraction smaller than 0.45 microns remained relatively constant at about 33 mg/l.

Some competition between heterotrophs and nitrifiers appeared to exist in some sections of the tower, based on the decline in total COD concentrations with increased tower depth in Figure 38. However, the decrease in nitrification performance subsequent to 11/19/86 appears to be unrelated to COD concentrations in the bulk liquid since both the total and filterable fractions of COD in the tower influent were essentially constant for Figures 35-38 related to the discussion above.

The average hydraulic loading rate was increased to 1.15 l/sq. m • s, with a recirculation rate of 38 percent of the total flow, on 12/4/86. Data were collected two to three weeks later. These data are plotted on Figure 34. They indicate that the rate of nitrification was independent of bulk liquid NH_4^+-N concentration at NH_4^+-N concentrations greater than 6 mg/l.

The data in Figure 34 also show that the nitrification rate observed five weeks earlier at essentially the same hydraulic loading conditions could not be regained at this high hydraulic loading, at least when intermittent dosing was in use. Thus, part of the gradual loss of nitrification performance observed between 11/11/86 and 11/13/86 and between 11/19/86 and 12/4/86 could have been due to scouring or washout effects of intermittent dosing at relatively high, total average hydraulic loads of 0.8 to 1.2 1/sq. m • s.

Intermittent dosing was discontinued on 12/19/86. The total average hydraulic loading was not altered. Figures 33 and 39 indicate that nitrification performance was regained by the discontinuation of intermittent dosing. In fact, the rate of nitrification in the lowest section of the tower returned to the levels observed in early November. The return of nitrification performance occurred despite the fact that the fraction of influent COD smaller than 0.45 microns was higher in January, 1987 than it was in November and December, 1986.

The effects of hydraulic loading rate on cold-climate nitrification were further demonstrated by reducing the hydraulic loading rate from 1.25 down to 0.62 1/sq. m • s on January 27, 1987, while maintaining continuous, rather than intermittent, dosing. Comparison of February 13, 1987 nitrification performance (Figure 40) with that of January 25, 1987 (Figure 33) clearly shows an improvement in nitrification performance at the lower hydraulic loading rate.

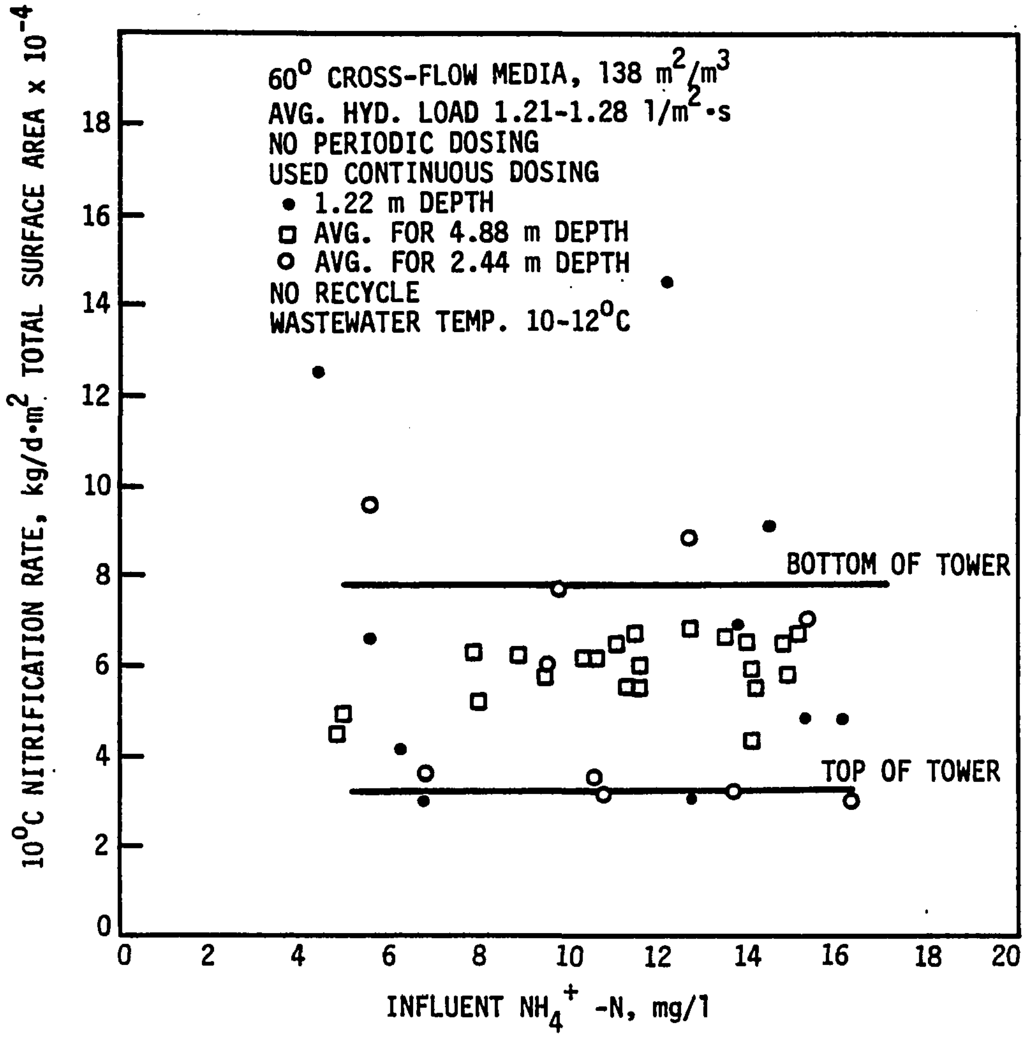

Figure 39. Nitrification rate versus influent NH_4^+-N concentration for average total hydraulic loading rates of 1.21-1.28 l/m²· s and continuous dosing. Average nitrification performance of the bottom half of the biofilter and the top half of the biofilter have been shown by the upper and lower solid lines, respectively

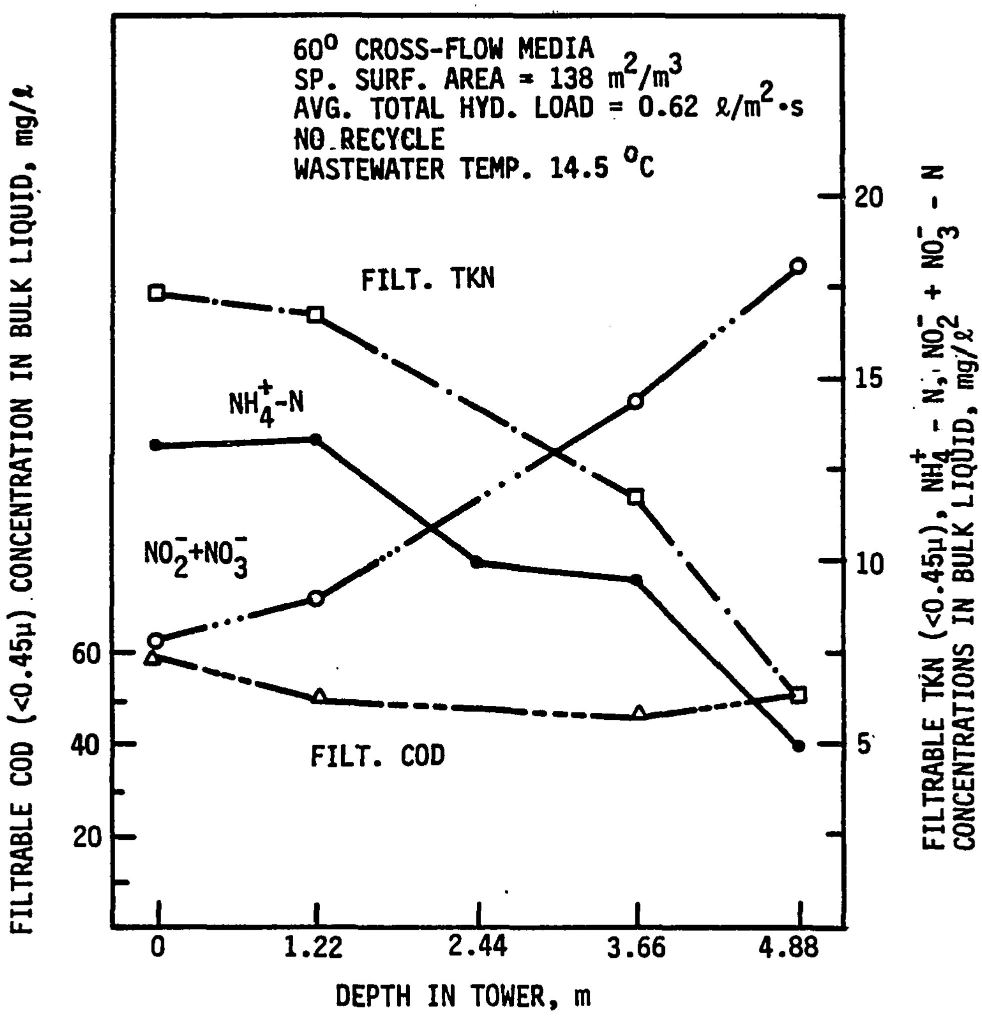

Figure 40. Analytical parameter concentrations versus depth in tower, 2/13/87

Operating Parameter Effects

The performance of nitrifying biofilters can be affected by many operating parameters. These include: 1) wastewater temperature, 2) wastewater pH, 3) wastewater alkalinity, 4) wastewater suspended solids, (5) carbonaceous oxygen demand of the wastewater, 6) wastewater dissolved oxygen concentrations, 7) hydraulic loading, 8) method of wastewater application, 9) media configuration and specific surface area, 10) toxicity of the wastewater, 11) NH_4^+-N concentrations < 4 mg/l, and 12) previous operation history.

The influences of most of these operating parameters were observed at some point during the nitrification study at the Ames WPCP. The project budget and staffing were insufficient to investigate possible toxicity effects. Distinguishing which of the operating parameters is most influential at any given time is a difficult task. Many of the observations of this study are contrary to those previously reported in the literature.

Wastewater temperature effects

The effects of wastewater temperature on the rate of nitrification are well documented in the literature. The rate of nitrification would be expected to increase with increasing temperature whether the fixed-film process is metabolism-limited or diffusion-limited. Previous discussions have established that the Nernst-Einstein equation adequately predicts the effects of temperature. Results of this study neither confirm or refute the validity of the Nernst-Einstein theory.

When other factors such as carbonaceous oxygen demand and dissolved oxygen effects were not apparent, the transformation of nitrification rate data to a common 10°C basis by the Nernst-Einstein equation appeared to be acceptable (reference Figure 29).

pH and alkalinity effects

The pH measurements in this study were observed to range from 7.1 to 8.1 during cold weather data collection periods. The pH increased slightly from the nitrifying biofilter influent to the effluent, an observation contrary to theoretical considerations. The nitrification process produces hydrogen ions which react instantaneously with bicarbonate in the wastewater to form carbonic acid. The consumption of alkalinity in the nitrifying biofilter was observed and was generally close to the theoretical value of 7 mg $CaCO_3$ per mg N oxidized. The decrease in alkalinity and the resulting presence of carbonic acid would be expected to produce a lower pH.

The increase of pH from the nitrifying tower influent to the effluent has been observed in many studies (Brown and Caldwell, 1980, Baxter and Woodman, Inc., 1973, Duddles and Richardson, 1973, and Sampayo and Metcalf, 1984). Air stripping of carbon dioxide has been credited with these observed pH changes. Consumption of carbon dioxide by autotrophic microorganisms may account for part of the observed pH changes.

The observed pH changes from the biofilter influent to the effluent during summer data collection were in agreement with theoretical expectations. The pH was observed to range from 7.0 to 7.7 for summer nitrification data and to decrease slightly from the influent to the effluent of the tower. Figure 28 indicates that nitrification did not appear to be hindered at alkalinity concentrations greater than 30 mg/l.

Suspended solids effects

Sarner (1981 and 1986) reported that solids adversely affect the removal of soluble substrate in trickling filters. The influent suspended solids concentrations in the Ames WPCP study ranged from 30 to 60 mg/l. The Ames study data within this narrow suspended solids range neither support nor refute Sarner's conclusion.

Evidence that NH_4^+-N may be adsorbed onto solids in the biofilter process has been presented in discussions related to Figure 35. Sloughing of solids onto which NH_4^+-N has been adsorbed would have an adverse impact on biofilter nitrification performance. However, the impact would likely be small unless massive sloughing occurred.

Carbonaceous oxygen demand effects

The effects of carbonaceous oxygen demand on the rate of nitrification are usually evaluated in terms of the concentration of soluble carbon (expressed as BOD_5, COD, or TOC) and the ratio of carbon to TKN. These approaches were both examined in this study.

Plots of the rate of nitrification, converted to a common 10°C basis by the use of the Nernst-Einstein equation, versus influent total COD:influent total TKN and versus influent 0.45 micron filterable COD: influent 0.45 micron filterable TKN or total TKN (as indicated) were constructed for the hydraulic loading conditions used in this study.

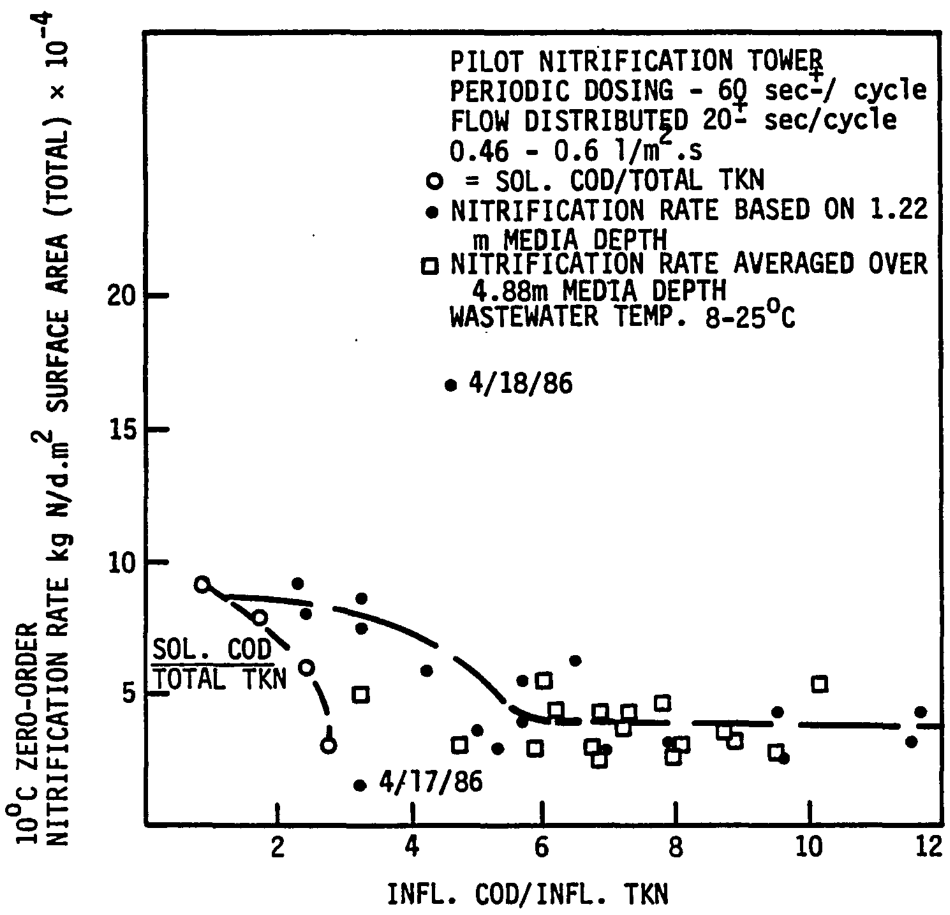

Figure 41. Nitrification versus COD:TKN ratios for average total hydraulic loading rates of 0.46-0.6 l/m^2 • s

Figure 41, constructed for average total hydraulic loading rates of 0.46-0.61 1/sq. m • s with intermittent dosing, indicates that the ratio of COD:TKN can have an effect on the rate of nitrification at these hydraulic loading conditions.

Similarly, Figure 42 demonstrates that the ratio of COD:TKN appears to influence the rate of nitrification at average total hydraulic loading rates of 0.67-0.8 1/sq. m • s with intermittent dosing. Figure 43 demonstrates that at higher hydraulic loading rates without intermittent dosing, the ratio of COD:TKN exhibits little, if any, effect on the rate of nitrification. In fact, low COD:TKN ratio data existed for which the rate of nitrification was zero, indicating that some factor, other than carbonaceous oxygen demand, was influencing the rate of nitrification.

Nitrification rates were plotted versus the ratios of total influent COD:total influent TKN and versus 0.45 micron filterable COD:0.45 micron filterable TKN for average total hydraulic loading rates of 1.13-1.28 1/sq. m •s with intermittent dosing. However, these plots revealed no relationship between COD:TKN ratios and the rate of nitrification, and, therefore, have not been included in this presentation.

The observation that COD:TKN ratios have a greater effect at lower hydraulic loading rates is consistent with mass transport expectations. At low hydraulic loading rates, the mass transfer of organic and nonorganic molecules into the biofilm is dependent on both liquid and biofilm phase resistance or diffusion. At high hydraulic loading rates,the resistance may be essentially a biofilm diffusion resistance,

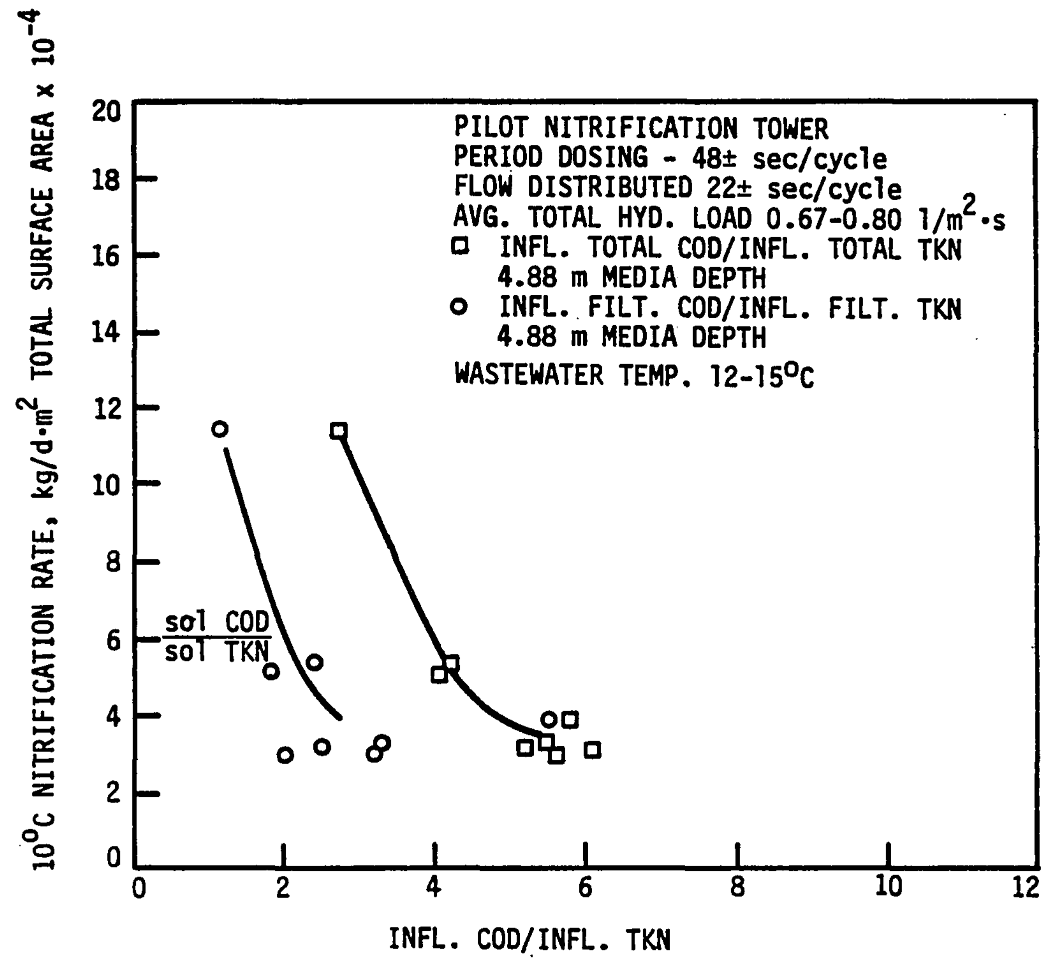

Figure 42: Nitrification rate versus COD:TKN ratios for average total hydraulic loading rates of 0.67-0.8 l/m² • s

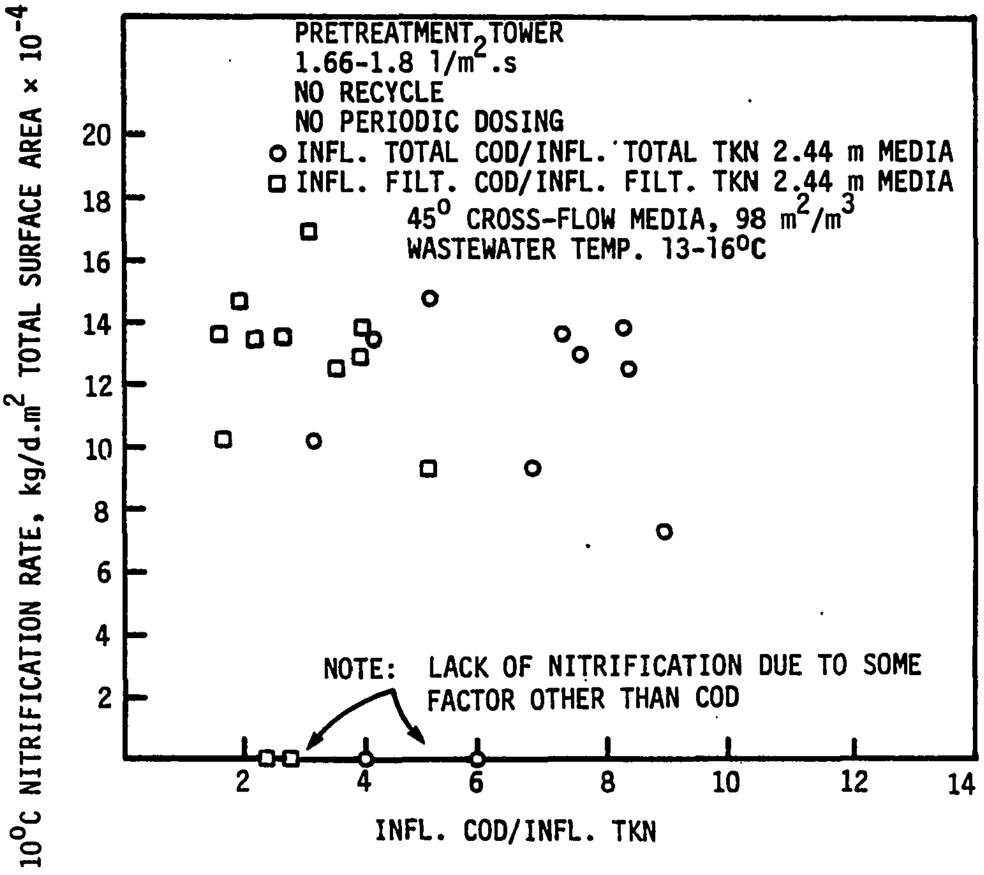

Figure 43. Pretreatment tower nitrification rate versus COD:TKN ratios for average total hydraulic loading rates of 1.66-1.8 $l/m^2 \cdot s$

and mass transport of both organic and nonorganic molecules would be expected to increase.

The diffusivities of smaller (nonorganic) molecules such as NH_4^+-N and oxygen are greater than those of organic molecules. In denser media, such as biofilms, the relative diffusivities of oxygen and NH_4^+-N compared to organic molecules are greater than the relative diffusivities of oxygen and NH_4^+-N compared to organic molecules in water. Thus, at high hydraulic loading rates, the relative mass transport of oxygen and NH_4^+-N compared to the mass transport of organic molecules would be greater. Under these relative mass transport conditions, the rate of nitrification would be expected to show less response to bulk liquid variations in COD concentrations typical of separate-stage nitrification (i.e., low COD concentrations).

Wanner and Gujer (1984) have reported that nitrifiers would be displaced completely from biofilms if the soluble fraction of COD in the wastewater was greater than 27 mg/l. To test the effect of the filterable fraction of COD in the wastewater on the rate of nitrification, the rate of nitrification, converted to a common 10°C basis by the use of the Nernst-Einstein equation, was plotted versus the 0.45 micron filterable fraction COD bulk liquid concentration. The plots were constructed for each of the following hydraulic loading conditions: 1) < 0.6 l/sq. m • s with intermittent dosing, 2) 1.13-1.27 l/sq. m • s with intermittent dosing, 3) 0.67-0.8 l/sq. m • s with intermittent dosing, 4) 1.2-1.28 l/sq. m • s without intermittent dosing, and 5) 1.7-1.9 l/sq. m • s (pretreatment tower) without intermittent dosing.

No relationship was found to exist between the filterable COD concentration and the rate of nitrification for any of the above hydraulic loading conditions. Nitrification rates were often high when the 0.45 micron filterable COD concentration was in excess of 60 mg/l. Conversely, the rate of nitrification was often low when the concentration of 0.45 micron filterable COD was 34 mg/l or less. The plots have, therefore, not been included in this presentation.

Dissolved oxygen effects

It has been hypothesized in earlier discussions that the D.O. concentration in the wastewater was an important factor in the observed nitrification performance in a number of circumstances. However, because of the limited financial and personnel resources available for this study, the D.O. data base was not large.

Chen and Bungay (1981) used microprobes in their study of external mass transfer in fixed film processes. Figure 44 clearly demonstrates their finding that the concentration of oxygen at the biofilm surface can be appreciably lower than the concentration in the bulk liquid. Bungay et al. (1969) used microprobe techniques to measure D.O. concentrations within biofilms. They determined that respiration ceased, i.e., oxygen was depleted, at depths into the biofilm of 50 to 150 microns depending upon the substrate concentration in the biofilm. Thus, the concept of a thin active layer was established. Chen and Bungay (1981) also found that the active layer can be defined by depletion of either the electron donor or the electron acceptor.

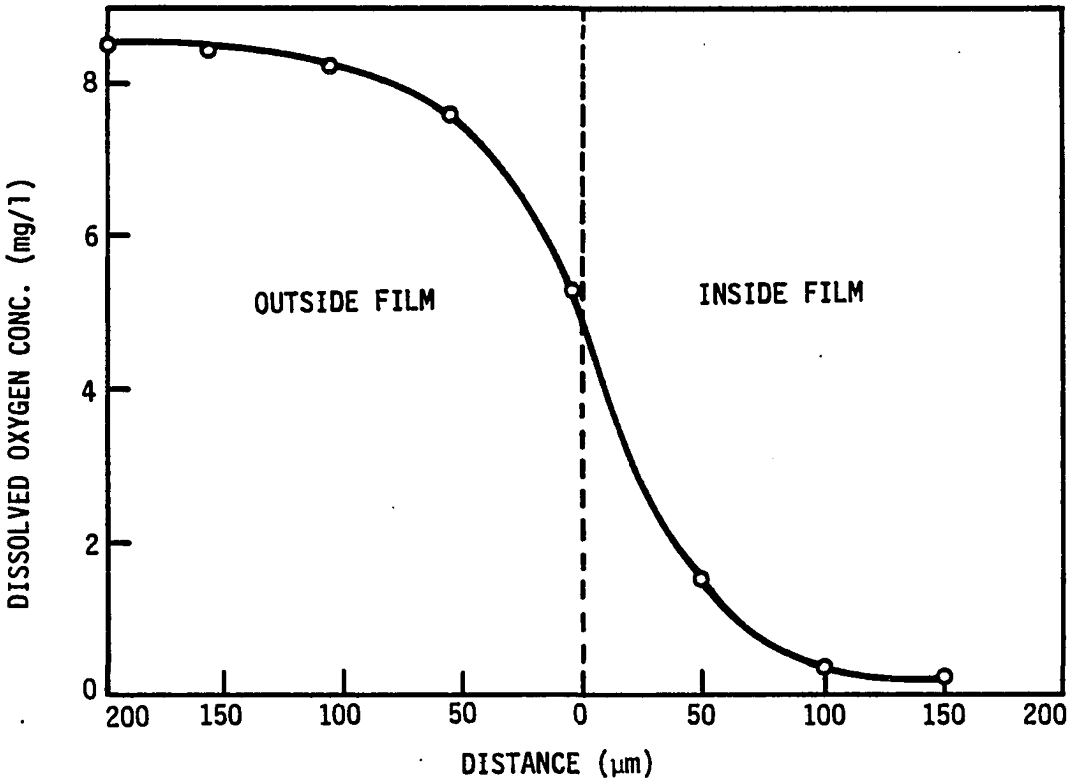

Figure 44. Oxygen concentration profile up to and through the biofilm on a rock from a trickling filter. Data from Chen and Bungay (1981)

In order to test the effect of D.O. on the rate of nitrification, the rate of nitrification, converted to a common 10°C basis by the use of the Nernst-Einstein equation, was plotted versus the percent of D.O. saturation in the bulk liquid at the prevailing water temperature when the sample was collected. The percent of D.O. saturation was selected rather than the D.O. concentration because the investigator felt that it would better reflect the oxygen mass transfer potential across both the air-liquid and liquid-biofilm interfaces. The data appear in Figure 45.

The rates of nitrification observed in the pretreatment tower (45 degree cross-flow media) at hydraulic loading rates of 1.63-1.91 l/sq. m • s were plotted against the percent of D.O. saturation of the Ames WPCP final effluent, as reported by Ames WPCP personnel. The relationship between the nitrification rate and the D.O. saturation was observed to be a straight line having an R-squared value of 0.87. The relationship is significant at the 0.001 level.

The data collected from the nitrifying biofilter (60 degree cross-flow media) were plotted for hydraulic loading rates ranging from 0.57-0.78 l/sq. m • s with intermittent dosing (Figure 45). These data are less reliable than the Ames WPCP data because the samples for D.O. analysis had to be collected from the tower sampling ports. The nitrifying biofilter samples were, therefore, subject to higher aeration. Nonetheless, the data indicate that D.O. in the wastewater did affect the rate of nitrification.

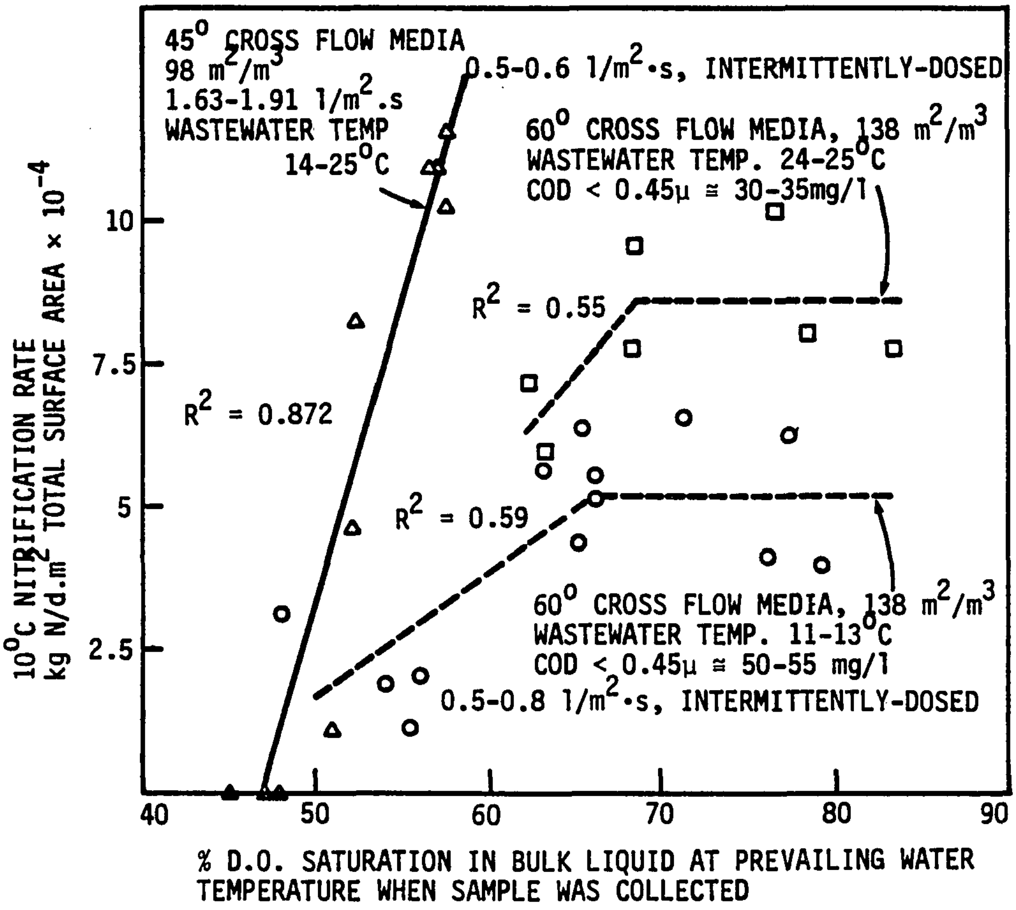

Figure 45. Nitrification rate versus bulk liquid D.O.

The two sets of data for the nitrifying biofilter should overlap if all conditions were equal since the rates of nitrification were converted to a common 10°C basis. However, the COD:TKN ratio effects, which have been shown to be active at low hydraulic loading rates, influenced the two data sets. Figure 45 suggests that nitrification rates can be affected significantly by bulk liquid D.O. levels less than 60 to 65% of saturation. Figure 45 also suggests that nitrification may be totally nonexistent at 45 to 50% D.O. bulk liquid saturation. Thus, for normal wastewater operating temperatures of 10 to 25°C, nitrification rates can be reduced by bulk liquid D.O. concentrations less than 7 to 5.5 mg/l, respectively.

Another observation of possible significance was that the D.O. concentrations in the Ames WPCP final effluent were quite low at times. Effluent from trickling filter towers would generally not be expected to have D.O. concentrations as low as those observed in the final clarifier effluent. Continued biomass metabolism during detention in the final clarifier reduces the D.O. concentration of the wastewater. Records at the Ames WPCP indicate that the oxygen depletion in the final clarifiers can exceed 1 mg/l of D.O. This might have significance in recommendations regarding intermediate clarifiers between the first and second stage filters in separate-stage nitrification systems.

Brown and Caldwell (1980) reported poor nitrification in the trickling filter plant at Stockton, California, despite effluent D.O. concentrations which were reported to be generally in excess of 5 mg/l. The same study reported that the nitrogen balance indicated the loss of total nitrogen from the influent to the effluent. This nitrogen loss was composed of NO_2^--N and NO_3^--N which were consistently low, despite significant ammonia and organic nitrogen removal in the secondary treatment process. The disappearance of NO_2^--N and NO_3^--N was most likely indicative of oxygen deficiency in the trickling filter since the nitrogen balance could not be rectified by the calculated nitrogen assimilation in effluent solids from the tower.

Increasing the rate of recirculation and the number of forced draft fans increased the nitrification performance of the plant. It was not known whether it was the increased forced draft or the increased recirculation that had the greatest impact on the rate of nitrification. However, both the increased forced draft and the increased recirculation would increase the D.O. concentration in the tower influent.

Hydraulic loading and application method effects

Figures 25, 29 and 34 show that the rate of nitrification observed in this study increased with increasing average hydraulic loading, except in the period of time subsequent to 11/13/86. The influence of depleted D.O. concentrations has been shown to have affected nitrification subsequent to 11/13/86. This was true for both the pretreatment tower and the nitrifying biofilter.

There is evidence in this study that high hydraulic loading rates, greater than 0.8-1.0 l/sq. m • s, have the potential of reducing or totally eliminating the nitrification activity in the upper section(s) of biofilters when influent D.O. concentrations are low. Similar observations were reported by Richards and Reinhart (1986). Intermittent dosing, which produces higher instantaneous hydraulic loadings and shear forces, is disadvantageous in this regard. The thicker biofilms and D.O. deficiencies associated with cold-weather operation may make biofilms more susceptible to shearing in winter months.

There is strong evidence that high hydraulic loadings, particularly when intermittent dosing is in use and cold temperatures prevail, prevent the return of nitrification activity once the nitrification activity in the upper sections has been depleted. This can be verified by inspection of the nitrifying biofilter data of 12/14/86 to 12/19/86 (Figures 31 and 34), 1/19/87 to 1/27/87 (Figures 33 and 39), and 2/13/87 (Figure 40).

Intermittent dosing was expected to reduce the hydraulic residence time in the nitrifying biofilter due to the increase in instantaneous superficial velocities. To test this theory, tracer analyses were performed at similar average hydraulic loadings of 1.12 to 1.23 l/sq. m • s for both continous and intermittent dosing cases. NH_4Cl was used as the tracer. The average hydraulic residence time was defined as the time required to collect 50% of the applied Cl^- in the biofilter effluent. Biofilter effluent background concentrations of Cl^- were accounted for.

The average contact time of NH_4^+ was defined as the time required to collect 50% of the applied NH_4^+. Biofilter effluent background NH_4^+ concentrations were accounted for. Since effluent NH_4^+-N concentrations were greater than 4 mg/l, a constant NH_4^+-N mass removal across the biofilter depth, independent of the bulk liquid NH_4^+-N concentration, was assumed. For this condition, the influent NH_4^+-N mass increase due to spiking would produce an equal effluent NH_4^+-N mass increase.

The results of the hydraulic residence tests are shown in Figures 46 and 47. The average hydraulic residence times for average hydraulic loadings of 1.2 l/sq. m • s were 92 seconds and 89 seconds, respectively, for intermittently-dosed and continuously-dosed conditions. The average NH_4^+-N contact time was, for all practical purposes, the same as the average hydraulic residence time for both types of wastewater application. These results are in agreement with literature reports that intermittent dosing and continuous dosing provide essentially equal trickling filter performance (Richards and Reinhart, 1986 and Albertson and Davies, 1984).

The average hydraulic residence times determined in this study are in good agreement with the biofilm-free hydraulic residence times reported for 3 m of 60° cross-flow media by Harrison and Daigger (1985). The residence times determined in the Ames WPCP study were only 1/5 of their reported values for media with biofilm present, despite the fact that active nitrifying biofilm was present in the Ames WPCP study when the hydraulic residence tests were run. The hydraulic residence times reported by Richards and Reinhart (1986) for 3 m of 60° cross-flow media with biofilm present agree fairly well with those reported by Harrison and Daigger (1985). Both of the literature studies involved heterotrophic biofilms, while the present study involved a nitrifier biofilm.

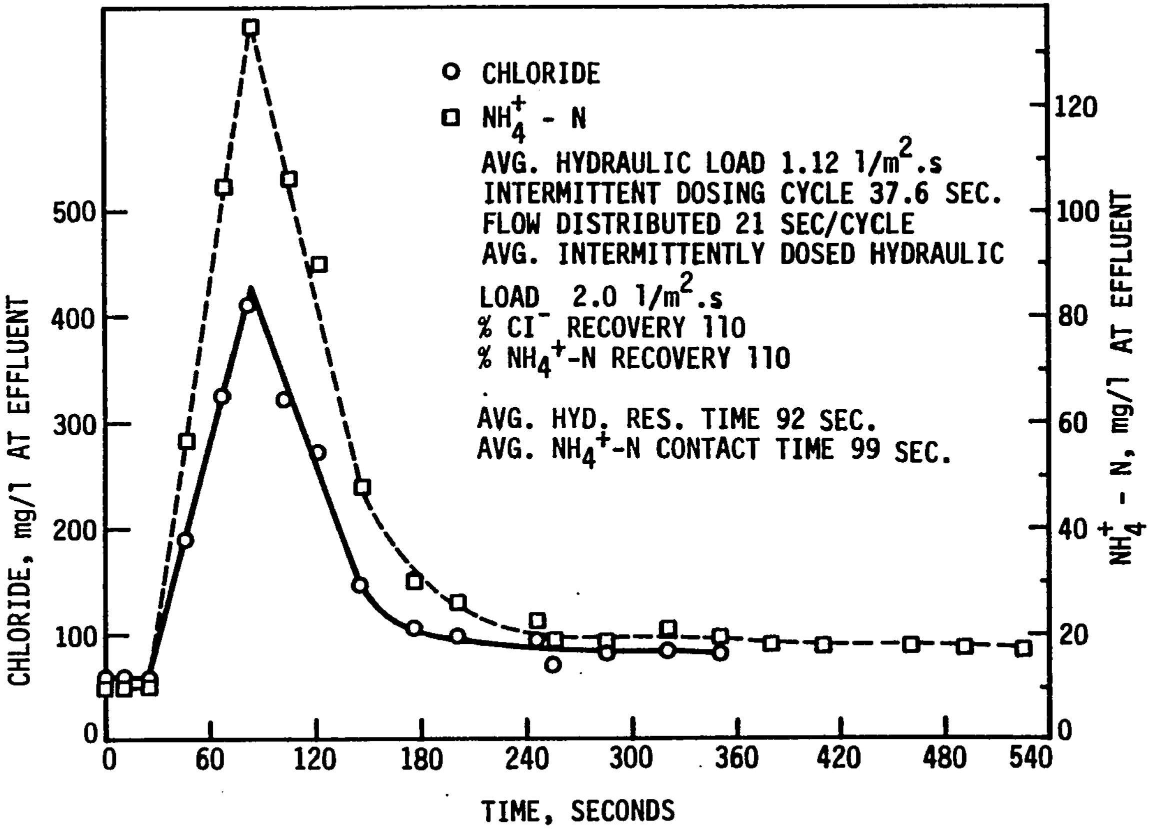

Figure 46. Hydraulic residence test on December 19, 1986

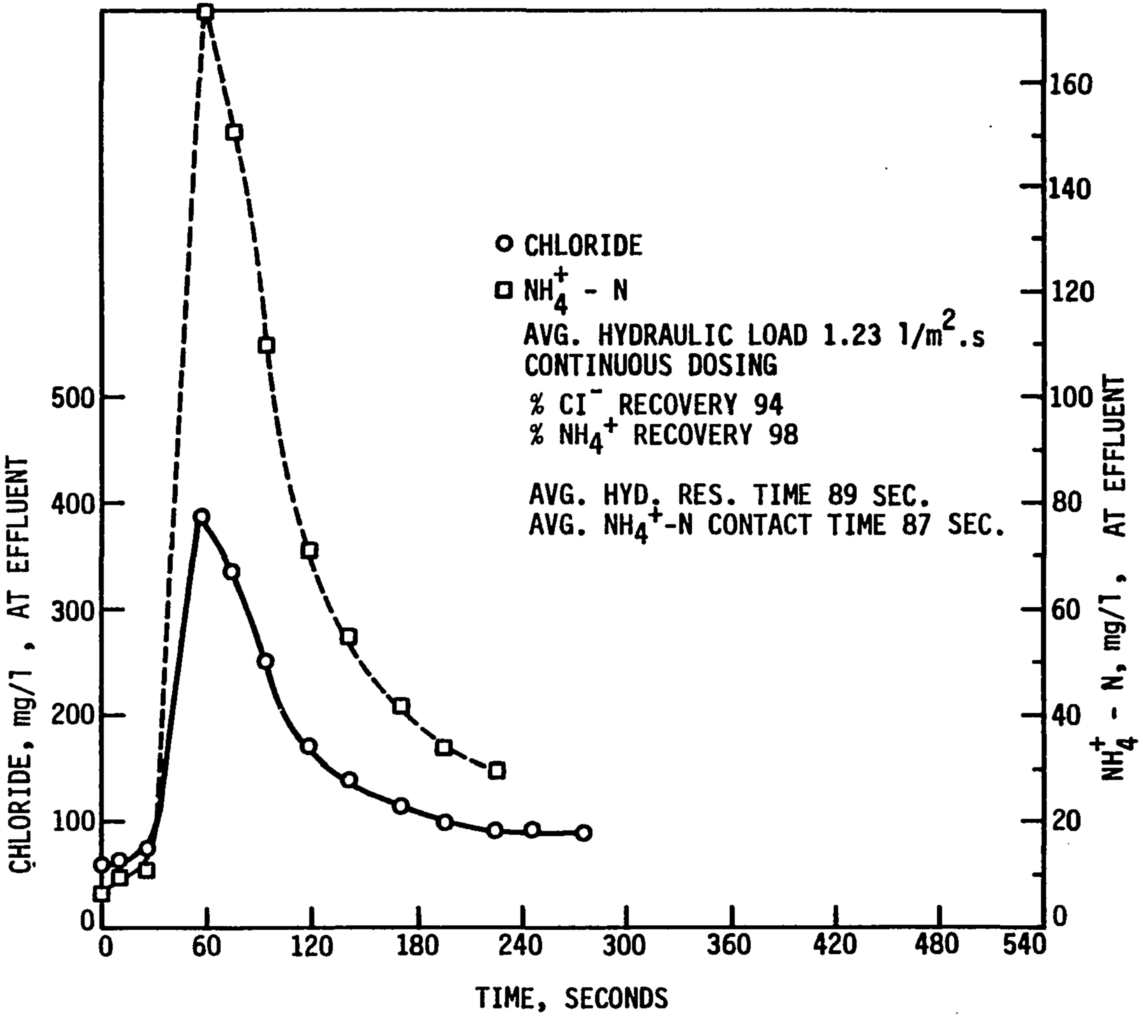

Figure 47. Hydraulic residence test on January 12, 1987

Thus, it appears that nitrifier biofilms have little effect on hydraulic residence times.

Richards (1984) and Richards and Reinhart (1986) reported that intermittent dosing produced shorter hydraulic residence times than continuous dosing for hydraulic loading rates greater than 0.5 l/sq. m • s. Inspection of their published data for 6.1 m towers containing 60 degree, cross-flow media with specific surface areas of 98 sq.m/cu. m (Richards, 1984), reveals that hydraulic residence times for average hydraulic loading rates of 0.5 l/sq. m • s, but with different application methods, agree within 7 percent or less.

The results of this study indicate that intermittent dosing had little effect at low hydraulic loading rates and at high wastewater temperatures and corresponding higher influent percentages of D.O. saturation (Figures 28, 29 and 45). However, intermittent dosing, which more closely resembles the rotary distributor application of full-scale trickling filters, appears to be detrimental for cold-weather operation (Figures 31-40). These detrimental effects of intermittent dosing should be minimized by operating at lower average hydraulic loading rates in winter months as evidenced by Figures 33, 34, 35, 36, 39 and 40.

Media effects

Partial plugging of the 60° cross-flow media in the nitrifying biofilter, particularly at the 2.44-3.66 m depth, was suspected at various times during the study. However, the tower has not been disassembled, and these suspicions have not been verified. Partial plugging of similar 60° cross-flow media was reported by Richards and Reinhart (1986). That reported incidence indicated that plugging occurred primarily at the contact points within the media pack where two corrugated plastic sheets touched and at the interface between stacked pack units. Richards and Reinhart (1986) also reported that partial plugging of the media occurred to a greater extent in the winter months, a finding largely substantiated by the transient, reduced performance of various tower sections in this study, as well.

Partial plugging of cross-flow media channels would not prevent redistribution of water and air flow to other unrestricted channels. Nonetheless, overall efficiency in partially plugged media sections would be reduced due to lower effective media surface area, higher hydraulic loading per unit of effective media surface area, and lower oxygen transfer efficiency.

The performance of the bottom section of 45° cross-flow media in the pretreatment tower was very consistent, both in warm and cold weather. The top section performed much the same as that of the nitrifying biofilter, reflecting the effects of high hydraulic loading and/or D.O. deficient wastewater. Plugging potential of the 45° cross-flow media could not be evaluated because of the design of the tower, i.e., the individual media packs were not stacked in direct contact and had no common interfaces where plugging would occur.

The effective media specific surface area is a poorly understood parameter in trickling filter processes. Estimated effective surface areas may differ by 100%, depending on the method used to calculate the area. The Onda equation agrees fairly well with the work of Hosono et al. (1980) and the lower range of the calculations of Gullicks and Cleasby (1986). The percolation theory, discussed by Crine (1986), agrees closely with the reported effective areas calculated by Atkinson and Abdel Rahman Ali (1976).

Nitrification rates predicted by Wanner and Gujer (1984) and calculated using the models of Strand (1986) and Harremoes (1982) for wastewater conditions similar to those at the Ames WPCP are summarized in Table 11. These values are applicable to 100% effective surface areas. Some typical nitrification rates observed in the Ames WPCP study are shown in Table 12. The Ames WPCP nitrification rates in Table 12 have been compared to the theoretical maximum nitrification rates predicted by the Strand and Harremoes models in order to estimate the percent of effective media surface area for various hydraulic loading rates.

These effective surface area percentages have been compared to the percentages of effective surface area predicted by the Onda et al. (1968) and percolation theory (Crine, 1986) curves presented in Figures 20 and 21, respectively. The percolation theory relationship appears to give the best agreement with maximum observed effective media surface area percentages, and, therefore, probably provides a better estimate of the wetted specific surface area. However, the average effective media surface area for the entire tower depth was usually intermediate between the Onda and percolation theory predictions.

Table 11. Maximum nitrification rates predicted by the models of Strand (1986) and Harremoes (1982) and by Wanner and Gujer (1984)

	Bulk Liquid Concentrations, mg/l				
Reference	Soluble COD	Soluble BOD_5	NH_4^+-N	D.O.	Predicted Maximum Nitrification Rates kg/d m^2 Biofilm Surface
Strand (1986)	35	—	> 1.5	5	0.00148[a]
	35	—	> 1.9	6	0.00161[a]
	35	—	> 2.2	7	0.00169[a]
	35	—	> 2.4	8	0.00178[a]
	50	—	> 1	5	0.00063[a]
	50	—	> 1.2	6	0.00085[a]
	50	—	> 1.5	7	0.00096[a]
	50	—	> 1.9	8	0.00114[a]
	10	—	> 2.1	5	0.00245[a]
	10	—	> 3.2	8	0.00315[a]
			At 20°C±		
Harremoes (1982)	—	10	—	5	0.0014
	—	10	—	6	0.0016
	—	10	—	7	0.0018
	—	10	—	8	0.0020

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[a] Converted to 10°C basis by the use of the Nernst-Einstein equation.

[b] Measured at the biofilm surface.

Table 11. (Continued)

Reference	Soluble COD	Soluble BOD_5	NH_4^+-N	D.O.	Predicted Maximum Nitrification Rates kg/d • m^2 Biofilm Surface
Bulk Liquid Concentrations, mg/l					
			At 20°C±		
Wanner and Gujer (1984)	0	--	13	8^b	0.0032
	13	--	13	8^b	0.0008
	30	--	13	8^b	0.0000

Table 12. Ames WPCP nitrification rates, corresponding effective area based on maximum predicted nitrification rates, and predicted effective areas by the Onda correlations and percolation theory

					Influent Conc. mg/l		
Date	Tower Depth m	Avg. Hyd. Load $l/m^2 \cdot s$	Intermittent Dosing Cycle, s	Flow Dist. Time, s/cycle	NH_4^+-N	D.O.	COD $<0.45\mu$
4/2/86	0-1.2	0.577	60	18	14.2	5.2	50[b]
	1.2-2.4	0.577	60	18	13.1	7.0	50[b]
	2.4-3.7	0.577	60	18	10.8	5.8	50[b]
	3.7-4.9	0.577	60	18	10.1	8.2	50[b]
4/3/86	0-1.2	0.578	60	18	8.3	6.1	50[b]
	1.2-2.4	0.578	60	18	7.6	7.1	50[b]
	2.4-3.7	0.578	60	18	5.8		50[b]
	3.7-4.9	0.578	60	18	5.0	7.0	50[b]
4/10/86	0-1.2	0.589	60	18	14.0	7.0	50[b]
	1.2-2.4	0.589	60	18	12.5	7.6	50[b]

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[a] Not converted to 10°C basis because of range of constants assumed.

[b] Based on 4/18/86 data. Total COD 100-125 mg/l.

[c] D.O. Conc. on 12/4/86.

					Predicted Effective Area %	
Δ NH_4^+	Obs. Nit. Rate 10°C Basis by Nernst-Einstein Eq. kg/d • m² sp. surf	Predicted Nit. Rate Strand (1986) 10°C Basis by Nernst-Einstein Eq. kg/d • m² biofilm	Predicted Nit. Rate Harremoes (1982)[a] kg/d • m² biofilm	Effective Area, %	Onda et al. (1968)	Percolation Theory
1.1	0.00030	0.00067		45	31	73
2.3	0.00063	0.00096		66	31	73
0.7	0.00019	0.00081		23	31	73
2.3	0.00063	0.00114		55	31	73
0.7	0.00019	0.00086		22	31	73
1.8	0.00050	0.00098		51	31	73
0.8	0.00022	0.00085		26	31	73
2.0	0.00055	0.00096		57	31	73
1.5	0.00042	0.00096		44	31	73
2.3	0.00064	0.00107		60	31	73

Table 12. (Continued)

					Influent Conc. mg/l		
Date	Tower Depth m	Avg. Hyd. Load $l/m^2 \cdot s$	Intermittent Dosing Cycle, s	Flow Dist. Time, s/cycle	NH_4^+-N	D.O.	COD <0.45μ
	2.4-3.7	0.589	60	18	10.2	8.4	50[b]
	3.7-4.9	0.589	60	18	8.8	8.0	50[b]
7/30/86	0-1.2	0.568	60	18	20.8	6.4	14-33
	1.2-2.4	0.568	60	18	15.6	5.2	14-33
	2.4-3.7	0.568	60	18	11.9	6.0	14-33
	3.7-4.9	0.568	60	18	9.6	6.6	14-33
	0-1.2	0.568	60	18	18.1	7.0	14-33
	1.2-2.4	0.568	60	18	14.1	5.8	14-33
	2.4-3.7	0.568	60	18	9.2	5.3	14-33
	3.7-4.9	0.568	60	18	6.2	5.8	14-33
12/3/86	0-1.2	0.781	50	23	16.2	6[c]	34
	1.2-2.4	0.781	50	23	15.7	7[c]	31

					Predicted Effective Area %	
Δ NH_4^+ $(NO_2^-+NO_3^-)$	Obs. Nit. Rate 10°C Basis by Nernst-Einstein Eq. $kg/d \cdot m^2$ sp. surf	Predicted Nit. Rate Strand (1986) 10°C Basis by Nernst-Einstein Eq. $kg/d \cdot m^2$ biofilm	Predicted Nit. Rate Harremoes (1982)[a] $kg/d \cdot m^2$ biofilm	Effective Area, %	Onda et al. (1968)	Percolation Theory
1.4	0.00039	0.00120		33	31	73
1.4	0.00039	0.00114		34	31	73
5.2	0.00100	0.00164	0.00168	60	32	76
3.7	0.00071	0.00151	0.00144	48	32	76
2.3	0.00044	0.00161	0.00160	28	32	76
4.2	0.00080	0.00166	0.00172	47	32	76
4.0	0.00077	0.00169	0.00180	44	32	76
4.9	0.00095	0.00158	0.00156	61	32	76
3.0	0.00058	0.00152	0.00146	39	32	76
4.0	0.00077	0.00158	0.00156	49	32	76
0.5 (0.2)	0.00013	0.00161	0.00160	8	30	70
0.9 (1.2)	0.00039	0.00169	0.00180	22	30	70

Table 12. (Continued)

					Influent Conc. mg/l		
Date	Tower Depth m	Avg. Hyd. Load $l/m^2 \cdot s$	Intermittent Dosing Cycle, s	Flow Dist. Time, s/cycle	NH_4^+-N	D.O.	COD <0.45µ
	2.4-3.7	0.781	50	23	14.8	7[c]	31
	3.7-4.9	0.781	50	23	14.5	7[c]	31

					Predicted Effective Area %	
Δ NH_4 (NO_2^-+NO_3^-)	Obs. Nit. Rate 10°C Basis by Nernst-Einstein Eq. $kg/d \cdot m^2$ sp. surf	Predicted Nit. Rate Strand (1986) 10°C Basis by Nernst-Einstein Eq. $kg/d \cdot m^2$ biofilm	Predicted Nit. Rate Harremoes (1982)[a] $kg/d \cdot m^2$ biofilm	Effective Area, %	Onda et al. (1968)	Percolation Theory
0.3 (0.3)	0.00011	0.00169	0.00180	7	30	70
1.5 (1.8)	0.00062	0.00169	0.00180	35	30	70

Previous operating history effects

The effects of previous operating conditions on nitrification performance cannot be separated from the discussion of the effects of the factors already discussed. It has been documented in this study that the nitrifying biofilter performed satisfactorily at high hydraulic loading rates for about one week to ten days after the onset of cold weather. The performance of the upper section of the pretreatment tower dropped off sooner. Thereafter, the nitrifying biofilter performance dropped off, probably due to both the documented reduction in bulk liquid D.O. saturation and the high shear forces associated with high hydraulic loads.

The difficulty experienced in the Ames WPCP study with reestablishing nitrification performance lost during cold weather at high hydraulic loading rates is a significant finding. The operation of nitrification towers at low hydraulic loading rates would help prevent the initial loss of performance and has been shown to promote the return of satisfactory nitrification performance during cold weather operation.

Modification of the Design Curves of Gullicks and Cleasby (1986)

Data from this study, the work of Duddles and Richardson (1973), Baxter and Woodman, Inc. (1973), Richards (1984), Richards and Reinhart (1986), Parker and Richards (1985), Sampayo and Metcalf (1984), and Sampayo (1973) have been assembled in the Appendix. The rates of nitrification in the appendix have been adjusted to a common 10°C basis by the use of the Nernst-Einstein equation. The data have been used to construct a nitrifying biofilter design curve (Figure 48) for wastewater temperatures of 10°C similar to those presented by Gullicks and Cleasby (1986). Only Ames WPCP data are shown in Figure 48.

The 10°C nitrification rates were plotted versus both the total applied NH_4^+-N concentrations and the total applied hydraulic loading rates, including recirculated NH_4^+-N and flow. Winter discharge standards for NH_4^+-N are usually less stringent than 3 mg/l, and it has been shown that nitrification rates above 3-4 mg/l are relatively independent of NH_4^+-N concentration. The design curve was constructed using data for which the effluent concentrations from the biofilters (or sections of biofilters) generally exceeded 3 mg NH_4^+-N/l. Some data for which the effluent concentrations from biofilters (or sections of biofilters) were less than 3 mg NH_4^+-N/l were included in cases where oxygen still appeared to be the rate-limiting reactant.

The new curve can be used in exactly the same manner described by Gullicks and Cleasby (1986). The new design curve was constructed primarily with data from towers which contained 6-6.55 m of plastic media with specific surface areas of 89-98 m^2/m^3. No safety factor is implied in the design curve.

Additional surface area should be provided by increasing the tower media depth to account for the desired safety factor and to account for bulk liquid percent of D.O. saturation less than 65% and/or the partial plugging potential of media with specific surface areas greater than

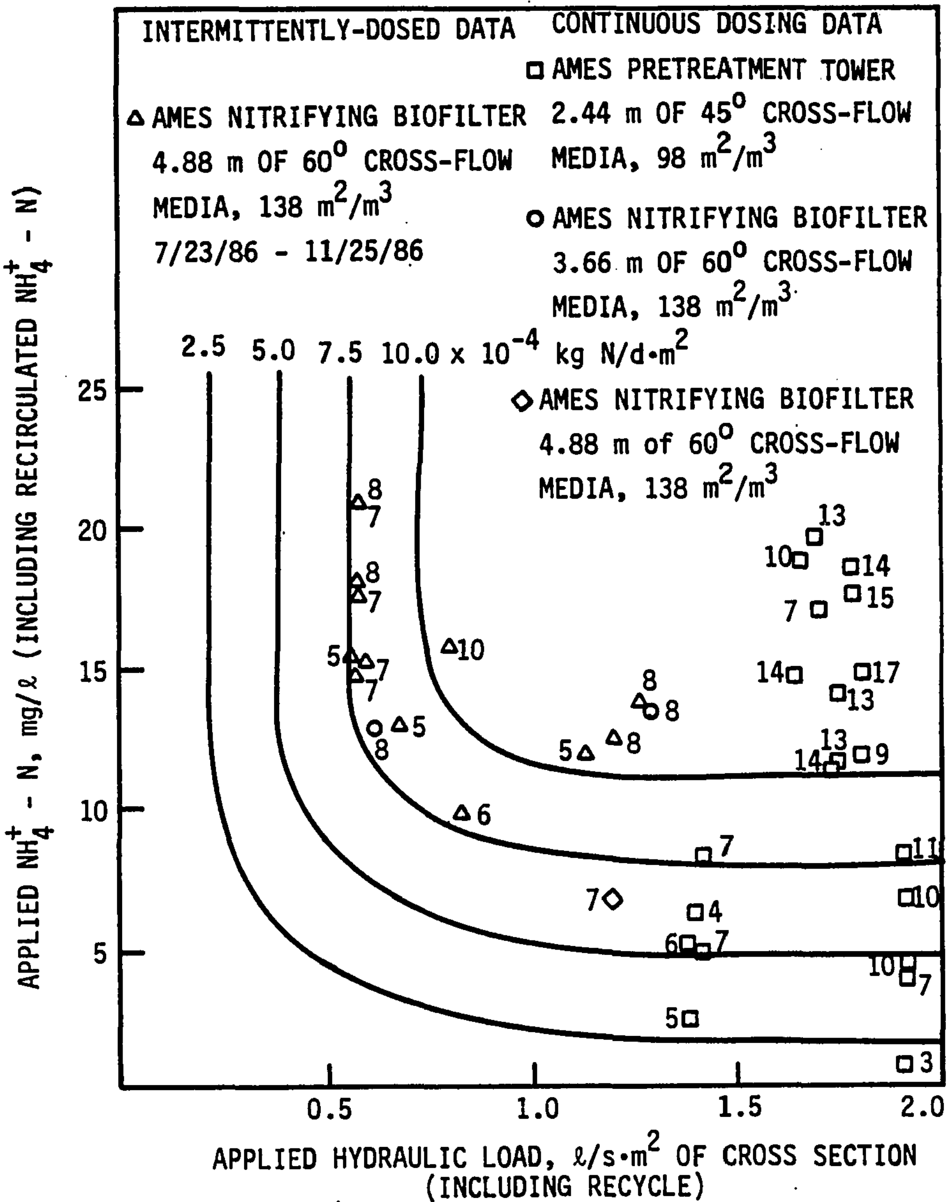

Figure 48. Predicted NH_4^+-N removal, kg/d • m² of media surface, versus applied hydraulic load and applied NH_4^+-N for nitrification of municipal secondary clarifier effluent (BOD_5 < 30 mg/l and SS < 30 mg/l), wastewater temperature 10°C and media depths of 6-6.55 m of vertical or cross-flow plastic media (specific surface = 89-98 m²/m³). No safety factor is implied. Allow additional surface area (25-50%) for bulk liquid percent of D.O. saturation less than 65% and/or higher specific surface area media to account for plugging

98 m^2/m^3. If the percent of D.O. saturation is less than 65%, the secondary effluent could be aerated prior to application onto the plastic media so that additional media surface area would not have to be provided.

DISCUSSION

The experimental equipment, procedures, assumptions, and results used in the investigation and analysis of nitrification in separate-stage nitrifying biofilters at the Ames WPCP were included in the initial presentations of those topics and will not be repeated. There are aspects of this investigation that require further discussion and development in order to clarify some of the observations and results and to keep the conclusions in the proper, limiting perspective.

General Discussion

The primary data obtained in the Ames WPCP study were nitrogen parameter concentrations at various depths in a structured, plastic-media, separate-stage nitrifying biofilter. A variety of secondary effluent application rates and conditions were examined. Additional chemical parameters were analyzed, within the monetary and personnel constraints of the project budget, to assist in the evaluation of the nitrification performance of the nitrifying biofilter.

Experimental considerations

The existing Ames, WPCP is an overloaded facility. Therefore, the secondary effluent from this conventional trickling filter plant exhibited greater variability than the secondary effluent applied in nitrifying biofilter studies examined in the literature. The overloaded condition of the Ames plant had an impact on the carbonaceous oxygen demand (measured by the COD test in this study), the suspended solids, and the D.O. concentrations in the secondary effluent that served as the influent to the pilot-scale nitrification tower.

Wastewater, including secondary effluent, at any plant exhibits seasonal and diurnal variability in pollutant concentrations. The overloaded condition of the Ames plant increased the seasonal secondary effluent variability, however, diurnal variability was not observed to be excessive. The seasonal fluctuation of the population of Ames, revolving around the academic calendar at Iowa State University, also affected the seasonal variability of the load on the existing Ames WPCP, and, subsequently, the variability of the secondary effluent pollutant concentrations from the plant.

The seasonal variability of the influent to the pilot-scale nitrifying biofilter made it necessary to supplement the NH_4^+-N concentration in the biofilter influent with NH_4Cl during data collection periods when Iowa State University was not in session. Data collected during March, 1986 did not involve NH_4^+-N supplementation. The low NH_4^+-N concentrations in the Ames WPCP secondary effluent during the second and third weeks of March, 1986 may have retarded the pilot nitrifying biofilter's initial approach to pseudo-steady state.

Alkalinity, COD, pH, suspended solids, and D.O. measurements were performed throughout the project duration, within the project budgetary and personnel restrictions, to assist in evaluation of the nitrification performance of the pilot-scale nitrifying biofilter. Manual sampling was performed simultaneously at the sampling points of both the pretreatment filter and the nitrifying biofilter whenever possible. When manual sampling was not possible for the investigator, automated sampling was instituted at selected nitrifying biofilter sampling points. Sampling probe location was critical during automatic sampling of the nitrifying biofilter effluent collection tank to prevent disturbance of sediments in the collection tank during the backflushing of the sampling tube and resulting high solids in the collected samples.

Analytical parameters associated with suspended solids, such as COD and TKN, were occasionally biased in automatic sampling at this sampling point when the backflushing of the sampling tube disturbed sediments in the effluent collection tank. Soluble parameters, such as NH_4^+-N and NO_2^- + NO_3^--N would not be significantly affected by the increased suspended solids occasionally captured by the automated sampler. D.O. measurements for samples, taken manually from the nitrifying biofilter sampling ports, as well as those reported by the Ames WPCP personnel for the secondary effluent, proved to be critical to proper evaluation of the pilot-scale nitrifying biofilter performance.

Previous studies from the literature did not measure the D.O. concentration in the influent to the nitrifying biofilters and rarely measured the D.O. concentration in the effluent from nitrifying biofilters. The D.O. concentrations in the effluent from nitrifying biofilters, which were reported in some studies, were similar to those measured in the Ames study. However, previous investigators failed to associate the reported D.O. values with the observed nitrification performance. In retrospect, additional D.O. concentration measurements would have been desirable in the evaluation of nitrification at the Ames

WPCP; however, that fact was not apparent until a detailed evaluation of the project data was completed.

Considerable effort was expended to prevent or minimize short circuiting through the Ames nitrifying biofilter, as described in the Experimental section. However, the possibility of short circuiting effects cannot be completely ruled out in any study.

The structured, plastic media used in the Ames study, nitrifying biofilter had a higher specific surface area and more complicated geometry than media used in the majority of nitrifying biofilter studies in the literature. Partial plugging of the 60 degree, cross-flow media, with a specific surface area of 138 sq. m/cu. m, was suspected at various times and at various depths in the biofilter. The construction of the biofilter tower available for the Ames study was not suitable for examination of the media at various depths to verify or refute the partial plugging suspicions without disassembly. The implications of partial plugging of the media in the biofilter have been presented in the Results and Analysis section and will not be repeated here.

There were brief periods of unexplained low nitrification performance during this study. No direct evidence of toxicity was observed. The effects of toxicity could not be evaluated extensively in the Ames study because of the limited project budget. Ames is not a heavily industrialized city, however, the research facilities associated with Iowa State University and government agencies and the industries located in Ames cannot be ruled out as potential sources of toxicity.

CONCLUSIONS AND RECOMMENDATIONS

The Ames WPCP pilot-scale, separate-stage nitrifying biofilter study was similar to studies reported in the literature which applied settled secondary effluent to the media in the biofilters. However, the overloaded condition of the Ames WPCP allowed the examination of nitrification in separate-stage biofilters at slightly greater organic loadings than previous studies. The Ames study was an important contribution to the separate-stage, nitrifying biofilter data base for a number of reasons previously outlined in the Results and Analysis section. It emphasized cold-climate performance and oxygen flux-limited operating conditions.

Many important conclusions can be drawn from the results of the Ames study. Some of these observations have not been reported in previous literature or are contrary to findings reported in previous literature. The significant findings from the Ames study were:

1. D.O. is critical to nitrifying biofilter performance when oxygen flux limitation conditions exist. When the percent of D.O. saturation drops below 60 to 65 percent, nitrification performance will be diminished. When the percent of D.O. saturation drops below 45 to 50 percent, nitrification may be totally eliminated. This finding suggests that tower influent aeration and/or forced draft ventilation of nitrifying biofilters may be desirable.
2. Carbonaceous oxygen demand has greater impact on nitrification performance at low hydraulic loading rates than at high hydraulic loading rates.

3. The bulk liquid filterable (< 0.45 micron) COD concentration necessary to cause elimination of nitrifier populations from the biofilm is greater than 60 mg/l. However, competition between heterotrophs and nitrifiers can occur at somewhat lower filterable COD concentrations resulting in partial reduction in nitrification performance.
4. Nitrification is not limited by bulk liquid alkalinity concentrations greater than 30 mg/l as $CaCO_3$.
5. Above bulk liquid NH_4^+-N concentrations of about 4 mg/l, nitrification in biofilters is essentially zero-order relative to bulk liquid NH_4^+-N concentrations and linear with respect to tower depth and is, therefore, oxygen flux-limited.
6. Denitrification can occur in the upper levels of separate-stage, nitrifying biofilters when bulk liquid NO_2^--N and NO_3^--N concentrations are high, when filterable COD concentrations as low as 50 mg/l exist in the bulk liquid, and when bulk liquid D.O. concentrations are low.
7. Nitrification performance is improved by recirculation when bulk liquid D.O. concentrations in the influent wastewater stream are inadequate for maximum nitrification performance. Temperature changes in the wastewater resulting from recirculation should be considered in cold-climate operation when recycle decisions are being made. However, the effects of small temperature changes can be predicted adequately by the Nernst-Einstein equation when the percent of D.O. saturation in the bulk liquid is greater than 65

percent and carbonaceous oxygen demand does not foster heterotroph competition within the biofilm.

8. When intermediate clarification is used between the carbon oxidation stage biofilters and the nitrifying stage biofilters, the detrimental effect of clarification due to dissolved oxygen reduction must be considered, as well as the beneficial effects of carbonaceous oxygen demand and suspended solids loading reductions. Relatively short detention in the intermediate clarifiers may be desirable to minimize dissolved oxygen reduction. This would also reduce heat loss effects in winter operation.
9. Hydraulic loading rates greater than 0.8 l/sq. m • s are detrimental to stable operation of nitrifying biofilters in cold-weather operation. This is particularly true when intermittent dosing is used and when bulk liquid D.O. concentrations are low. Low bulk liquid D.O. concentrations, though not necessarily below typical summer D.O. concentrations, are likely to be the case in the colder weather conditions. In cold weather, first-stage biological treatment is impaired and continued metabolism in intermediate clarifiers results in greater reductions in D.O. concentrations. This, coupled with reduced diffusivity of D.O. in the bulk liquid and biofilm in cold weather, results in reduced oxygen mass transfer into the biofilm.
10. If nitrification performance in sections of the nitrifying biofilter is lost during cold-weather operation, high hydraulic loading rates will prevent the return of nitrification performance. Low

hydraulic loading rates are desirable to prevent the initial loss of nitrification performance in cold weather, as well as to assist in restoring nitrification performance if it is temporarily lost.

11. Nitrifier populations can be established in fixed-film reactors even in cold-weather start-up operations provided a treated effluent from another plant containing active nitrifiers is used for seeding.
12. Near-steady state operation of nitrifying biofilters can be established in six to seven weeks in warm weather operation. Two to three additional weeks may be required in cold weather.
13. Actively nitrifying biofilms respond quite rapidly to environmental changes. The majority of acclimation to new environmental conditions occurs within one to two days.
14. The 60-degree, cross-flow media with a specific surface area of 138 sq. m/cu. m used in this study appeared to have a tendency toward partial plugging. The partial plugging appeared to be transient, both in regard to tower depth location and longevity at any location. Partial plugging may persist at a given depth for fairly long periods of time. The biofilter used in this study has not been disassembled, and confirmation or negation of the partial plugging hypothesis has not been made.
15. The cold weather empirical design curve (Figure 10) proposed by Gullicks and Cleasby (1986) was revised to reflect additional data from this pilot-scale study and the literature. The revised design curve (Figure 48) presents an empirical relationship between the

areal rate of nitrification and the total applied hydraulic load and the applied NH_4^+-N concentration, including recirculated flow and NH_4^+-N, for 10°C secondary effluent. The design curve was constructed primarily with data from towers which contained 6-6.55 m of plastic media with specific surface areas of 89-98 m^2/m^3. No safety factor is implied in the design curve. The new design curve can be used in exactly the same manner described by Gullicks and Cleasby (1986) for the use of Figure 10. Additional surface area should be provided by increasing the media depth to account for the desired safety factor and to account for bulk liquid percent of D.O. saturation less than 65% and/or the partial plugging potential of media with specific surface areas greater than 98 m^2/m^3. Nitrification performance conformed well with the previous design curve (Figure 10) when continuous secondary effluent dosing was used. When intermittent dosing was used, the rate of nitrification was less than that predicted by the previous design curve (Figure 10).

16. Percolation theory (Figure 21) predicted the maximum effective media surface areas observed in this study quite well. However, the average effective media surface areas observed in this study were intermediate between the effective areas predicted by the Onda correlations (Figure 20) and by the percolation theory (Figure 21).

The Ames study has been beneficial to improving the design and operation of nitrifying biofilters. Additional studies are desirable to further expand the design and operation knowledge of nitrifying biofilters. Topics requiring further research include:

1. More detailed studies of the effects of bulk liquid D.O. concentrations on the nitrification performance of biofilters, including forced draft ventilation effects and influent aeration effects,
2. Detailed studies of the effect of intermediate clarifier detention time on the nitrification performance of biofilters,
3. Evaluation of partial plugging potential and its effects on nitrification performance,
4. Additional evaluation of the effect that intermittently-dosed versus continuously-dosed wastewater application has on nitrification, and comparison of full-scale nitrifying biofilter performance to pilot-scale performance for intermittent versus continuous wastewater dosing, and
5. Additional cold-climate nitrification evaluation.

Careful attention should be given to the design of pilot-scale biofilters used in researching these topics. The design should allow direct visual observation of the media and removal of media segments at various depths in the tower. Bulk liquid sampling should be possible at various depths along the tower so that nitrification performance can be related to individual segments of the tower. The effects of D.O., temperature, carbonaceous oxygen demand, pH, and alkalinity should all be considered.

Some of the effects of D.O. concentrations on nitrification performance may be studied effectively on a laboratory scale. The study of other D.O. effects, particularly related to intermediate clarification and forced draft ventilation, could best be evaluated with pilot-scale or full-scale facilities.

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APPENDIX: EXPERIMENTAL AND CALCULATED DATA

Some of the terms used in the appendix merit explanation. The term total flow means the influent flow plus the recycle flow, when recycle was in use. The term D10/DT is the Nernst-Einstein correction (multiplier) for temperature effects. Influent concentrations were the parameter concentrations influent to the specified section of the biofilter tower. The term oxidized N was used to represent the change in the concentrations of the various specified nitrogen forms for any given section of the biofilter tower. Thus, oxidized nitrogen is really a misnomer that was used in order to facilitate the spreadsheet organization.

The data of Duddles and Richardson (1973) and Baxter and Woodman, Inc. (1973) were the data from the Midland, Michigan and Bloom Township, Illinois studies, respectively, that were used in construction of the original design curves of Gullicks and Cleasby (1986). However, in this appendix, the data have been converted to a common 10 degree C basis by the Nernst-Einstein equation.

The influent-effluent data from the Ames WPCP study were often collected on the same day as the biofilter profile data. However, these data represent distinct sampling times when complete profile data were not collected simultaneously.

Ames WPCP
Pilot-Scale Nitrifying Biofilter
Tower Profile Data

```
Source:  AMES                               Date:    031086
Avg. Total Flow, l/ sq. m x s:                          .468
Recycle, percent total flow:                              59
Periodic Dosing Cycle, sec:                               73
Distribution Time, sec/cycle:                             27
Avg. Distributed Flow, l/sq. m x s:                      1.3

Media Spec. Surf. Area, sq.m/cu. m:                    137.8
Onda % Wetted Area:                                       26
Water Temp., C:            10          D10/DT:             1
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent            Oxidized            10  C
Depth     Concentration       Nitrogen            Nit. Rate
  m         mg/l              mg/l                kg/d sq.m
                                                  tot. sur-
                                                  face area

0-1.2     NH4-N             4        1.3           .0003126
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
1.2-2.4   NH4-N           2.7        1.1           .0002645
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
2.4-3.6   NH4-N           1.6         .6           .0001443
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
3.7-4.9   NH4-N             1         .4           .0000962
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
```

Source: AMES Date: 031186
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 10 D10/DT: 1
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	1.6	.6	.0001412
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	1	.5	.0001177
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	.5	.3	.0000706
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.2	0	0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031186
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 10 D10/DT: 1
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	1.4	.5	.0001177
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	.9	.5	.0001177
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	.4	.2	.0000471
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.2	.1	.0000235
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031386
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 8.8 D10/DT: 1.043
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	1.8	.8	.0001963
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	1	.6	.0001473
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	.4	.2	.0000491
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.2	-.1	-.0000245
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031386
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 8.8 D10/DT: 1.043
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	3.2	1	.0002454
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	2.2	1	.0002454
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	1.2	.6	.0001473
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.6	.2	.0000491
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031386
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 9 D10/DT: 1.036
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.9 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	3.5	1	.0002438
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	2.5	1	.0002438
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	1.5	.9	.0002194
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.6	0	0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031386
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 9 D10/DT: 1.036
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 8 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	3.4	1	.0002438
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	2.4	1	.0002438
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	1.4	.8	.000195
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.6	.1	.0000244
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031386
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 9 D10/DT: 1.036
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 8 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	3.2	.9	.0002194
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	2.3	1	.0002438
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	1.3	.7	.0001707
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.6	.1	.0000244
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031386
Avg. Total Flow, l/ sq. m x s: .458
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 9.5 D10/DT: 1.018
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	3.2	1	.0002396
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	2.2	1.1	.0002635
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	1.1	.7	.0001677
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.4	0	0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 031486
Avg. Total Flow, l/ sq. m x s: .461
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 8.7 D10/DT: 1.047
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	2	.7	.0001736
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	1.3	.8	.0001984
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	.5	.3	.0000744
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.2	0	0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source: AMES                              Date:     031486
Avg. Total Flow, l/ sq. m x s:                        .461
Recycle, percent total flow:                            59
Periodic Dosing Cycle, sec:                             73
Distribution Time, sec/cycle:                           27
Avg. Distributed Flow, l/sq. m x s:                    1.3

Media Spec. Surf. Area, sq.m/cu. m:                  137.8
Onda % Wetted Area:                                     26
Water Temp., C:         8.7           D10/DT:        1.047
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                 VSS, mg/l:
pH:              8   Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent            Oxidized            10  C
Depth     Concentration       Nitrogen            Nit. Rate
  m         mg/l              mg/l                kg/d sq.m
                                                  tot. sur-
                                                  face area

0-1.2     NH4-N          1.6         .6            .0001488
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
1.2-2.4   NH4-N            1         .6            .0001488
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
2.4-3.6   NH4-N           .4         .2            .0000496
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
3.7-4.9   NH4-N           .2          0                   0
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
```

Source: AMES Date: 031786
Avg. Total Flow, l/ sq. m x s: .466
Recycle, percent total flow: 58
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 11.7 D10/DT: .95
Infl. COD, mg/l: 104
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	5.6	1	.0002275
	TKN	10.8		0
	NO2+NO3	15.2		0
	Filt. TKN			0
1.2-2.4	NH4-N	4.6	2.3	.0005231
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	2.3	.9	.0002047
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	1.4	.4	.000091
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	5.6	4.6	.0002616
	TKN	10.8	5.8	.0003298
	NO2+NO3	15.2	4.8	.0002729
	Filt. TKN			

Source: AMES Date: 031986
Avg. Total Flow, l/ sq. m x s: .485
Recycle, percent total flow: 30
Periodic Dosing Cycle, sec: 67
Distribution Time, sec/cycle: 23
Avg. Distributed Flow, l/sq. m x s: 1.4

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 27
Water Temp., C: 7.4 D10/DT: 1.094
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	6.3	1.2	.0003271
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	5.1	1.6	.0004362
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	3.5	1	.0002726
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	2.5	.7	.0001908
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	6.3	4.5	.0003067
	TKN			0
	NO2+NO3			0
	Filt. TKN			

```
Source: AMES                        Date:    031986
Avg. Total Flow, 1/ sq. m x s:                    .501
Recycle, percent total flow:                        31
Periodic Dosing Cycle, sec:                         67
Distribution Time, sec/cycle:                       23
Avg. Distributed Flow, 1/sq. m x s:                1.5

Media Spec. Surf. Area, sq.m/cu. m:              137.8
Onda % Wetted Area:                                 27
Water Temp., C:         8.7         D10/DT:      1.047
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:             7.9   Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent           Oxidized           10  C
Depth    Concentration      Nitrogen           Nit. Rate
  m        mg/l             mg/l               kg/d sq.m
                                               tot. sur-
                                               face area

0-1.2    NH4-N              8       1.2         .0003234
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0
1.2-2.4  NH4-N            6.8       1.8         .0004851
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0
2.4-3.6  NH4-N              5       1.4         .0003773
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0
3.7-4.9  NH4-N            3.6        .5         .0001348
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0

0-4.9    NH4-N              8       4.9         .0003301
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN
```

Source: AMES Date: 031986
Avg. Total Flow, l/ sq. m x s: .507
Recycle, percent total flow: 32
Periodic Dosing Cycle, sec: 67
Distribution Time, sec/cycle: 23
Avg. Distributed Flow, l/sq. m x s: 1.5

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 27
Water Temp., C: 8.4 D10/DT: 1.058
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.8 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	7	1.2	.0003307
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	5.8	1.7	.0004685
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	4.1	1.1	.0003032
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	3	.4	.0001102
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	7	4.4	.0003032
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source: AMES                        Date:    032086
Avg. Total Flow, l/ sq. m x s:                    .501
Recycle, percent total flow:                        31
Periodic Dosing Cycle, sec:                         65
Distribution Time, sec/cycle:                       23
Avg. Distributed Flow, l/sq. m x s:                1.4

Media Spec. Surf. Area, sq.m/cu. m:              137.8
Onda % Wetted Area:                                 27
Water Temp., C:            7        D10/DT:      1.109
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent          Oxidized        10  C
Depth    Concentration     Nitrogen        Nit. Rate
  m        mg/l            mg/l            kg/d sq.m
                                           tot. sur-
                                           face area

0-1.2    NH4-N          6.3      2.8        .0007993
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
1.2-2.4  NH4-N          3.5      1.2        .0003426
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
2.4-3.6  NH4-N          2.3        1        .0002855
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
3.7-4.9  NH4-N          1.3       .2        .0000571
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0

0-4.9    NH4-N          6.3      5.2        .0003711
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
```

Source: AMES Date: 032086
Avg. Total Flow, l/ sq. m x s: .511
Recycle, percent total flow: 32
Periodic Dosing Cycle, sec: 65
Distribution Time, sec/cycle: 23
Avg. Distributed Flow, l/sq. m x s: 1.4

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 27
Water Temp., C: 7.8 D10/DT: 1.079
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 8 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	2.6	.7	.0001983
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	1.9	1	.0002833
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	.9	.5	.0001416
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.4	.1	.0000283
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	2.6	2.3	.0001629
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 032086
Avg. Total Flow, l/ sq. m x s: .511
Recycle, percent total flow: 32
Periodic Dosing Cycle, sec: 65
Distribution Time, sec/cycle: 23
Avg. Distributed Flow, l/sq. m x s: 1.4

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 27
Water Temp., C: 7.8 D10/DT: 1.079
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 8 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	4.6	.9	.000255
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	3.7	1.7	.0004816
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	2	.7	.0001983
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	1.3	.5	.0001416
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	4.6	3.8	.0002691
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 032086
Avg. Total Flow, l/ sq. m x s: .503
Recycle, percent total flow: 31
Periodic Dosing Cycle, sec: 65
Distribution Time, sec/cycle: 23
Avg. Distributed Flow, l/sq. m x s: 1.4

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 27
Water Temp., C: 8 D10/DT: 1.072
Infl. COD, mg/l: 105
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	6.5	1.5	.0004156
	TKN	11	.3	.0000831
	NO2+NO3	9.4	.9	.0002493
	Filt. TKN			0
1.2-2.4	NH4-N	5	1.5	.0004156
	TKN	10.7	2.7	.000748
	NO2+NO3	10.3	1.9	.0005264
	Filt. TKN			0
2.4-3.6	NH4-N	3.5	1.1	.0003047
	TKN	8	.7	.0001939
	NO2+NO3	12.2		0
	Filt. TKN			0
3.7-4.9	NH4-N	2.4	.4	.0001108
	TKN	7.3	.6	.0001662
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	6.5	4.5	.0003117
	TKN	11	4.3	.0002978
	NO2+NO3	9.4	4.1	.000284
	Filt. TKN			0

Source: AMES Date: 033186
Avg. Total Flow, l/ sq. m x s: .583
Recycle, percent total flow: 27
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 16.9 D10/DT: .812
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	12.7	.9	.0002189
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	11.8	1.8	.0004378
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	10	1.3	.0003162
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	8.7	1.4	.0003405
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	12.7	5.4	.0003284
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 040286
Avg. Total Flow, l/ sq. m x s: .591
Recycle, percent total flow: 27
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 13.5 D10/DT: .899
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	17.1	1.1	.0003003
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	16	2.3	.0006279
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	13.7	.3	.0000819
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	13.4	1.2	.0003276
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	17.1	4.9	.0003344
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 040286
Avg. Total Flow, l/ sq. m x s: .577
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.7 D10/DT: .922
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	15.4	1.3	.0003553
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	14.1	2.4	.000656
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	11.7	.8	.0002187
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	10.9	2	.0005467
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	15.4	6.5	.0004442
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 040286
Avg. Total Flow, l/ sq. m x s: .577
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.4 D10/DT: .931
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.8 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5.2

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	14.2	1.1	.0003036
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	13.1	2.3	.0006348
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	10.8	.7	.0001932
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	10.1	2.3	.0006348
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	14.2	6.4	.0004416
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 040386
Avg. Total Flow, l/ sq. m x s: .581
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.5 D10/DT: .928
Infl. COD, mg/l: 118
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 50 VSS, mg/l: 35
pH: Infl. Alk, mg CaCO3/l: 166
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	13.1	1	.000277
	TKN	17	.5	.0001385
	NO2+NO3	9.9		0
	Filt. TKN			0
1.2-2.4	NH4-N	12.1	2.2	.0006094
	TKN	16.5	1.6	.0004432
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	9.9	.6	.0001662
	TKN	14.9	1.2	.0003324
	NO2+NO3	12.5		0
	Filt. TKN			0
3.7-4.9	NH4-N	9.3	1.9	.0005263
	TKN	13.7	.4	.0001108
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	13.1	5.7	.0003948
	TKN	17	3.7	.0002562
	NO2+NO3	9.9	4.7	.0003255
	Filt. TKN			0

Source: AMES Date: 040386
Avg. Total Flow, l/ sq. m x s: .578
Recycle, percent total flow: 24
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.3 D10/DT: .934
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.7 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 6.1

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	8.3	.7	.0001942
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	7.6	1.8	.0004993
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	5.8	.8	.0002219
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	5	2	.0005547
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	8.3	5.3	.0003675
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 041086
Avg. Total Flow, l/ sq. m x s: .572
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 11.5 D10/DT: .956
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.7 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	12.6	1.2	.0003371
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	11.4	1.6	.0004495
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	9.8	1.7	.0004776
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	8.1	1.1	.0003091
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	12.6	5.6	.0003933
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 041086
Avg. Total Flow, l/ sq. m x s: .589
Recycle, percent total flow: 28
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.7 D10/DT: .922
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.7 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 7

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	14	1.5	.0004185
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	12.5	2.3	.0006417
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	10.2	1.4	.0003906
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	8.8	1.4	.0003906
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	14	6.7	.0004674
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 041086
Avg. Total Flow, l/ sq. m x s: .58
Recycle, percent total flow: 27
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.5 D10/DT: .928
Infl. COD, mg/l: 101
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 42 VSS, mg/l: 29
pH: Infl. Alk, mg CaCO3/l: 160
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	13.3	1.4	.0003872
	TKN	17.7	1.2	.0003318
	NO2+NO3	10.9		0
	Filt. TKN			0
1.2-2.4	NH4-N	11.9	1.9	.0005254
	TKN	16.5	2.6	.000719
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	10	1.6	.0004425
	TKN	13.9	1.9	.0005254
	NO2+NO3	14.9		0
	Filt. TKN			0
3.7-4.9	NH4-N	8.4	1.3	.0003595
	TKN	12	-2.9	-.000802
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	13.3	6.2	.0004286
	TKN	17.7	2.8	.0001936
	NO2+NO3	10.9	5.8	.000401
	Filt. TKN			0

```
Source:  AMES                               Date:    071486
Avg. Total Flow, l/ sq. m x s:                         .586
Recycle, percent total flow:                              0
Periodic Dosing Cycle, sec:                              58
Distribution Time, sec/cycle:                            18
Avg. Distributed Flow, l/sq. m x s:                     1.9

Media Spec. Surf. Area, sq.m/cu. m:                   137.8
Onda % Wetted Area:                                      32
Water Temp., C:           21           D10/DT:         .723
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent            Oxidized            10  C
Depth    Concentration       Nitrogen           Nit. Rate
  m        mg/l              mg/l               kg/d sq.m
                                                tot. sur-
                                                face area

0-1.2    NH4-N          2.2      1.1             .0002394
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
1.2-2.4  NH4-N          1.1       .7             .0001524
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
2.4-3.6  NH4-N           .4       .3             .0000653
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
3.7-4.9  NH4-N           .1        0                    0
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0

0-4.9    NH4-N          2.2      2.1             .0001143
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
```

Source: AMES Date: 071486
Avg. Total Flow, l/ sq. m x s: .586
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 58
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 21 D10/DT: .723
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	3.7	1.8	.0003918
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	1.9	1.2	.0002612
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	.7	.4	.0000871
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	.3	.1	.0000218
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	3.7	3.5	.0001905
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 072186
Avg. Total Flow, l/ sq. m x s: .591
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 58
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 22.5 D10/DT: .695
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	11.3	1.8	.0003799
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	9.5	2.3	.0004854
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	7.2	.4	.0000844
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	6.8	1.2	.0002532
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	11.3	5.7	.0003007
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 072286
Avg. Total Flow, l/ sq. m x s: .573
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 58
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 23.5 D10/DT: .677
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	16.2	2.5	.0004983
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	13.7	3.4	.0006777
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	10.3	.6	.0001196
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	9.7	2.1	.0004185
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	16.2	8.6	.0004285
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 072386
Avg. Total Flow, l/ sq. m x s: .556
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 58
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 24.5 D10/DT: .658
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	15.5	3.3	.0006203
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	12.2	4.3	.0008083
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	7.9	.7	.0001316
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	7.2	3	.0005639
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	15.5	11.3	.000531
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 073086
Avg. Total Flow, l/ sq. m x s: .578
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 58
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 23.5 D10/DT: .677
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.4 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	15.3	3.9	.0007841
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	11.4	4.7	.0009449
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	6.7	1.8	.0003619
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	4.9	3.8	.000764
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	15.3	14.2	.0007137
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 073086
Avg. Total Flow, l/ sq. m x s: .568
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 58
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 24.6 D10/DT: .656
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 6.4

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	20.8	5.2	.0009955
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	15.6	3.7	.0007083
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	11.9	2.3	.0004403
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	9.6	4.2	.0008041
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	20.8	15.4	.000737
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 073086
Avg. Total Flow, l/ sq. m x s: .568
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 58
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 24.3 D10/DT: .662
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.2 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 7

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	18.1	4	.0007728
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	14.1	4.9	.0009466
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	9.2	3	.0005796
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	6.2	4	.0007728
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	18.1	15.9	.0007679
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 073186
Avg. Total Flow, l/ sq. m x s: .558
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 22 D10/DT: .705
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	14.7	3.3	.000667
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	11.4	5.1	.0010308
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	6.3	2.4	.0004851
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	3.9	3	.0006064
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	14.7	13.8	.0006973
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES Date: 073186
Avg. Total Flow, l/ sq. m x s: .563
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 32
Water Temp., C: 22.5 D10/DT: .695
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	20.6	3.7	.0007438
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	16.9	4.7	.0009449
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	12.2	2.5	.0005026
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	9.7	4.3	.0008645
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	20.6	15.2	.0007639
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES                             Date: 0730-073186
Avg. Total Flow, l/ sq. m x s:                         .566
Recycle, percent total flow:                              0
Periodic Dosing Cycle, sec:                              59
Distribution Time, sec/cycle:                            18
Avg. Distributed Flow, l/sq. m x s:                     1.9

Media Spec. Surf. Area, sq.m/cu. m:                   137.8
Onda % Wetted Area:                                      32
Water Temp., C:          23.5         D10/DT:          .677
Infl. COD, mg/l:                                         49
Infl. Filt. COD, mg/l:                                   33
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:        34          VSS, mg/l:                  26
pH:                     Infl. Alk, mg CaCO3/l:          148
Infl. D. O., mg/l:


Media   Influent              Oxidized             10  C
Depth   Concentration         Nitrogen             Nit. Rate
  m       mg/l                mg/l                 kg/d sq.m
                                                   tot. sur-
                                                   face area

0-1.2   NH4-N          17.8          4              .0007875
        TKN            20.4        3.8              .0007481
        NO2+NO3                                            0
        Filt. TKN                                          0
1.2-2.4 NH4-N          13.8        4.6              .0009056
        TKN            16.6        3.3              .0006497
        NO2+NO3                                            0
        Filt. TKN                                          0
2.4-3.6 NH4-N           9.2        2.5              .0004922
        TKN            13.3        1.9              .0003741
        NO2+NO3                                            0
        Filt. TKN                                          0
3.7-4.9 NH4-N           6.7        3.8              .0007481
        TKN            11.4        4.4              .0008662
        NO2+NO3                                            0
        Filt. TKN                                          0

0-4.9   NH4-N          17.8       14.9              .0007334
        TKN            20.4       13.4              .0006595
        NO2+NO3                                            0
        Filt. TKN                                          0
```

Source: AMES Date: 111186
Avg. Total Flow, l/ sq. m x s: 1.266
Recycle, percent total flow: 28
Periodic Dosing Cycle, sec: 31
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 2.2

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 33
Water Temp., C: 13.5 D10/DT: .899
Infl. COD, mg/l: 77
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	13.9	0	0
	TKN	18.2	.6	.0003509
	NO2+NO3	9.8	.6	.0003509
	Filt. TKN			0
1.2-2.4	NH4-N	13.9	1.1	.0006432
	TKN	17.6	1.6	.0009356
	NO2+NO3	10.4	.9	.0005263
	Filt. TKN			0
2.4-3.6	NH4-N	12.8	1.7	.0009941
	TKN	16		0
	NO2+NO3	11.3		0
	Filt. TKN			0
3.7-4.9	NH4-N	11.1	2.5	.0014619
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	13.9	5.3	.0007748
	TKN	18.2	6.3	.000921
	NO2+NO3	9.8	5.6	.0008187
	Filt. TKN			0

Source: AMES Date: 111286
Avg. Total Flow, l/ sq. m x s: 1.201
Recycle, percent total flow: 28
Periodic Dosing Cycle, sec: 31
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 2.1

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 33
Water Temp., C: 11.5 D10/DT: .956
Infl. COD, mg/l: 91
Infl. Filt. COD, mg/l: 53
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	12.4	0	0
	TKN	16.6	.2	.000118
	NO2+NO3	9.9	-.9	-.0005309
	Filt. TKN	13.8		0
1.2-2.4	NH4-N	12.4	2.1	.0012388
	TKN	16.4	1.9	.0011208
	NO2+NO3	9	2	.0011798
	Filt. TKN			0
2.4-3.6	NH4-N	10.3	.4	.000236
	TKN	14.5		0
	NO2+NO3	11		0
	Filt. TKN			0
3.7-4.9	NH4-N	9.9	2.9	.0017107
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	12.4	5.4	.0007964
	TKN	16.6	5.7	.0008406
	NO2+NO3	9.9	4.3	.0006342
	Filt. TKN			0

```
Source:  AMES                               Date:     111386
Avg. Total Flow, l/ sq. m x s:                           1.128
Recycle, percent total flow:                                32
Periodic Dosing Cycle, sec:                                 34
Distribution Time, sec/cycle:                               18
Avg. Distributed Flow, l/sq. m x s:                        2.1

Media Spec. Surf. Area, sq.m/cu. m:                      137.8
Onda % Wetted Area:                                         32
Water Temp., C:         12.8        D10/DT:               .919
Infl. COD, mg/l:                                            93
Infl. Filt. COD, mg/l:                                      47
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent              Oxidized            10  C
Depth     Concentration         Nitrogen            Nit. Rate
  m         mg/l                mg/l                kg/d sq.m
                                                    tot. sur-
                                                    face area

0-1.2     NH4-N         12.1         .5             .0002663
          TKN           15.8         .3             .0001598
          NO2+NO3       10.4        -.9            -.0004793
          Filt. TKN     12.7                               0
1.2-2.4   NH4-N         11.6        1.6             .0008522
          TKN           15.5         .8             .0004261
          NO2+NO3        9.5        1.9              .001012
          Filt. TKN                                        0
2.4-3.6   NH4-N           10        1.5             .0007989
          TKN           14.7                               0
          NO2+NO3       11.4                               0
          Filt. TKN                                        0
3.7-4.9   NH4-N          8.5         .4              .000213
          TKN                                              0
          NO2+NO3                                          0
          Filt. TKN                                        0

0-4.9     NH4-N         12.1          4             .0005326
          TKN           15.8       -1.9             -.000253
          NO2+NO3       10.4        4.2             .0005592
          Filt. TKN                                        0
```

Source: AMES Date: 111986
Avg. Total Flow, l/ sq. m x s: .786
Recycle, percent total flow: 44
Periodic Dosing Cycle, sec: 49
Distribution Time, sec/cycle: 20
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 14 D10/DT: .885
Infl. COD, mg/l: 103
Infl. Filt. COD, mg/l: 36
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	15.7	5.1	.0018227
	TKN	38.1	21.7	.0077555
	NO2+NO3	11.9	2.8	.0010007
	Filt. TKN	34		0
1.2-2.4	NH4-N	10.6	-1.4	-.0005004
	TKN	16.4	-13.2	-.0047176
	NO2+NO3	14.7	1.2	.0004289
	Filt. TKN			0
2.4-3.6	NH4-N	12	4.8	.0017155
	TKN	29.6	17.4	.0062187
	NO2+NO3	15.9	1.8	.0006433
	Filt. TKN			0
3.7-4.9	NH4-N	7.2	2.8	.0010007
	TKN	12.2	3.7	.0013224
	NO2+NO3	17.7	2.9	.0010364
	Filt. TKN			0
0-4.9	NH4-N	15.7	11.3	.0010096
	TKN	38.1	30	.0026805
	NO2+NO3	11.9	8.7	.0007773
	Filt. TKN			0

Source: AMES Date: 112186
Avg. Total Flow, 1/ sq. m x s: .798
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 45
Distribution Time, sec/cycle: 20
Avg. Distributed Flow, 1/sq. m x s: 1.8

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 30
Water Temp., C: 13.8 D10/DT: .891
Infl. COD, mg/l: 70
Infl. Filt. COD, mg/l: 33
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m		Influent Concentration mg/l	Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	9.6	1	.0003653
	TKN	16.7	2.1	.0007672
	NO2+NO3	7.3	1	.0003653
	Filt. TKN	13.5		0
1.2-2.4	NH4-N	8.6	1.1	.0004018
	TKN	14.6	1	.0003653
	NO2+NO3	8.3	1.4	.0005114
	Filt. TKN			0
2.4-3.6	NH4-N	7.5	1.8	.0006576
	TKN	13.6	3.6	.0013151
	NO2+NO3	9.7	2.5	.0009133
	Filt. TKN			0
3.7-4.9	NH4-N	5.7	2	.0007306
	TKN	10	1.5	.000548
	NO2+NO3	12.2	2.5	.0009133
	Filt. TKN			0
0-4.9	NH4-N	9.6	5.9	.0005388
	TKN	16.7	8.2	.0007489
	NO2+NO3	7.3	7.4	.0006758
	Filt. TKN			0

Source: AMES Date: 112586
Avg. Total Flow, l/ sq. m x s: .669
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 57
Distribution Time, sec/cycle: 23
Avg. Distributed Flow, l/sq. m x s: 1.6

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 30
Water Temp., C: 14.7 D10/DT: .865
Infl. COD, mg/l: 65
Infl. Filt. COD, mg/l: 25
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	13	1.4	.0004163
	TKN	15.8	1.8	.0005352
	NO2+NO3	6.6	1.4	.0004163
	Filt. TKN	13.6		0
1.2-2.4	NH4-N	11.6	1.7	.0005054
	TKN	14	1.8	.0005352
	NO2+NO3	8	2	.0005946
	Filt. TKN			0
2.4-3.6	NH4-N	9.9	1.5	.000446
	TKN	12.2		0
	NO2+NO3	10		0
	Filt. TKN			0
3.7-4.9	NH4-N	8.4	2.3	.0006838
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	13	6.9	.0005129
	TKN	15.8	8.4	.0006244
	NO2+NO3	6.6	7.8	.0005798
	Filt. TKN			0

Source: AMES Date: 113086
Avg. Total Flow, l/ sq. m x s: .79
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 49
Distribution Time, sec/cycle: 21
Avg. Distributed Flow, l/sq. m x s: 1.8

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 30
Water Temp., C: 12.8 D10/DT: .919
Infl. COD, mg/l: 79
Infl. Filt. COD, mg/l: 60
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l: 200
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	11.1	1	.000373
	TKN	13.7	1.2	.0004476
	NO2+NO3	8.9	.6	.0002238
	Filt. TKN	10.9		0
1.2-2.4	NH4-N	10.1	1.1	.0004103
	TKN	12.9	.6	.0002238
	NO2+NO3	9.5	.8	.0002984
	Filt. TKN			0
2.4-3.6	NH4-N	9	.7	.0002611
	TKN	12.3		0
	NO2+NO3	10.3		0
	Filt. TKN			0
3.7-4.9	NH4-N	8.3	1.4	.0005222
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	11.1	4.2	.0003917
	TKN	13.7	4.5	.0004196
	NO2+NO3	8.9	3.8	.0003544
	Filt. TKN			0

Source: AMES Date: 120186

Avg. Total Flow, l/ sq. m x s: .786

Recycle, percent total flow: 0

Periodic Dosing Cycle, sec: 51

Distribution Time, sec/cycle: 24

Avg. Distributed Flow, l/sq. m x s: 1.7

Media Spec. Surf. Area, sq.m/cu. m: 137.8

Onda % Wetted Area: 30

Water Temp., C: 13.8 D10/DT: .891

Infl. COD, mg/l: 127

Infl. Filt. COD, mg/l: 49

Infl. BOD5, mg/l:

Infl. Filt. BOD5, mg/l:

SS, mg/l: VSS, mg/l:

pH: Infl. Alk, mg CaCO3/l:

Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	14.1	.5	.0001799
	TKN	20.8	1.7	.0006117
	NO2+NO3	5.1	1.9	.0006837
	Filt. TKN	15.4		0
1.2-2.4	NH4-N	13.6	1	.0003598
	TKN	19.1	1.2	.0004318
	NO2+NO3	7	1.8	.0006477
	Filt. TKN			0
2.4-3.6	NH4-N	12.6	.4	.0001439
	TKN	17.9	.8	.0002879
	NO2+NO3	8.8	.5	.0001799
	Filt. TKN			0
3.7-4.9	NH4-N	12.2	1.5	.0005397
	TKN	17.1	3.2	.0011514
	NO2+NO3	9.3	2.2	.0007916
	Filt. TKN			0
0-4.9	NH4-N	14.1	3.4	.0003058
	TKN	20.8	6.9	.0006207
	NO2+NO3	5.1	6.4	.0005757
	Filt. TKN			0

Source: AMES Date: 120386
Avg. Total Flow, l/ sq. m x s: .781
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 50
Distribution Time, sec/cycle: 23
Avg. Distributed Flow, l/sq. m x s: 1.7

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 30
Water Temp., C: 12.4 D10/DT: .931
Infl. COD, mg/l: 109
Infl. Filt. COD, mg/l: 34
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m		Influent Concentration mg/l	Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	16.2	.5	.0001868
	TKN	19.6	.6	.0002241
	NO2+NO3	8.3	.2	.0000747
	Filt. TKN	17	1.2	.0004483
1.2-2.4	NH4-N	15.7	.9	.0003362
	TKN	19	1.5	.0005604
	NO2+NO3	8.5	1.2	.0004483
	Filt. TKN	15.8		0
2.4-3.6	NH4-N	14.8	.3	.0001121
	TKN	17.5	-.4	-.0001494
	NO2+NO3	9.7	.3	.0001121
	Filt. TKN			0
3.7-4.9	NH4-N	14.5	1.5	.0005604
	TKN	17.9	1.6	.0005977
	NO2+NO3	10	1.8	.0006724
	Filt. TKN			0
0-4.9	NH4-N	16.2	3.2	.0002989
	TKN	19.6	3.3	.0003082
	NO2+NO3	8.3	3.5	.0003269
	Filt. TKN			0

Source: AMES Date: 011987
Avg. Total Flow, l/ sq. m x s: 1.25
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.25

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 11.8 D10/DT: .948
Infl. COD, mg/l: 69
Infl. Filt. COD, mg/l: 42
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 54 VSS, mg/l: 42
pH: Infl. Alk, mg CaCO3/l: 155
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	16.3	.2	.0001218
	TKN	21.2	.6	.0003653
	NO2+NO3	9.6		0
	Filt. TKN	18		0
1.2-2.4	NH4-N	16.1	.8	.0004871
	TKN	20.6	-.4	-.0002435
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	15.3	.8	.0004871
	TKN	21	-.4	-.0002435
	NO2+NO3	10.4		0
	Filt. TKN	16.9		0
3.7-4.9	NH4-N	14.5	1.5	.0009133
	TKN	21.4	3.9	.0023745
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	16.3	3.3	.0005023
	TKN	21.2	3.7	.0005632
	NO2+NO3	9.6	3.1	.0004719
	Filt. TKN	18	3.4	.0005175

Source: AMES Date: 012587
Avg. Total Flow, l/ sq. m x s: 1.278
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.278

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 27
Water Temp., C: 11.4 D10/DT: .959
Infl. COD, mg/l: 140
Infl. Filt. COD, mg/l: 66
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 57 VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l: 161
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	13.7	-.1	-.000063
	TKN	19.7	.3	.0001889
	NO2+NO3	7.5		0
	Filt. TKN	16		0
1.2-2.4	NH4-N	13.8	1.1	.0006927
	TKN	19.4	1.8	.0011335
	NO2+NO3			0
	Filt. TKN			0
2.4-3.6	NH4-N	12.7	.5	.0003148
	TKN	17.6	.5	.0003148
	NO2+NO3	8.5		0
	Filt. TKN	14.7		0
3.7-4.9	NH4-N	12.2	2.3	.0014483
	TKN	17.1	2.6	.0016372
	NO2+NO3			0
	Filt. TKN			0
0-4.9	NH4-N	13.7	3.8	.0005982
	TKN	19.7	5.2	.0008186
	NO2+NO3	7.5	3.8	.0005982
	Filt. TKN	16	3.9	.000614

```
Source: AMES                               Date:    012787
Avg. Total Flow, l/ sq. m x s:                       1.207
Recycle, percent total flow:                             0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:                  1.207

Media Spec. Surf. Area, sq.m/cu. m:                  137.8
Onda % Wetted Area:                                     26
Water Temp., C:          11.2          D10/DT:        .965
Infl. COD, mg/l:                                       106
Infl. Filt. COD, mg/l:                                  53
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:        46          VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:         147
Infl. D. O., mg/l:


Media    Influent              Oxidized          10  C
Depth    Concentration         Nitrogen          Nit. Rate
  m        mg/l                mg/l              kg/d sq.m
                                                 tot. sur-
                                                 face area

0-1.2    NH4-N          6.8         .5            .0002992
         TKN           11.4        -.2           -.0001197
         NO2+NO3        8.2                              0
         Filt. TKN      8.8                              0
1.2-2.4  NH4-N          6.3         .7            .0004189
         TKN           11.6        2.1            .0012567
         NO2+NO3                                         0
         Filt. TKN                                       0
2.4-3.6  NH4-N          5.6        1.1            .0006583
         TKN            9.5        1.1            .0006583
         NO2+NO3        9.3                              0
         Filt. TKN      7.4                              0
3.7-4.9  NH4-N          4.5        2.1            .0012567
         TKN            8.4        3.5            .0020945
         NO2+NO3                                         0
         Filt. TKN                                       0

0-4.9    NH4-N          6.8        4.4            .0006583
         TKN           11.4        6.5            .0009725
         NO2+NO3        8.2        3.4            .0005087
         Filt. TKN      8.8        3.6            .0005386
```

Source: AMES Date: 021387
Avg. Total Flow, l/ sq. m x s: .62
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .62

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 21
Water Temp., C: 14.5 D10/DT: .871
Infl. COD, mg/l:
Infl. Filt. COD, mg/l: 59
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m		Influent Concentration mg/l	Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	13.2	-.2	-.0000555
	TKN			0
	NO2+NO3	7.8	1.2	.0003329
	Filt. TKN	17.3	1.5	.0004162
1.2-2.4	NH4-N	13.4	3.4	.0009433
	TKN			0
	NO2+NO3	9		0
	Filt. TKN	16.8		0
2.4-3.6	NH4-N	10	.5	.0001387
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
3.7-4.9	NH4-N	9.5	4.6	.0012763
	TKN			0
	NO2+NO3	14.4	3.6	.0009988
	Filt. TKN	11.8	5.5	.001526
0-4.9	NH4-N	13.2	8.4	.0005827
	TKN			0
	NO2+NO3	7.8	10.2	.0007075
	Filt. TKN	17.3	11	.000763

Ames WPCP
Pilot-Scale Nitrifying Biofilter
Influent/Effluent Data

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    031086
Avg. Total Flow, l/ sq. m x s:                   .468
Recycle, percent total flow:                       59
Periodic Dosing Cycle, sec:                        73
Distribution Time, sec/cycle:                      27
Avg. Distributed Flow, l/sq. m x s:               1.3

Media Spec. Surf. Area, sq.m/cu. m:             137.8
Onda % Wetted Area:                                26
Water Temp., C:          10         D10/DT:         1
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent              Oxidized           10  C
Depth     Concentration         Nitrogen           Nit. Rate
  m         mg/l                mg/l               kg/d sq.m
                                                   tot. sur-
                                                   face area

0-2.4     NH4-N          4.7        2.7            .0003247
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
2.4-4.9   NH4-N            2          1            .0001203
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
0-4.88    NH4-N          4.7        3.7            .0002225
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:     031186
Avg. Total Flow, l/ sq. m x s:                  .458
Recycle, percent total flow:                      59
Periodic Dosing Cycle, sec:                       73
Distribution Time, sec/cycle:                     27
Avg. Distributed Flow, l/sq. m x s:              1.3

Media Spec. Surf. Area, sq.m/cu. m:            137.8
Onda % Wetted Area:                               26
Water Temp., C:         10.3         D10/DT:    .991
Infl. COD, mg/l:                                  74
Infl. Filt. COD, mg/l:                            48
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent             Oxidized            10  C
Depth    Concentration        Nitrogen            Nit. Rate
  m        mg/l               mg/l                kg/d sq.m
                                                  tot. sur-
                                                  face area

0-2.4    NH4-N          1.6       1.1              .0001283
         TKN            4.9                               0
         NO2+NO3       11.1                               0
         Filt. TKN                                        0
2.4-4.9  NH4-N           .5        .3               .000035
         TKN                                              0
         NO2+NO3                                          0
         Filt. TKN                                        0
0-4.88   NH4-N          1.6       1.4              .0000816
         TKN            4.9       1.3              .0000758
         NO2+NO3       11.1      -1.9             -.0001108
         Filt. TKN                                        0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    031486
Avg. Total Flow, l/ sq. m x s:                 .461
Recycle, percent total flow:                     59
Periodic Dosing Cycle, sec:                      73
Distribution Time, sec/cycle:                    27
Avg. Distributed Flow, l/sq. m x s:             1.3

Media Spec. Surf. Area, sq.m/cu. m:           137.8
Onda % Wetted Area:                              26
Water Temp., C:          8.7        D10/DT:   1.047
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent           Oxidized         10  C
Depth     Concentration      Nitrogen         Nit. Rate
  m         mg/l             mg/l             kg/d sq.m
                                              tot. sur-
                                              face area

0-2.4     NH4-N          2.6       1.8         .0002233
          TKN                                         0
          NO2+NO3                                     0
          Filt. TKN                                   0
2.4-4.9   NH4-N           .8        .5          .000062
          TKN                                         0
          NO2+NO3                                     0
          Filt. TKN                                   0
0-4.88    NH4-N          2.6       2.3         .0001426
          TKN                                         0
          NO2+NO3                                     0
          Filt. TKN                                   0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 031486
Avg. Total Flow, l/ sq. m x s: .461
Recycle, percent total flow: 59
Periodic Dosing Cycle, sec: 73
Distribution Time, sec/cycle: 27
Avg. Distributed Flow, l/sq. m x s: 1.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 9 D10/DT: 1.036
Infl. COD, mg/l: 68
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	2.6		0
	TKN	6.3		0
	NO2+NO3	10.4		0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	2.6	2.2	.000135
	TKN	6.3	2.9	.000178
	NO2+NO3	10.4	2.4	.0001473
	Filt. TKN			0

```
Source: AMES NIT.TOWER INFL/EFFL   Date:    031986
Avg. Total Flow, l/ sq. m x s:                 .517
Recycle, percent total flow:                     32
Periodic Dosing Cycle, sec:                      67
Distribution Time, sec/cycle:                    23
Avg. Distributed Flow, l/sq. m x s:             1.5

Media Spec. Surf. Area, sq.m/cu. m:           137.8
Onda % Wetted Area:                              27
Water Temp., C:         8.7         D10/DT:   1.047
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media    Influent          Oxidized         10  C
Depth    Concentration     Nitrogen         Nit. Rate
  m        mg/l            mg/l             kg/d sq.m
                                            tot. sur-
                                            face area

0-2.4    NH4-N          7.3                          0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
2.4-4.9  NH4-N                                       0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
0-4.88   NH4-N          7.3      4.7          .0003269
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    032086
Avg. Total Flow, l/ sq. m x s:                  .503
Recycle, percent total flow:                      31
Periodic Dosing Cycle, sec:                       65
Distribution Time, sec/cycle:                     23
Avg. Distributed Flow, l/sq. m x s:              1.4

Media Spec. Surf. Area, sq.m/cu. m:            137.8
Onda % Wetted Area:                               27
Water Temp., C:         7.5        D10/DT:      1.09
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent          Oxidized          10  C
Depth    Concentration     Nitrogen          Nit. Rate
  m        mg/l            mg/l              kg/d sq.m
                                             tot. sur-
                                             face area

0-2.4    NH4-N        6.1                            0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
2.4-4.9  NH4-N                                       0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
0-4.88   NH4-N        6.1      4.3           .0003029
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
```

```
Source: AMES NIT.TOWER INFL/EFFL    Date:    032086
Avg. Total Flow, l/ sq. m x s:                .506
Recycle, percent total flow:                    31
Periodic Dosing Cycle, sec:                     65
Distribution Time, sec/cycle:                   23
Avg. Distributed Flow, l/sq. m x s:            1.4

Media Spec. Surf. Area, sq.m/cu. m:          137.8
Onda % Wetted Area:                             27
Water Temp., C:        7          D10/DT:    1.109
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                 VSS, mg/l:
pH:                Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent          Oxidized        10  C
Depth    Concentration     Nitrogen        Nit. Rate
  m        mg/l            mg/l            kg/d sq.m
                                           tot. sur-
                                           face area

0-2.4    NH4-N         3.6                         0
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
2.4-4.9  NH4-N                                     0
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
0-4.88   NH4-N         3.6         3        .0002163
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:     032086
Avg. Total Flow, l/ sq. m x s:                  .503
Recycle, percent total flow:                      31
Periodic Dosing Cycle, sec:                       65
Distribution Time, sec/cycle:                     23
Avg. Distributed Flow, l/sq. m x s:              1.4

Media Spec. Surf. Area, sq.m/cu. m:            137.8
Onda % Wetted Area:                               27
Water Temp., C:         9.4         D10/DT:    1.022
Infl. COD, mg/l:                                  92
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent            Oxidized         10  C
Depth    Concentration       Nitrogen         Nit. Rate
  m        mg/l              mg/l             kg/d sq.m
                                              tot. sur-
                                              face area

0-2.4    NH4-N          6.4                           0
         TKN           10.4                           0
         NO2+NO3        9.9                           0
         Filt. TKN                                    0
2.4-4.9  NH4-N                                        0
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
0-4.88   NH4-N          6.4         4.6       .0003038
         TKN           10.4         4.8        .000317
         NO2+NO3        9.9         4.7       .0003104
         Filt. TKN                                    0
```

```
Source:  AMES NIT.TOWER INFL/EFFL    Date:    032086
Avg. Total Flow, l/ sq. m x s:                  .503
Recycle, percent total flow:                      31
Periodic Dosing Cycle, sec:                       65
Distribution Time, sec/cycle:                     23
Avg. Distributed Flow, l/sq. m x s:              1.4

Media Spec. Surf. Area, sq.m/cu. m:            137.8
Onda % Wetted Area:                               27
Water Temp., C:          12         D10/DT:     .942
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                 VSS, mg/l:
pH:                 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent          Oxidized          10  C
Depth    Concentration     Nitrogen          Nit. Rate
  m        mg/l            mg/l              kg/d sq.m
                                             tot. sur-
                                             face area

0-2.4    NH4-N        5.7                            0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
2.4-4.9  NH4-N                                       0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
0-4.88   NH4-N        5.7       5.4           .0003287
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 032686
Avg. Total Flow, l/ sq. m x s: .58
Recycle, percent total flow: 27
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12 D10/DT: .942
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	9.7		0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	9.7	5	.000351
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    032786
Avg. Total Flow, l/ sq. m x s:                     .581
Recycle, percent total flow:                         27
Periodic Dosing Cycle, sec:                          59
Distribution Time, sec/cycle:                        18
Avg. Distributed Flow, l/sq. m x s:                 1.9

Media Spec. Surf. Area, sq.m/cu. m:               137.8
Onda % Wetted Area:                                  31
Water Temp., C:        11.7         D10/DT:         .95
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent          Oxidized           10  C
Depth    Concentration     Nitrogen           Nit. Rate
  m        mg/l            mg/l               kg/d sq.m
                                              tot. sur-
                                              face area

0-2.4    NH4-N         10.7                           0
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
2.4-4.9  NH4-N                                        0
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
0-4.88   NH4-N         10.7      6.3           .0004468
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    032786
Avg. Total Flow, l/ sq. m x s:              .581
Recycle, percent total flow:                  27
Periodic Dosing Cycle, sec:                   59
Distribution Time, sec/cycle:                 18
Avg. Distributed Flow, l/sq. m x s:          1.9

Media Spec. Surf. Area, sq.m/cu. m:        137.8
Onda % Wetted Area:                           31
Water Temp., C:      13.6       D10/DT:     .896
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:               VSS, mg/l:
pH:                Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media   Influent        Oxidized        10  C
Depth   Concentration   Nitrogen        Nit. Rate
  m       mg/l          mg/l            kg/d sq.m
                                        tot. sur-
                                        face area

0-2.4   NH4-N        11.5                      0
        TKN                                    0
        NO2+NO3                                0
        Filt. TKN                              0
2.4-4.9 NH4-N                                  0
        TKN                                    0
        NO2+NO3                                0
        Filt. TKN                              0
0-4.88  NH4-N        11.5    5.8        .0003879
        TKN                                    0
        NO2+NO3                                0
        Filt. TKN                              0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 033186
Avg. Total Flow, l/ sq. m x s: .577
Recycle, percent total flow: 26
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 15.7 D10/DT: .84
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	7.3		0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	7.3	4.1	.0002553
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    040186
Avg. Total Flow, l/ sq. m x s:                  .583
Recycle, percent total flow:                      26
Periodic Dosing Cycle, sec:                       59
Distribution Time, sec/cycle:                     18
Avg. Distributed Flow, l/sq. m x s:              1.9

Media Spec. Surf. Area, sq.m/cu. m:            137.8
Onda % Wetted Area:                               31
Water Temp., C:         13.5        D10/DT:     .899
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                     VSS, mg/l:
pH:                      Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent             Oxidized          10  C
Depth    Concentration        Nitrogen          Nit. Rate
  m        mg/l               mg/l              kg/d sq.m
                                                tot. sur-
                                                face area

0-2.4    NH4-N        11.8                              0
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
2.4-4.9  NH4-N                                          0
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
0-4.88   NH4-N        11.8      4.5               .000303
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 040286
Avg. Total Flow, l/ sq. m x s: .584
Recycle, percent total flow: 26
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 13 D10/DT: .913
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	16.7		0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	16.7	6.6	.0004521
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES NIT.TOWER INFL/EFFL Date: 040286
Avg. Total Flow, l/ sq. m x s: .58
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.5 D10/DT: .928
Infl. COD, mg/l: 123
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 41 VSS, mg/l: 28
pH: Infl. Alk, mg CaCO3/l: 165
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	12.5		0
	TKN	17		0
	NO2+NO3	10.4		0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	12.5	5.5	.0003804
	TKN	17	3.9	.0002697
	NO2+NO3	10.4	4.3	.0002974
	Filt. TKN			0

Source: AMES NIT.TOWER INFL/EFFL Date: 040386
Avg. Total Flow, l/ sq. m x s: .577
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.2 D10/DT: .936
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C. Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	9.3		0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	9.3	4.7	.0003261
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    040386
Avg. Total Flow, l/ sq. m x s:                 .581
Recycle, percent total flow:                     24
Periodic Dosing Cycle, sec:                      59
Distribution Time, sec/cycle:                    18
Avg. Distributed Flow, l/sq. m x s:             1.9

Media Spec. Surf. Area, sq.m/cu. m:           137.8
Onda % Wetted Area:                              31
Water Temp., C:         12.6         D10/DT:   .925
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                     VSS, mg/l:
pH:                      Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media    Influent              Oxidized        10  C
Depth    Concentration         Nitrogen        Nit. Rate
  m        mg/l                mg/l            kg/d sq.m
                                               tot. sur-
                                               face area

0-2.4    NH4-N          11.7                          0
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
2.4-4.9  NH4-N                                        0
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
0-4.88   NH4-N          11.7         6         .0004143
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
```

```
Source:  AMES NIT.TOWER INFL/EFFL    Date:     040386
Avg. Total Flow, l/ sq. m x s:                   .583
Recycle, percent total flow:                       25
Periodic Dosing Cycle, sec:                        59
Distribution Time, sec/cycle:                      18
Avg. Distributed Flow, l/sq. m x s:               1.9

Media Spec. Surf. Area, sq.m/cu. m:             137.8
Onda % Wetted Area:                                31
Water Temp., C:         12.5        D10/DT:      .928
Infl. COD, mg/l:                                  104
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:       66       VSS, mg/l:                46
pH:                 Infl. Alk, mg CaCO3/l:        180
Infl. D. O., mg/l:


Media    Influent           Oxidized          10  C
Depth    Concentration      Nitrogen          Nit. Rate
  m        mg/l             mg/l              kg/d sq.m
                                              tot. sur-
                                              face area

0-2.4    NH4-N          10.5                        0
         TKN            14.2                        0
         NO2+NO3        10.5                        0
         Filt. TKN                                  0
2.4-4.9  NH4-N                                      0
         TKN                                        0
         NO2+NO3                                    0
         Filt. TKN                                  0
0-4.88   NH4-N          10.5       5.9       .0004101
         TKN            14.2      -4.7      -.0003267
         NO2+NO3        10.5       4.3       .0002989
         Filt. TKN                                  0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:     040386
Avg. Total Flow, l/ sq. m x s:                      .581
Recycle, percent total flow:                          25
Periodic Dosing Cycle, sec:                           59
Distribution Time, sec/cycle:                         18
Avg. Distributed Flow, l/sq. m x s:                  1.9

Media Spec. Surf. Area, sq.m/cu. m:                137.8
Onda % Wetted Area:                                   31
Water Temp., C:        12.5          D10/DT:        .928
Infl. COD, mg/l:                                     105
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent             Oxidized           10  C
Depth     Concentration        Nitrogen           Nit. Rate
  m         mg/l               mg/l               kg/d sq.m
                                                  tot. sur-
                                                  face area

0-2.4     NH4-N            10.9                            0
          TKN              15.4                            0
          NO2+NO3           9.9                            0
          Filt. TKN                                        0
2.4-4.9   NH4-N                                            0
          TKN                                              0
          NO2+NO3                                          0
          Filt. TKN                                        0
0-4.88    NH4-N            10.9        4.2           .000291
          TKN              15.4       -8.4        -.0005819
          NO2+NO3           9.9        4.4         .0003048
          Filt. TKN                                        0
```

```
Source: AMES NIT.TOWER INFL/EFFL   Date:    040486
Avg. Total Flow, l/ sq. m x s:                .584
Recycle, percent total flow:                    25
Periodic Dosing Cycle, sec:                     59
Distribution Time, sec/cycle:                   18
Avg. Distributed Flow, l/sq. m x s:            1.9

Media Spec. Surf. Area, sq.m/cu. m:          137.8
Onda % Wetted Area:                             31
Water Temp., C:        12.5        D10/DT:    .928
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                VSS, mg/l:
pH:                 Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent            Oxidized        10  C
Depth    Concentration       Nitrogen        Nit. Rate
  m        mg/l              mg/l            kg/d sq.m
                                             tot. sur-
                                             face area

0-2.4    NH4-N        9.6                            0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
2.4-4.9  NH4-N                                       0
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
0-4.88   NH4-N        9.6       5.8           .0004039
         TKN                                         0
         NO2+NO3                                     0
         Filt. TKN                                   0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    040486
Avg. Total Flow, l/ sq. m x s:                    .584
Recycle, percent total flow:                        25
Periodic Dosing Cycle, sec:                         59
Distribution Time, sec/cycle:                       18
Avg. Distributed Flow, l/sq. m x s:                1.9

Media Spec. Surf. Area, sq.m/cu. m:              137.8
Onda % Wetted Area:                                 31
Water Temp., C:        11.5         D10/DT:       .956
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                     VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent             Oxidized          10  C
Depth    Concentration        Nitrogen          Nit. Rate
  m        mg/l               mg/l              kg/d sq.m
                                                tot. sur-
                                                face area

0-2.4    NH4-N          5.7                             0
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
2.4-4.9  NH4-N                                          0
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
0-4.88   NH4-N          5.7        4.8           .0003443
         TKN                                            0
         NO2+NO3                                        0
         Filt. TKN                                      0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    040486
Avg. Total Flow, l/ sq. m x s:                 .584
Recycle, percent total flow:                     25
Periodic Dosing Cycle, sec:                      59
Distribution Time, sec/cycle:                    18
Avg. Distributed Flow, l/sq. m x s:             1.9

Media Spec. Surf. Area, sq.m/cu. m:           137.8
Onda % Wetted Area:                              31
Water Temp., C:          12         D10/DT:    .942
Infl. COD, mg/l:                                110
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent             Oxidized        10  C
Depth     Concentration        Nitrogen        Nit. Rate
  m         mg/l               mg/l            kg/d sq.m
                                               tot. sur-
                                               face area

0-2.4     NH4-N          7.9                           0
          TKN           11.6                           0
          NO2+NO3       10.2                           0
          Filt. TKN                                    0
2.4-4.9   NH4-N                                        0
          TKN                                          0
          NO2+NO3                                      0
          Filt. TKN                                    0
0-4.88    NH4-N          7.9         3.9        .0002757
          TKN           11.6         -15       -.0010602
          NO2+NO3       10.2         4.3        .0003039
          Filt. TKN                                    0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 040586
Avg. Total Flow, l/ sq. m x s: .584
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 11.2 DtO/DT: .965
Infl. COD, mg/l: 73
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	9.5		0
	TKN	11.7		0
	NO2+NO3	10.3		0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	9.5	5.8	.00042
	TKN	11.7	2.2	.0001593
	NO2+NO3	10.3	2.5	.000181
	Filt. TKN			0

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    040586
Avg. Total Flow, l/ sq. m x s:                 .584
Recycle, percent total flow:                     25
Periodic Dosing Cycle, sec:                      59
Distribution Time, sec/cycle:                    18
Avg. Distributed Flow, l/sq. m x s:             1.9

Media Spec. Surf. Area, sq.m/cu. m:           137.8
Onda % Wetted Area:                              31
Water Temp., C:          11.5         D10/DT:  .956
Infl. COD, mg/l:                                 91
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                     VSS, mg/l:
pH:                      Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent             Oxidized         10  C
Depth    Concentration        Nitrogen         Nit. Rate
  m        mg/l               mg/l             kg/d sq.m
                                               tot. sur-
                                               face area

0-2.4    NH4-N           6.6                          0
         TKN            11.2                          0
         NO2+NO3         9.7                          0
         Filt. TKN                                    0
2.4-4.9  NH4-N                                        0
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
0-4.88   NH4-N           6.6         4.1       .0002941
         TKN            11.2        -2.3       -.000165
         NO2+NO3         9.7         1.5       .0001076
         Filt. TKN                                    0
```

Source: AMES NIT.TOWER INFL/EFFL   Date: 040686
Avg. Total Flow, l/ sq. m x s: .568
Recycle, percent total flow: 24
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 12.4   D10/DT: .931
Infl. COD, mg/l: 98
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	7.6		0
	TKN	11.3		0
	NO2+NO3			0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	7.6	5.1	.0003465
	TKN	11.3	-1.7	-.0001155
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    040786
Avg. Total Flow, l/ sq. m x s:                .577
Recycle, percent total flow:                    25
Periodic Dosing Cycle, sec:                     59
Distribution Time, sec/cycle:                   18
Avg. Distributed Flow, l/sq. m x s:            1.9

Media Spec. Surf. Area, sq.m/cu. m:          137.8
Onda % Wetted Area:                             31
Water Temp., C:        12.8        D10/DT:    .919
Infl. COD, mg/l:                               101
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media      Influent            Oxidized         10  C
Depth     Concentration        Nitrogen         Nit. Rate
  m         mg/l               mg/l             kg/d sq.m
                                                tot. sur-
                                                face area

0-2.4      NH4-N          10.6                          0
           TKN              13                          0
           NO2+NO3        10.9                          0
           Filt. TKN                                    0
2.4-4.9    NH4-N                                        0
           TKN                                          0
           NO2+NO3                                      0
           Filt. TKN                                    0
0-4.88     NH4-N          10.6       6.7         .0004565
           TKN              13       2.3         .0001567
           NO2+NO3        10.9       5.4         .0003679
           Filt. TKN                                    0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 040986
Avg. Total Flow, l/ sq. m x s: .574
Recycle, percent total flow: 26
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 11 D10/DT: .971
Infl. COD, mg/l: 103
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 52 VSS, mg/l: 40
pH: Infl. Alk, mg CaCO3/l: 169
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	15.7		0
	TKN	17.3		0
	NO2+NO3	11.9		0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	15.7	7.6	.0005442
	TKN	17.3	-1.4	-.0001003
	NO2+NO3	11.9	4.1	.0002936
	Filt. TKN			0

Source: AMES NIT.TOWER INFL/EFFL Date: 041086
Avg. Total Flow, l/ sq. m x s: .529
Recycle, percent total flow: 20
Periodic Dosing Cycle, sec: 59
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 11.9 D10/DT: .945
Infl. COD, mg/l: 151
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 49 VSS, mg/l: 38
pH: Infl. Alk, mg CaCO3/l: 192
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	12.7		0
	TKN	14.7		0
	NO2+NO3	10.2		0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	12.7	8.3	.0005331
	TKN	14.7	3.1	.0001991
	NO2+NO3	10.2	6.4	.0004111
	Filt. TKN			0

Source: AMES NIT.TOWER INFL/EFFL		Date:	041086
Avg. Total Flow, l/ sq. m x s:			.589
Recycle, percent total flow:			28
Periodic Dosing Cycle, sec:			59
Distribution Time, sec/cycle:			18
Avg. Distributed Flow, l/sq. m x s:			1.9
Media Spec. Surf. Area, sq.m/cu. m:			137.8
Onda % Wetted Area:			31
Water Temp., C:	13	D10/DT:	.913
Infl. COD, mg/l:			108
Infl. Filt. COD, mg/l:			
Infl. BOD5, mg/l:			
Infl. Filt. BOD5, mg/l:			
SS, mg/l:	54	VSS, mg/l:	44
pH:		Infl. Alk, mg CaCO3/l:	170
Infl. D. O., mg/l:			

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	20.1		0
	TKN	22.8		0
	NO2+NO3	8.7		0
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N	20.1	4.4	.000304
	TKN	22.8	3.8	.0002626
	NO2+NO3	8.7	4.8	.0003316
	Filt. TKN			0

```
Source: AMES NIT.TOWER INFL/EFFL   Date:   041086
Avg. Total Flow, l/ sq. m x s:                    .571
Recycle, percent total flow:                        26
Periodic Dosing Cycle, sec:                         59
Distribution Time, sec/cycle:                       18
Avg. Distributed Flow, l/sq. m x s:                1.9

Media Spec. Surf. Area, sq.m/cu. m:              137.8
Onda % Wetted Area:                                 31
Water Temp., C:        12.3         D10/DT:       .934
Infl. COD, mg/l:                                   122
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media     Influent             Oxidized          10  C
Depth     Concentration        Nitrogen          Nit. Rate
  m         mg/l               mg/l              kg/d sq.m
                                                 tot. sur-
                                                 face area

0-2.4     NH4-N          13.5                            0
          TKN            17.6                            0
          NO2+NO3         8.8                            0
          Filt. TKN                                      0
2.4-4.9   NH4-N                                          0
          TKN                                            0
          NO2+NO3                                        0
          Filt. TKN                                      0
0-4.88    NH4-N          13.5          4          .0002741
          TKN            17.6        -.3         -.0000206
          NO2+NO3         8.8        5.4            .00037
          Filt. TKN                                      0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    041186
Avg. Total Flow, l/ sq. m x s:                 .578
Recycle, percent total flow:                     27
Periodic Dosing Cycle, sec:                      59
Distribution Time, sec/cycle:                    18
Avg. Distributed Flow, l/sq. m x s:             1.9

Media Spec. Surf. Area, sq.m/cu. m:           137.8
Onda % Wetted Area:                              31
Water Temp., C:         13.4        D10/DT:    .902
Infl. COD, mg/l:                                 95
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:         80         VSS, mg/l:          72
pH:                  Infl. Alk, mg CaCO3/l:     184
Infl. D. O., mg/l:

Media     Influent             Oxidized        10  C
Depth     Concentration        Nitrogen        Nit. Rate
  m         mg/l               mg/l            kg/d sq.m
                                               tot. sur-
                                               face area

0-2.4     NH4-N          11.8                          0
          TKN            13.7                          0
          NO2+NO3         9.8                          0
          Filt. TKN                                    0
2.4-4.9   NH4-N                                        0
          TKN                                          0
          NO2+NO3                                      0
          Filt. TKN                                    0
0-4.88    NH4-N          11.8       6.2         .0004153
          TKN            13.7       3.3         .0002211
          NO2+NO3         9.8       5.2         .0003483
          Filt. TKN                                    0
```

```
Source:  AMES NIT.TOWER INFL/EFFL    Date:    041186
Avg. Total Flow, l/ sq. m x s:                   .578
Recycle, percent total flow:                       27
Periodic Dosing Cycle, sec:                        59
Distribution Time, sec/cycle:                      18
Avg. Distributed Flow, l/sq. m x s:               1.9

Media Spec. Surf. Area, sq.m/cu. m:             137.8
Onda % Wetted Area:                                31
Water Temp., C:           13        D10/DT:      .913
Infl. COD, mg/l:                                   96
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent             Oxidized         10  C
Depth    Concentration        Nitrogen         Nit. Rate
  m        mg/l               mg/l             kg/d sq.m
                                               tot. sur-
                                               face area

0-2.4    NH4-N          8.7                            0
         TKN             12                            0
         NO2+NO3        9.2                            0
         Filt. TKN                                     0
2.4-4.9  NH4-N                                         0
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0
0-4.88   NH4-N          8.7        4            .0002712
         TKN             12      1.6            .0001085
         NO2+NO3        9.2      4.7            .0003187
         Filt. TKN                                     0
```

```
Source:  AMES NIT.TOWER INFL/EFFL    Date:     041686
Avg. Total Flow, l/ sq. m x s:                         .56
Recycle, percent total flow:                            28
Periodic Dosing Cycle, sec:                             53
Distribution Time, sec/cycle:                           17
Avg. Distributed Flow, l/sq. m x s:                    1.8

Media Spec. Surf. Area, sq.m/cu. m:                  137.8
Onda % Wetted Area:                                     31
Water Temp., C:        13.2         D10/DT:           .907
Infl. COD, mg/l:                                       133
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:        40         VSS, mg/l:                  28
pH:                  Infl. Alk, mg CaCO3/l:            173
Infl. D. O., mg/l:


Media    Influent              Oxidized              10  C
Depth    Concentration         Nitrogen              Nit. Rate
  m        mg/l                mg/l                  kg/d sq.m
                                                     tot. sur-
                                                     face area

0-2.4    NH4-N          19.2        2.2              .0002871
         TKN            25.2        2.8              .0003655
         NO2+NO3        10.1        3.1              .0004046
         Filt. TKN                                          0
2.4-4.9  NH4-N            17        2.7              .0003524
         TKN            22.4       -7.9             -.0010311
         NO2+NO3        13.2        1.6              .0002088
         Filt. TKN                                          0
0-4.88   NH4-N          19.2        4.9              .0003198
         TKN            25.2       -5.1             -.0003328
         NO2+NO3        10.1        4.7              .0003067
         Filt. TKN                                          0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 041786
Avg. Total Flow, l/ sq. m x s: .565
Recycle, percent total flow: 29
Periodic Dosing Cycle, sec: 53
Distribution Time, sec/cycle: 17
Avg. Distributed Flow, l/sq. m x s: 1.8

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 31
Water Temp., C: 15.1 D10/DT: .853
Infl. COD, mg/l: 91
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 44 VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l: 178
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	25	4	.0004954
	TKN	28.2	4.9	.0006068
	NO2+NO3	8.3	5.5	.0006811
	Filt. TKN			0
2.4-4.9	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0-4.88	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    041786
Avg. Total Flow, l/ sq. m x s:                 .563
Recycle, percent total flow:                     29
Periodic Dosing Cycle, sec:                      53
Distribution Time, sec/cycle:                    17
Avg. Distributed Flow, l/sq. m x s:             1.8

Media Spec. Surf. Area, sq.m/cu. m:           137.8
Onda % Wetted Area:                              31
Water Temp., C:         15.1        D10/DT:    .853
Infl. COD, mg/l:                                154
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent            Oxidized         10  C
Depth    Concentration       Nitrogen         Nit. Rate
  m        mg/l              mg/l             kg/d sq.m
                                              tot. sur-
                                              face area

0-2.4    NH4-N          21.2                          0
         TKN            26.6                          0
         NO2+NO3         9.2                          0
         Filt. TKN                                    0
2.4-4.9  NH4-N                                        0
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
0-4.88   NH4-N          21.2       4.7           .00029
         TKN            26.6     -11.8        -.0007281
         NO2+NO3         9.2       6.7         .0004134
         Filt. TKN                                    0
```

```
Source:  AMES NIT.TOWER INFL/EFFL   Date:    041886
Avg. Total Flow, l/ sq. m x s:                  .574
Recycle, percent total flow:                      29
Periodic Dosing Cycle, sec:                       53
Distribution Time, sec/cycle:                     17
Avg. Distributed Flow, l/sq. m x s:              1.8

Media Spec. Surf. Area, sq.m/cu. m:            137.8
Onda % Wetted Area:                               31
Water Temp., C:        14.9         D10/DT:     .859
Infl. COD, mg/l:                                  93
Infl. Filt. COD, mg/l:                            53
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:        47        VSS, mg/l:
pH:                   Infl. Alk, mg CaCO3/l:     160
Infl. D. O., mg/l:


Media    Influent            Oxidized          10  C
Depth    Concentration       Nitrogen          Nit. Rate
  m        mg/l              mg/l              kg/d sq.m
                                               tot. sur-
                                               face area

0-2.4    NH4-N           18.1       4.7         .0005955
         TKN             22.1       2.1         .0002661
         NO2+NO3          9.4       2.7         .0003421
         Filt. TKN                                     0
2.4-4.9  NH4-N           13.4       2.4         .0003041
         TKN               20       -.5        -.0000634
         NO2+NO3         12.1       1.3         .0001647
         Filt. TKN                                     0
0-4.88   NH4-N           18.1       7.1         .0004498
         TKN             22.1       1.6         .0001014
         NO2+NO3          9.4         4         .0002534
         Filt. TKN                                     0
```

```
Source:  AMES NIT.TOWER INFL/EFFL    Date:        120386
Avg. Total Flow, l/ sq. m x s:                      .783
Recycle, percent total flow:                          0
Periodic Dosing Cycle, sec:                          50
Distribution Time, sec/cycle:                        23
Avg. Distributed Flow, l/sq. m x s:                 1.7

Media Spec. Surf. Area, sq.m/cu. m:               137.8
Onda % Wetted Area:                                  30
Water Temp., C:           13         D10/DT:       .913
Infl. COD, mg/l:                                     86
Infl. Filt. COD, mg/l:                               42
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                   Infl. Alk, mg CaCO3/l:        193
Infl. D. O., mg/l:


Media    Influent             Oxidized          10  C
Depth    Concentration        Nitrogen          Nit. Rate
  m        mg/l               mg/l              kg/d sq.m
                                                tot. sur-
                                                face area

0-2.4    NH4-N          11.6        .9           .0001653
         TKN            15.5      -2.8          -.0005144
         NO2+NO3         8.7       -.3          -.0000551
         Filt. TKN      12.8        .9           .0001653
2.4-4.9  NH4-N          10.7       2.7            .000496
         TKN            18.3       6.5           .0011941
         NO2+NO3         8.4       4.3           .0007899
         Filt. TKN      11.9         3           .0005511
0-4.88   NH4-N          11.6       3.6           .0003307
         TKN            15.5       3.7           .0003398
         NO2+NO3         8.7         4           .0003674
         Filt. TKN      12.8       3.9           .0003582
```

Source: AMES NIT.TOWER INFL/EFFL Date: 120486
Avg. Total Flow, l/ sq. m x s: .775
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 41
Distribution Time, sec/cycle: 17
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 30
Water Temp., C: 12.5 D10/DT: .928
Infl. COD, mg/l: 82
Infl. Filt. COD, mg/l: 34
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: 7.9 Infl. Alk, mg CaCO3/l: 194
Infl. D. O., mg/l: 6

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	12.2	.6	.0001109
	TKN	15.9	1.3	.0002403
	NO2+NO3	7	3.7	.0006838
	Filt. TKN	13.6	.9	.0001663
2.4-4.9	NH4-N	11.6	2.9	.000536
	TKN	14.6	2.9	.000536
	NO2+NO3	10.7	.7	.0001294
	Filt. TKN	12.7	3.3	.0006099
0-4.88	NH4-N	12.2	3.5	.0003234
	TKN	15.9	4.2	.0003881
	NO2+NO3	7	4.4	.0004066
	Filt. TKN	13.6	4.2	.0003881

```
Source:  AMES NIT.TOWER INFL/EFFL    Date:     121686
Avg. Total Flow, l/ sq. m x s:                   1.17
Recycle, percent total flow:                       38
Periodic Dosing Cycle, sec:                        35
Distribution Time, sec/cycle:                      18
Avg. Distributed Flow, l/sq. m x s:               2.3

Media Spec. Surf. Area, sq.m/cu. m:             137.8
Onda % Wetted Area:                                33
Water Temp., C:        14.2          D10/DT:     .879
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                     VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:


Media    Influent            Oxidized          10  C
Depth    Concentration       Nitrogen          Nit. Rate
  m        mg/l              mg/l              kg/d sq.m
                                               tot. sur-
                                               face area

0-2.4    NH4-N           11.3       .2          .0000529
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0
2.4-4.9  NH4-N           11.1        1          .0002643
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0
0-4.88   NH4-N           11.3      1.2          .0001586
         TKN                                           0
         NO2+NO3                                       0
         Filt. TKN                                     0
```

Source: AMES NIT.TOWER INFL/EFFL Date: 121786
Avg. Total Flow, l/ sq. m x s: 1.16
Recycle, percent total flow: 38
Periodic Dosing Cycle, sec: 36
Distribution Time, sec/cycle: 18
Avg. Distributed Flow, l/sq. m x s: 2.3

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 33
Water Temp., C: 14 D10/DT: .885
Infl. COD, mg/l: 73
Infl. Filt. COD, mg/l: 44
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	9.7	.3	.0000791
	TKN	13.9	.6	.0001583
	NO2+NO3	11.6	-.1	-.0000264
	Filt. TKN	11.4		0
2.4-4.9	NH4-N	9.4	.9	.0002374
	TKN	13.3	.3	.0000791
	NO2+NO3	11.5	1.5	.0003957
	Filt. TKN			0
0-4.88	NH4-N	9.7	1.2	.0001583
	TKN	13.9	.9	.0001187
	NO2+NO3	11.6	1.4	.0001847
	Filt. TKN	11.4	1.8	.0002374

```
Source:  AMES NIT.TOWER INFL/EFFL   Date: 1218-121986
Avg. Total Flow, l/ sq. m x s:                    1.137
Recycle, percent total flow:                         38
Periodic Dosing Cycle, sec:                          37
Distribution Time, sec/cycle:                        18
Avg. Distributed Flow, l/sq. m x s:                 2.3

Media Spec. Surf. Area, sq.m/cu. m:               137.8
Onda % Wetted Area:                                  33
Water Temp., C:        13.7         D10/DT:        .893
Infl. COD, mg/l:                                     71
Infl. Filt. COD, mg/l:                               45
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media    Influent          Oxidized          10  C
Depth    Concentration     Nitrogen          Nit. Rate
  m        mg/l            mg/l              kg/d sq.m
                                             tot. sur-
                                             face area

0-2.4    NH4-N          9.9       .4          .0001044
         TKN           14.6        1          .0002609
         NO2+NO3       10.1       .4          .0001044
         Filt. TKN     11.8                          0
2.4-4.9  NH4-N          9.5       .7          .0001826
         TKN           13.6       .6          .0001565
         NO2+NO3       10.5      1.3          .0003392
         Filt. TKN                                   0
0-4.88   NH4-N          9.9      1.1          .0001435
         TKN           14.6      1.6          .0002087
         NO2+NO3       10.1      1.7          .0002218
         Filt. TKN     11.8      1.5          .0001957
```

Source: AMES NIT.TOWER INFL/EFFL Date: 012587
Avg. Total Flow, l/ sq. m x s: 1.271
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.271

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 27
Water Temp., C: 11 D10/DT: .971
Infl. COD, mg/l: 120
Infl. Filt. COD, mg/l: 49
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 48 VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l: 157
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	10.6	1.1	.0003488
	TKN	16.8	3	.0009514
	NO2+NO3	7.4	1.7	.0005391
	Filt. TKN	13.1	1.1	.0003488
2.4-4.9	NH4-N	9.5	1.9	.0006026
	TKN	13.8	1.9	.0006026
	NO2+NO3	9.1	3	.0009514
	Filt. TKN	12	2.3	.0007294
0-4.88	NH4-N	10.6	3	.0004757
	TKN	16.8	4.9	.000777
	NO2+NO3	7.4	4.7	.0007453
	Filt. TKN	13.1	3.4	.0005391

Source: AMES NIT.TOWER INFL/EFFL Date: 012787
Avg. Total Flow, l/ sq. m x s: 1.243
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.243

Media Spec. Surf. Area, sq.m/cu. m: 137.8
Onda % Wetted Area: 26
Water Temp., C: 11.3 D10/DT: .962
Infl. COD, mg/l: 104
Infl. Filt. COD, mg/l: 50
Infl. BOD5, mg/l:
Infl. Filt. BOD5, mg/l:
SS, mg/l: 42 VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l: 159
Infl. D. O., mg/l:

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-2.4	NH4-N	10.8	1	.0003073
	TKN	16.6	3	.0009218
	NO2+NO3	7.2	1.5	.0004609
	Filt. TKN	12.8	.9	.0002765
2.4-4.9	NH4-N	9.8	2.5	.0007682
	TKN	13.6	2.2	.000676
	NO2+NO3	8.7	2.3	.0007067
	Filt. TKN	11.9	2.2	.000676
0-4.88	NH4-N	10.8	3.5	.0005377
	TKN	16.6	5.2	.0007989
	NO2+NO3	7.2	3.8	.0005838
	Filt. TKN	12.8	3.1	.0004763

Ames WPCP

Pretreatment Tower Data

```
Source:  AMES PRETREATMENT TOWER     Date:     071486
Avg. Total Flow, l/ sq. m x s:                   1.37
Recycle, percent total flow:                        0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:              1.37

Media Spec. Surf. Area, sq.m/cu. m:                98
Onda % Wetted Area:                                33
Water Temp., C:          21         D10/DT:      .723
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                  11
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:      5.4

Media     Influent          Oxidized         10  C
Depth     Concentration     Nitrogen         Nit. Rate
  m         mg/l            mg/l             kg/d sq.m
                                             tot. sur-
                                             face area

0-1.2     NH4-N            5.3      .7        .0005009
          TKN                                        0
          NO2+NO3                                    0
          Filt. TKN                                  0
1.2-2.4   NH4-N            4.6      .9         .000644
          TKN                                        0
          NO2+NO3                                    0
          Filt. TKN                                  0
0.0-2.44  NH4-N            5.3     1.6        .0005726
          TKN                                        0
          NO2+NO3                                    0
          Filt. TKN                                  0
```

Source: AMES PRETREATMENT TOWER Date: 071486
Avg. Total Flow, l/ sq. m x s: 1.37
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.37

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 33
Water Temp., C: 22 D10/DT: .705
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l: 11
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	2.6	.7	.0004884
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	1.9	.9	.000628
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	2.6	1.6	.0005584
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 072186
Avg. Total Flow, l/ sq. m x s: 1.41
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.41

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 33
Water Temp., C: 22.5 D10/DT: .695
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l: 12
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	5	1.1	.0007788
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	3.9	.9	.0006372
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	5	2	.0007082
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 072286
Avg. Total Flow, l/ sq. m x s: 1.43
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.43

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 33
Water Temp., C: 23.5 D10/DT: .677
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l: 12
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 4.9

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	8.5	1.2	.0008393
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	7.3	.7	.0004896
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	8.5	1.9	.0006646
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES PRETREATMENT TOWER    Date:    072386
Avg. Total Flow, l/ sq. m x s:                 1.37
Recycle, percent total flow:                      0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:            1.37

Media Spec. Surf. Area, sq.m/cu. m:              98
Onda % Wetted Area:                              33
Water Temp., C:        24.5        D10/DT:     .658
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                15
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:      4.6

Media     Influent             Oxidized         10  C
Depth     Concentration        Nitrogen         Nit. Rate
  m         mg/l               mg/l             kg/d sq.m
                                                tot. sur-
                                                face area

0-1.2     NH4-N            6.4          .6      .0003908
          TKN                                          0
          NO2+NO3                                      0
          Filt. TKN                                    0
1.2-2.4   NH4-N            5.8          .7      .0004559
          TKN                                          0
          NO2+NO3                                      0
          Filt. TKN                                    0
0.0-2.44  NH4-N            6.4         1.3      .0004234
          TKN                                          0
          NO2+NO3                                      0
          Filt. TKN                                    0
```

```
Source:  AMES PRETREATMENT TOWER     Date:     073086
Avg. Total Flow, l/ sq. m x s:                     1.9
Recycle, percent total flow:                         0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:                1.9

Media Spec. Surf. Area, sq.m/cu. m:                 98
Onda % Wetted Area:                                 36
Water Temp., C:        22.5         D10/DT:       .695
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                   18
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:        5


Media    Influent            Oxidized           10  C
Depth    Concentration       Nitrogen           Nit. Rate
  m        mg/l              mg/l               kg/d sq.m
                                                tot. sur-
                                                face area

0-1.2    NH4-N          3.9       1.1          .0010494
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
1.2-2.4  NH4-N          2.8        .4          .0003816
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
0.0-2.44 NH4-N          3.9       1.5          .0007157
         TKN                                          0
         NO2+NO3                                      0
         Filt. TKN                                    0
```

Source: AMES PRETREATMENT TOWER Date: 073086
Avg. Total Flow, l/ sq. m x s: 1.91
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.91

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 36
Water Temp., C: 24.2 D10/DT: .663
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l: 18
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 4.7

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	6.9	1.2	.0010978
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	5.7	1.1	.0010063
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	6.9	2.3	.0010524
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 073086
Avg. Total Flow, l/ sq. m x s: 1.9
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.9

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 36
Water Temp., C: 24.3 D10/DT: .661
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l: 18
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 4.7

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	4.1	1.2	.0010888
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	2.9	1	.0009073
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	4.1	2.2	.0009983
	TKN			0
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES PRETREATMENT TOWER    Date:    073186
Avg. Total Flow, l/ sq. m x s:                   1.89
Recycle, percent total flow:                        0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:              1.89

Media Spec. Surf. Area, sq.m/cu. m:                98
Onda % Wetted Area:                                36
Water Temp., C:           22         D10/DT:     .705
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                  20
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:         5

Media    Influent          Oxidized          10  C
Depth    Concentration     Nitrogen          Nit. Rate
  m        mg/l            mg/l              kg/d sq.m
                                             tot. sur-
                                             face area

0-1.2    NH4-N           .8       .5        .0004813
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
1.2-2.4  NH4-N           .3       .1        .0000963
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
0.0-2.44 NH4-N           .8       .6        .0002889
         TKN                                       0
         NO2+NO3                                   0
         Filt. TKN                                 0
```

```
Source:  AMES PRETREATMENT TOWER    Date:    073186
Avg. Total Flow, l/ sq. m x s:                    1.9
Recycle, percent total flow:                        0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:               1.9

Media Spec. Surf. Area, sq.m/cu. m:                98
Onda % Wetted Area:                                36
Water Temp., C:        22.5         D10/DT:      .695
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                  20
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                   Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:      4.9

Media     Influent              Oxidized           10  C
Depth     Concentration         Nitrogen           Nit. Rate
  m         mg/l                mg/l               kg/d sq.m
                                                   tot. sur-
                                                   face area

0-1.2     NH4-N            8.6       1.2           .0011448
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
1.2-2.4   NH4-N            7.4       1.1           .0010494
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
0.0-2.44  NH4-N            8.6       2.3           .0010974
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
```

```
Source:  AMES PRETREATMENT TOWER     Date:     111186
Avg. Total Flow, l/ sq. m x s:                   1.72
Recycle, percent total flow:                        0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:              1.72

Media Spec. Surf. Area, sq.m/cu. m:                98
Onda % Wetted Area:                                34
Water Temp., C:         16.3         D10/DT:     .827
Infl. COD, mg/l:                                   92
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                  35
Infl. Filt. BOD5, mg/l:
SS, mg/l:                  VSS, mg/l:
pH:                  Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:      5.1

Media     Influent             Oxidized         10  C
Depth     Concentration        Nitrogen         Nit. Rate
  m         mg/l               mg/l             kg/d sq.m
                                                tot. sur-
                                                face area

0-1.2     NH4-N           19.7        .8         .0008221
          TKN             22.3                          0
          NO2+NO3                                       0
          Filt. TKN                                     0
1.2-2.4   NH4-N           18.9       1.8         .0018498
          TKN                                           0
          NO2+NO3                                       0
          Filt. TKN                                     0
0.0-2.44  NH4-N           19.7       2.6         .0013363
          TKN             22.3      -1.1        -.0005654
          NO2+NO3                                       0
          Filt. TKN                                     0
```

Source: AMES PRETREATMENT TOWER Date: 111286
Avg. Total Flow, l/ sq. m x s: 1.72
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.72

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 13.2 D10/DT: .907
Infl. COD, mg/l: 181
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l: 38
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5.3

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	17.2	.1	.0001127
	TKN	20.4	.5	.0005635
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	17.1	1.2	.0013525
	TKN	19.9	.5	.0005635
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	17.2	1.3	.0007328
	TKN	20.4	1	.0005637
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 111386
Avg. Total Flow, l/ sq. m x s: 1.7
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.7

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 15.8 D10/DT: .838
Infl. COD, mg/l: 121
Infl. Filt. COD, mg/l: 47
Infl. BOD5, mg/l: 40
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5.2

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	14.2	-.7	-.0007204
	TKN	20.6	-1.3	-.001338
	NO2+NO3	4.6		0
	Filt. TKN			0
1.2-2.4	NH4-N	14.9	-1.3	-.001338
	TKN	21.9	-.9	-.0009263
	NO2+NO3			0
	Filt. TKN	16.8		0
0.0-2.44	NH4-N	14.2	-2	-.0010295
	TKN	20.6	-2.2	-.0011324
	NO2+NO3	4.6	.9	.0004633
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 111986
Avg. Total Flow, l/ sq. m x s: 1.66
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.66

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 15.5 D10/DT: .845
Infl. COD, mg/l: 84
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l: 40
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 4.7

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	19	0	0
	TKN	27.1	.9	.000912
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	19	2	.0020268
	TKN	26.2	2.3	.0023308
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	19	2	.0010137
	TKN	27.1	3.2	.0016219
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 112186
Avg. Total Flow, l/ sq. m x s: 1.63
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.63

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 14.8 D10/DT: .862
Infl. COD, mg/l: 80
Infl. Filt. COD, mg/l: 33
Infl. BOD5, mg/l: 51
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 4.9

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	11.7		0
	TKN	20.2		0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	11.7	0	0
	TKN	20.2	-.8	-.0004061
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 112586
Avg. Total Flow, l/ sq. m x s: 1.64
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.64

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 15.2 D10/DT: .851
Infl. COD, mg/l: 138
Infl. Filt. COD, mg/l: 25
Infl. BOD5, mg/l: 43
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 4.5

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	14.8	-.3	-.0003025
	TKN	19.3		0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N	15.1	3	.0030248
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	14.8	2.7	.0013616
	TKN	19.3	2.9	.0014624
	NO2+NO3			0
	Filt. TKN			0

```
Source:  AMES PRETREATMENT TOWER     Date:     113086
Avg. Total Flow, l/ sq. m x s:                   1.79
Recycle, percent total flow:                        0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:              1.79

Media Spec. Surf. Area, sq.m/cu. m:                98
Onda % Wetted Area:                                34
Water Temp., C:        13.2          D10/DT:     .907
Infl. COD, mg/l:                                  106
Infl. Filt. COD, mg/l:                             60
Infl. BOD5, mg/l:                                  43
Infl. Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                    Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:     6.8


Media     Influent             Oxidized           10  C
Depth     Concentration        Nitrogen           Nit. Rate
  m         mg/l               mg/l               kg/d sq.m
                                                  tot. sur-
                                                  face area

0-1.2     NH4-N          11.7                             0
          TKN            15.8                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
1.2-2.4   NH4-N                                           0
          TKN                                             0
          NO2+NO3                                         0
          Filt. TKN                                       0
0.0-2.44  NH4-N          11.7      1.6             .0009386
          TKN            15.8      3.7             .0021705
          NO2+NO3                                         0
          Filt. TKN                                       0
```

```
Source:  AMES PRETREATMENT TOWER    Date:    120186
Avg. Total Flow, l/ sq. m x s:                        1.81
Recycle, percent total flow:                           0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:                   1.81

Media Spec. Surf. Area, sq.m/cu. m:                     98
Onda % Wetted Area:                                     34
Water Temp., C:        14.8          D10/DT:          .862
Infl. COD, mg/l:                                       102
Infl. Filt. COD, mg/l:                                  49
Infl. BOD5, mg/l:                                       41
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:      5.6


Media     Influent           Oxidized         10  C
Depth     Concentration      Nitrogen         Nit. Rate
  m         mg/l             mg/l             kg/d sq.m
                                              tot. sur-
                                              face area

0-1.2     NH4-N         14.9                           0
          TKN            20                            0
          NO2+NO3                                      0
          Filt. TKN                                    0
1.2-2.4   NH4-N                                        0
          TKN                                          0
          NO2+NO3                                      0
          Filt. TKN                                    0
0.0-2.44  NH4-N         14.9        3          .0016912
          TKN            20        3.9         .0021986
          NO2+NO3         4        5.1         .0028751
          Filt. TKN                                    0
```

Source: AMES PRETREATMENT TOWER Date: 120386
Avg. Total Flow, l/ sq. m x s: 1.78
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.78

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 13 D10/DT: .913
Infl. COD, mg/l:
Infl. Filt. COD, mg/l: 34
Infl. BOD5, mg/l: 42
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5.8

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	17.6		0
	TKN	22.2		0
	NO2+NO3	6		0
	Filt. TKN			0
1.2-2.4	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	17.6	2.5	.001468
	TKN	22.2	3.8	.0022314
	NO2+NO3	6	3.4	.0019965
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 011987
Avg. Total Flow, l/ sq. m x s: 1.77
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.77

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 12.9 D10/DT: .916
Infl. COD, mg/l: 119
Infl. Filt. COD, mg/l: 42
Infl. BOD5, mg/l: 45
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5.7

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	18.8		0
	TKN	22.8		0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	18.8	2.3	.0013474
	TKN	22.8	1.5	.0008787
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 012587
Avg. Total Flow, 1/ sq. m x s: 1.75
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, 1/sq. m x s: 1.75

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 12.5 D10/DT: .928
Infl. COD, mg/l: 166
Infl. Filt. COD, mg/l: 66
Infl. BOD5, mg/l: 56
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 5.7

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	14.2		0
	TKN	22.2		0
	NO2+NO3			0
	Filt. TKN			0
1.2-2.4	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	14.2	2.2	.0012909
	TKN	22.2	3.2	.0018777
	NO2+NO3			0
	Filt. TKN			0

Source: AMES PRETREATMENT TOWER Date: 012587
Avg. Total Flow, l/ sq. m x s: 1.75
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.75

Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 34
Water Temp., C: 12 D10/DT: .942
Infl. COD, mg/l: 157
Infl. Filt. COD, mg/l: 48
Infl. BOD5, mg/l: 52
Infl. Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l: 6.2

Media Depth m	Influent Concentration mg/l		Oxidized Nitrogen mg/l	10 C Nit. Rate kg/d sq.m tot. surface area
0-1.2	NH4-N	11.9		0
	TKN	19		0
	NO2+NO3	4		0
	Filt. TKN	13.7		0
1.2-2.4	NH4-N			0
	TKN			0
	NO2+NO3			0
	Filt. TKN			0
0.0-2.44	NH4-N	11.9	2.1	.0012509
	TKN	19	4.4	.0026208
	NO2+NO3	4	4.5	.0026804
	Filt. TKN	13.7	1.9	.0011317

```
Source:  AMES PRETREATMENT TOWER     Date:     012787
Avg. Total Flow, l/ sq. m x s:                          1.76
Recycle, percent total flow:                               0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:                     1.76

Media Spec. Surf. Area, sq.m/cu. m:                       98
Onda % Wetted Area:                                       34
Water Temp., C:          12           D10/DT:           .942
Infl. COD, mg/l:                                         164
Infl. Filt. COD, mg/l:                                    56
Infl. BOD5, mg/l:                                         47
Infl. Filt. BOD5, mg/l:
SS, mg/l:                    VSS, mg/l:
pH:                     Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:      5.7


Media     Influent             Oxidized             10  C
Depth     Concentration        Nitrogen             Nit. Rate
  m         mg/l               mg/l                 kg/d sq.m
                                                    tot. sur-
                                                    face area

0-1.2     NH4-N          11.7                               0
          TKN              20                               0
          NO2+NO3         4.4                               0
          Filt. TKN      14.5                               0
1.2-2.4   NH4-N                                             0
          TKN                                               0
          NO2+NO3                                           0
          Filt. TKN                                         0
0.0-2.44  NH4-N          11.7         2.3           .0013778
          TKN              20         4.5           .0026957
          NO2+NO3         4.4         3.3           .0019769
          Filt. TKN      14.5         2.2           .0013179
```

Huxley WPCP
Oxygen-Limited Data,
Winter of 1986

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Source:  HUXLEY WPCP INFL/EFFL        Date:     022686
Avg. Total Flow, l/ sq. m x s:                    .249
Recycle, percent total flow:                         0



Media Spec. Surf. Area, sq.m/cu. m:                 98

Water Temp., C:         11.5         D10/DT:      .956
Infl. COD, mg/l:                                   133
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                   86
Infl. Filt. BOD5, mg/l:
SS, mg/l:       317         VSS, mg/l:
pH:             7.9   Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media      Influent            Oxidized             10  C
Depth      Concentration       Nitrogen             Nit. Rate
  m          mg/l              mg/l                 kg/d sq.m
                                                    tot. sur-
                                                    face area

0-4.27     NH4-N          17.3      15.2             .0007469
           TKN            26.7      18.9             .0009287
           NO2+NO3         6.1       1.6             .0000786
```

```
Source:  HUXLEY WPCP INFL/EFFL        Date:    031886
Avg. Total Flow, l/ sq. m x s:                    .401
Recycle, percent total flow:                         0



Media Spec. Surf. Area, sq.m/cu. m:                 98

Water Temp., C:         13.2        D10/DT:       .907
Infl. COD, mg/l:
Infl. Filt. COD, mg/l:
Infl. BOD5, mg/l:                                   25
Infl. Filt. BOD5, mg/l:
SS, mg/l:        35          VSS, mg/l:
pH:              7.8   Infl. Alk, mg CaCO3/l:
Infl. D. O., mg/l:

Media      Influent             Oxidized            10  C
Depth      Concentration        Nitrogen            Nit. Rate
  m          mg/l               mg/l                kg/d sq.m
                                                    tot. sur-
                                                    face area

0-4.27     NH4-N          9.8       4.6              .0003454
```

Data From
Duddles and Richardson (1973)
and
Baxter and Woodman, Inc. (1973)

Source: MIDLAND, MI

Sp. Surf. Area 89 sq.m/cu.m
Media Depth 6.55 m

Total applied hydraulic load l/sq.m s	Total applied ammonium conc. mg/l	Ammonium conc. change mg/l	Water temp. deg. C	10 C Nit. Rate, kg/d/sq.m tot. surf area
0.34 No Recycle	10.1	8.2	9.6	.00042
1.02 Recycle 67% of total	5.1	3.6	11.3	.00052
	6.6	5.2	18.2	.00062
	6.5	5.1	12.1	.00072
	6.5	3.2	9.5	.0005
	5.7	3.8	7.5	.00063
0.679 No Recycle	12.1	10.4	12.9	.00096
	13.0	10.5	17.5	.00084
	17.6	11.7	14.4	.00103
	15.6	9.3	8.0	.00101
1.36 No Recycle	13.1	8.1	16.1	.00136
1.41 Recycle 28% of total	11.5	8.1	18.3	.00132
1.07 Recycle 36% of total	11.3	7.9	19.1	.00126
1.02 Recycle 33% of total	12.2	6.1	7.3	.00102
0.822 Recycle 41% of total	9.9	7.2	6.5	.00099
	5.1	4.1	17.3	.0004

Source: MIDLAND, MI   Sp. Surf. Area 89 sq.m/cu.m
                               Media Depth 6.55 m

Total applied hydraulic load l/sq.m s	Total applied ammonium conc. mg/l	Ammonium conc. change mg/l	Water temp. deg. C	10 C Nit. Rate, kg/d/sq.m tot. surf area
0.482	7.5	6.3	7.2	.0005
No Recycle	8.1	6.9	10.4	.00049
	11.7	10.1	14.0	.00064
	12.5	10.4	15.5	.00063

Source: BLOOM TOWNSHIP, IL   Sp. Surf. Area 89 sq.m/cu.m
Media Depth 6.55 m

Total applied hydraulic load l/sq.m s	Total applied ammonium conc. mg/l	Ammonium conc. change mg/l	Water temp. deg. C	10 C Nit. Rate, kg/d/sq.m tot. surf area
0.767 Recycle 51% of total	5.4	4.6	23	.00036
	6.8	5.6	21	.00046
	7.3	6.0	21	.00048
	7.6	6.5	22	.00051
	6.4	5.6	21	.00045
0.373 No recycle	12.1	9.4	21	.00038
	16.3	12.0	20	.00049
	12.6	8.8	19	.00037
1.66 Recycle 51% of total	7.3	4.2	20	.00075
	11.2	5.4	20	.00097
	10.9	5.3	19	.00099
	8.4	5.3	19	.00098
	8.8	5.8	19	.00108
	8.2	4.2	20	.00076
	10.5	6.4	20	.00114
	10.3	3.2	18	.00062
2.78 Recycle 71% of total	8.5	3.3	19	.00104
	8.0	2.5	16	.00085
	12.1	3.1	16	.00106
	7.7	4.0	16	.00136
1.23 Recycle 69% of total	4.8	4.1	12	.0007
1.46 Recycle 58% of total	5.3	4.4	16	.00078
	5.6	4.2	15	.00077
	6.9	5.2	16	.00094
	7.9	5.6	18	.00095
	7.3	5.3	17	.00093
	5.3	3.6	14	.00068
	8.5	4.4	15	.00082
	9.1	3.7	14	.00071

Source: BLOOM TOWNSHIP, IL   Sp. Surf. Area 89 sq.m/cu.m
Media Depth 6.55 m

Total applied hydraulic load l/sq.m s	Total applied ammonium conc. mg/l	Ammonium conc. change mg/l	Water temp. deg. C	10 C Nit. Rate, kg/d/sq.m tot. surf area
1.70	5.0	2.6	12	.00061
Recycle	5.1	3.7	13	.00084
64% of	6.0	3.6	12	.00086
total	5.7	4.2	15	.00091
1.29	6.8	3.4	7	.00072
Recycle	4.8	3.8	8	.00077
66% of	4.8	3.5	5	.00079
total	5.3	3.3	4	.00079
	5.1	4.1	7	.00086
	4.9	3.8	6	.00084
0.81				
Recycle	7.8	7.0	11	.00082
50% of	7.8	6.7	9	.00084
total				
0.61	4.8	4.2	13	.00035
Recycle				
67% of				
total				
0.75				
Recycle	6.4	6.0	15	.00056
55% of				
total				
0.81	5.9	5.4	12	.00062
Recycle	5.6	4.9	9	.00061
50% of	5.9	5.4	8	.00069
total	5.9	5.5	9	.00068
	6.7	6.1	11	.00072

Data From
Parker and Richards (1985),
Richards (1984),
and
Richards and Reinhart (1986)

Source: Parker and Richards (1985) Date: 112482
Avg. Total Flow, l/ sq. m x s: .394
Recycle, percent total flow: 34
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .394
Media Depth, m: 2.44
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 23
Water Temp., C: 15 D10/DT: .856
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:
Filt. BOD5, mg/l: 50
SS, mg/l: VSS, mg/l:
pH: Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	18.5	1.8	.000219
NO2+NO3	0	0	0.000000
TKN			0.000000

Source: Parker and Richards (1985) Date: 112482
Avg. Total Flow, l/ sq. m x s: .394
Recycle, percent total flow: 34
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .394
Media Depth, m: 2.44
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 23
Water Temp., C: 14 D10/DT: .885
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:
Filt. BOD5, mg/l:
SS, mg/l: VSS, mg/l:
pH: Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	16.7	5	.000630
NO2+NO3	0	4.9	.000617
TKN			0.000000
0.45 micron Filt. TKN			

```
Source:  Parker and Richards (1985)  Date:    072585
Avg. Total Flow, l/ sq. m x s:                    .767
Recycle, percent total flow:                         0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:        >      .767
Media Depth, m:                                   2.44
Media Spec. Surf. Area, sq.m/cu. m:                 98
Onda % Wetted Area:                                 25
Water Temp., C:          25         D10/DT:       .649
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:
Filt. BOD5, mg/l:
SS, mg/l:                   VSS, mg/l:
pH:                         Alk, mg CaCO3/l:

Total Applied     Oxidized          10 C Nitrification
Influent Conc.    Nitrogen,         Rate, kg/d/sq. m
mg N/l            mg/l              total surface area

NH4
       10               5.7           .001025


NO2+NO3
       .6               4.1           .000737


TKN
                                     0.000000


0.45 micron
Filt. TKN
```

```
Source: Richards (1984)                        Period 1
Avg. Total Flow, l/ sq. m x s:                            .482
Recycle, percent total flow:                                 0
Periodic Dosing Cycle, sec:                                 12
Distribution Time, sec/cycle:                                6
Avg. Distributed Flow, l/sq. m x s:                        .96
Media Depth, m:                                            6.1
Media Spec. Surf. Area, sq.m/cu. m:                      137.8
Onda % Wetted Area:                                         26
Water Temp., C:          25           D10/DT:             .649
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l:                        43
Effluent BOD5, mg/l:                                        11
Effluent 1.5 micron filt. BOD5, mg/l:                        6
SS, mg/l:        11          VSS, mg/l:                      7
pH:               7          Alk, mg CaCO3/l:               21
```

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	8.6	8	.000257
NO2+NO3	1.5	7.7	.000248
TKN			0.000000
0.45 micron Filt. TKN			

```
Source: Richards (1984)                  Period 1
Avg. Total Flow, l/ sq. m x s:                        .475
Recycle, percent total flow:                             0
Periodic Dosing Cycle, sec:                             12
Distribution Time, sec/cycle:                            6
Avg. Distributed Flow, l/sq. m x s:                    .96
Media Depth, m:                                        6.1
Media Spec. Surf. Area, sq.m/cu. m:                  144.4
Onda % Wetted Area:                                     26
Water Temp., C:          25          D10/DT:          .649
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l:                    41
Effluent BOD5, mg/l:                                    15
Effluent 1.5 micron filt. BOD5, mg/l:                    7
SS, mg/l:       17          VSS, mg/l:                  11
pH:             7.2          Alk, mg CaCO3/l:           36

Total Applied     Oxidized          10 C Nitrification
Influent Conc.    Nitrogen,         Rate, kg/d/sq. m
mg N/l            mg/l              total surface area

NH4
      9.6                  8          .000242


NO2+NO3
                                     0.000000


TKN
                                     0.000000


0.45 micron
Filt. TKN
```

```
Source: Richards and Reinhart (1986)   Period 3
Avg. Total Flow, l/ sq. m x s:                        .472
Recycle, percent total flow:                             0
Periodic Dosing Cycle, sec:                             12
Distribution Time, sec/cycle:                            6
Avg. Distributed Flow, l/sq. m x s:                    .95
Media Depth, m:                                        6.1
Media Spec. Surf. Area, sq.m/cu. m:                     98
Onda % Wetted Area:                                     28
Water Temp., C:          21          D10/DT:          .723
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l:                    43
Effluent BOD5, mg/l:
Effluent 1.5 micron filt. BOD5, mg/l:                    8
SS, mg/l:       49          VSS, mg/l:                  36
pH:            7.2          Alk, mg CaCO3/l:            92

Total Applied       Oxidized           10 C Nitrification
Influent Conc.      Nitrogen,          Rate, kg/d/sq. m
mg N/l              mg/l               total surface area

NH4
     11.8                5               .000247


NO2+NO3
      .09              5.2               .000256


TKN
     15.1              3.9               .000192


0.45 micron
Filt. TKN
```

Source: Richards and Reinhart (1986) Period 3
Avg. Total Flow, l/ sq. m x s: .472
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 12
Distribution Time, sec/cycle: 6
Avg. Distributed Flow, l/sq. m x s: .95
Media Depth, m: 6.1
Media Spec. Surf. Area, sq.m/cu. m: 101
Onda % Wetted Area: 27
Water Temp., C: 21 D10/DT: .723
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l: 46
Effluent BOD5, mg/l:
Effluent 1.5 micron filt. BOD5, mg/l: 13
SS, mg/l: 49 VSS, mg/l: 36
pH: 7.2 Alk, mg CaCO3/l: 92

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
11.8	3.4	.000163
NO2+NO3		
.09	3.1	.000148
TKN		
15.1	2.4	.000115
0.45 micron Filt. TKN		

Source: Richards and Reinhart (1986) Period 1
Avg. Total Flow, l/ sq. m x s: 1
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1
Media Depth, m: 6.1
Media Spec. Surf. Area, sq.m/cu. m: 101
Onda % Wetted Area: 27
Water Temp., C: 18 D10/DT: .787
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l: 90
Effluent BOD5, mg/l: 38
Effluent 1.5 micron filt. BOD5, mg/l: 23
SS, mg/l: 59 VSS, mg/l: 44
pH: 7.2 Alk, mg CaCO3/l: 102

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	10.5	1.1	.000121
NO2+NO3	.03	.8	.000088
TKN	18.1	4.3	.000475
0.45 micron Filt. TKN			

Source: Richards and Reinhart (1986) Period 1
Avg. Total Flow, l/ sq. m x s: .389
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 12
Distribution Time, sec/cycle: 6
Avg. Distributed Flow, l/sq. m x s: .778
Media Depth, m: 3
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 26
Water Temp., C: 25 D10/DT: .649
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l: 48
Effluent BOD5, mg/l:
Effluent 1.5 micron filt. BOD5, mg/l: 17
SS, mg/l: 52 VSS, mg/l: 41
pH: 7.2 Alk, mg CaCO3/l: 101

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
11.4	2.7	.000200
NO2+NO3		
.04	1	.000074
TKN		
17.1	4	.000297
0.45 micron Filt. TKN		

Source: Richards and Reinhart (1986) Period 2

Avg. Total Flow, l/ sq. m x s:	.25
Recycle, percent total flow:	0
Periodic Dosing Cycle, sec:	12
Distribution Time, sec/cycle:	6
Avg. Distributed Flow, l/sq. m x s:	.5
Media Depth, m:	3
Media Spec. Surf. Area, sq.m/cu. m:	98
Onda % Wetted Area:	23
Water Temp., C: 21 D10/DT:	.723
COD, mg/l:	
Effluent 1.5 micron filt. COD, mg/l:	38
Effluent BOD5, mg/l:	
Effluent 1.5 micron filt. BOD5, mg/l:	12
SS, mg/l: 49 VSS, mg/l:	36
pH: 7.2 Alk, mg CaCO3/l:	92

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	11.8	4.3	.000228
NO2+NO3	.09	3.1	.000165
TKN	15.1	4.7	.000250
0.45 micron Filt. TKN			

Source: Richards and Reinhart (1986) Period 2

Avg. Total Flow, l/ sq. m x s: .25

Recycle, percent total flow: 0

Periodic Dosing Cycle, sec: 12

Distribution Time, sec/cycle: 6

Avg. Distributed Flow, l/sq. m x s: .5

Media Depth, m: 3

Media Spec. Surf. Area, sq.m/cu. m: 98

Onda % Wetted Area: 23

Water Temp., C: 21 D10/DT: .723

COD, mg/l:

Effluent 1.5 micron filt. COD, mg/l: 44

Effluent BOD5, mg/l:

Effluent 1.5 micron filt. BOD5, mg/l: 12

SS, mg/l: 49 VSS, mg/l: 36

pH: 7.2 Alk, mg CaCO3/l: 92

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
11.8	6	.000319
NO2+NO3		
.09	5.7	.000303
TKN		
15.1	5.7	.000303
0.45 micron Filt. TKN		

Source: Richards and Reinhart (1986) Period 5
Avg. Total Flow, l/ sq. m x s: .972
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .972
Media Depth, m: 6.1
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 28
Water Temp., C: 23.5 D10/DT: .677
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l: 32
Effluent BOD5, mg/l: 29
Effluent 1.5 micron filt. BOD5, mg/l: 10
SS, mg/l: 45 VSS, mg/l:
pH: 7 Alk, mg CaCO3/l: 94

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
8.1	1.2	.000114
NO2+NO3		
.5	1.3	.000124
TKN		
13.1	3.2	.000304
0.45 micron Filt. TKN		

Source: Richards and Reinhart (1986) Period 6
Avg. Total Flow, l/ sq. m x s: .667
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .667
Media Depth, m: 6.1
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 24
Water Temp., C: 20 D10/DT: .742
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l: 32
Effluent BOD5, mg/l: 25
Effluent 1.5 micron filt. BOD5, mg/l: 9
SS, mg/l: 45 VSS, mg/l:
pH: 7 Alk, mg CaCO3/l: 99

Total Applied Influent Conc. mg N/1	Oxidized Nitrogen, mg/1	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
12	3.1	.000222
NO2+NO3		
.2	1.9	.000136
TKN		
19	1.2	.000086
0.45 micron Filt. TKN		

Source: Richards and Reinhart (1986) Period 4
Avg. Total Flow, l/ sq. m x s: .25
Recycle, percent total flow: 0
Periodic Dosing Cycle, sec: 12
Distribution Time, sec/cycle: 6
Avg. Distributed Flow, l/sq. m x s: .5
Media Depth, m: 3
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 23
Water Temp., C: 23 D10/DT: .686
COD, mg/l:
Effluent 1.5 micron filt. COD, mg/l: 29
Effluent BOD5, mg/l: 32
Effluent 1.5 micron filt. BOD5, mg/l: 9
SS, mg/l: 50 VSS, mg/l:
pH: 7 Alk, mg CaCO3/l: 96

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
8.6	6.2	.000312
NO2+NO3		
.05	4.1	.000207
TKN		
12.9	7.7	.000388
0.45 micron Filt. TKN		

Data From
Sampayo (1973)
and
Sampayo and Metcalf (1984)

Source: Sampayo (1973) Date: 060472
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 50
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 6.55
Media Spec. Surf. Area, sq.m/cu. m: 88.6
Onda % Wetted Area: 24
Water Temp., C: 15.5 D10/DT: .845
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 7
Filt. BOD5, mg/l: 2
SS, mg/l: 9 VSS, mg/l:
pH: 7.7 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	5.5	5.2	.000444
NO2+NO3	8.9	7.7	.000658
TKN	8	6.5	.000555
0.45 micron Filt. TKN			

Source: Sampayo (1973) Date: 060572
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 50
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 6.55
Media Spec. Surf. Area, sq.m/cu. m: 88.6
Onda % Wetted Area: 24
Water Temp., C: 15.5 DIO/DT: .845
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 7
Filt. BOD5, mg/l: 3
SS, mg/l: 17 VSS, mg/l:
pH: 7.6 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	3.2	2.7	.000231
NO2+NO3	10.1	7.9	.000675
TKN	9.2	6.8	.000581
0.45 micron Filt. TKN			

Source: Sampayo (1973) Date: 060672
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 50
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 6.55
Media Spec. Surf. Area, sq.m/cu. m: 88.6
Onda % Wetted Area: 24
Water Temp., C: 15.5 D10/DT: .845
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 6
Filt. BOD5, mg/l: 3
SS, mg/l: 5 VSS, mg/l:
pH: 7.5 Alk, mg CaCO3/l:

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
5.5	5.3	.000453
NO2+NO3		
7.1	6.3	.000538
TKN		
7.4	6	.000513
0.45 micron Filt. TKN		

Source: Sampayo (1973) Date: 060772
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 50
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 6.55
Media Spec. Surf. Area, sq.m/cu. m: 88.6
Onda % Wetted Area: 24
Water Temp., C: 15.5 D10/DT: .845
COD, mg/l: 39
0.45 micron Filt. COD, mg/l: 31
BOD5, mg/l: 6
Filt. BOD5, mg/l: 1
SS, mg/l: 7 VSS, mg/l:
pH: 7.6 Alk, mg CaCO3/l:

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
6.7	6.5	.000555
NO2+NO3		
9.1	8.1	.000692
TKN		
7.4	6	.000513
0.45 micron Filt. TKN		

Source: Sampayo (1973) Date: 060882
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 50
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 6.55
Media Spec. Surf. Area, sq.m/cu. m: 88.6
Onda % Wetted Area: 24
Water Temp., C: 15.5 D10/DT: .845
COD, mg/l: 43
0.45 micron Filt. COD, mg/l: 31
BOD5, mg/l: 7
Filt. BOD5, mg/l:
SS, mg/l: 17 VSS, mg/l:
pH: 7.5 Alk, mg CaCO3/l:

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
7.2	7.1	.000606
NO2+NO3		
7.7	6.8	.000581
TKN		
10.2	8.8	.000752
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 060782
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 33
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 24
Water Temp., C: 19.2 D10/DT: .761
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:
Filt. BOD5, mg/l:
SS, mg/l: 20 VSS, mg/l:
pH: 7.6 Alk, mg CaCO3/l: 230

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
6.7	4.6	.000286
NO2+NO3		
7.2	4.2	.000262
TKN		
10.5	5.2	.000324
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 060882
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 33
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 24
Water Temp., C: 20.3 D10/DT: .736
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:
Filt. BOD5, mg/l:
SS, mg/l: 29 VSS, mg/l:
pH: 7.6 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	7.3	6	.000361
NO2+NO3	11.1	4	.000241
TKN	9.8	4.7	.000283
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 060982
Avg. Total Flow, l/ sq. m x s: .679
Recycle, percent total flow: 33
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: .679
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 24
Water Temp., C: 19.9 D10/DT: .744
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:
Filt. BOD5, mg/l:
SS, mg/l: 14 VSS, mg/l:
pH: 7.8 Alk, mg CaCO3/l: 226

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	4.1	2.9	.000177
NO2+NO3	5.2	1.9	.000116
TKN	6	2.2	.000134
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 080282
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.5 D10/DT: .695
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 5
Filt. BOD5, mg/l:
SS, mg/l: 11 VSS, mg/l:
pH: 7 Alk, mg CaCO3/l:

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
5	1.5	.000171
NO2+NO3		
7	2.1	.000239
TKN		
8.5	2.5	.000284
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 080682
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 24 D10/DT: .667
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 5
Filt. BOD5, mg/l:
SS, mg/l: 13 VSS, mg/l:
pH: 7 Alk, mg CaCO3/l:

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
5.6	3.7	.000404
NO2+NO3		
11.2	2.8	.000306
TKN		
8.7	2.3	.000251
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 080982
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.5 D10/DT: .695
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 5
Filt. BOD5, mg/l:
SS, mg/l: 6 VSS, mg/l:
pH: 6.8 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	6	3.7	.000421
NO2+NO3	7.9	4.2	.000478
TKN	8.1	4.1	.000466
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 081082
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.1 D10/DT: .703
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 7
Filt. BOD5, mg/l:
SS, mg/l: 18 VSS, mg/l:
pH: 6.9 Alk, mg CaCO3/l: 188

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	5.1	3.9	.000449
NO2+NO3	5.3	4.5	.000518
TKN	6.7	2.4	.000276
0.45 micron Filt. TKN			

```
Source:  Sampayo and Metcalf (1984) Date:    081182
Avg. Total Flow, l/ sq. m x s:                     1.358
Recycle, percent total flow:                          25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:                1.358
Media Depth, m:                                    7.315
Media Spec. Surf. Area, sq.m/cu. m:                   98
Onda % Wetted Area:                                   31
Water Temp., C:         22.1        D10/DT:         .703
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:                                            8
Filt. BOD5, mg/l:
SS, mg/l:        18        VSS, mg/l:
pH:             6.9        Alk, mg CaCO3/l:

Total Applied      Oxidized           10 C Nitrification
Influent Conc.    Nitrogen,          Rate, kg/d/sq. m
mg N/l             mg/l               total surface area

NH4
      5.6                 4.2           .000483


NO2+NO3
     10.1                 5.4           .000621


TKN
      8.6                 4.8           .000552


0.45 micron
Filt. TKN
```

Source: Sampayo and Metcalf (1984) Date: 081282
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.7 D10/DT: .691
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 5
Filt. BOD5, mg/l:
SS, mg/l: 8 VSS, mg/l:
pH: 7 Alk, mg CaCO3/l: 232

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	6.2	4.6	.000520
NO2+NO3	4.8	5.9	.000667
TKN	8.9	5.9	.000667
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 081382
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 23.2 D10/DT: .682
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 5
Filt. BOD5, mg/l:
SS, mg/l: 11 VSS, mg/l:
pH: 6.9 Alk, mg CaCO3/l:

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
5.8	4	.000446
NO2+NO3		
6.3	4.4	.000491
TKN		
9.5	4.4	.000491
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 093082
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.2 D10/DT: .701
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 9
Filt. BOD5, mg/l:
SS, mg/l: 36 VSS, mg/l:
pH: 7.1 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	6.1	3.3	.000379
NO2+NO3	6	4	.000459
TKN	9.5	-1.6	-.000184
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 100182
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.3 D10/DT: .699
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 8
Filt. BOD5, mg/l:
SS, mg/l: 37 VSS, mg/l:
pH: 7.1 Alk, mg CaCO3/l: 258

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	6.4	3.4	.000389
NO2+NO3	4.7	5.9	.000675
TKN	9.1	2.6	.000297
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 100482
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 21.7 D10/DT: .71
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 15
Filt. BOD5, mg/l:
SS, mg/l: 39 VSS, mg/l:
pH: 7.5 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	9.6	4.5	.000523
NO2+NO3	3.6	6.3	.000732
TKN	13.4	4.6	.000535
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 100582
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.3 D10/DT: .699
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 13
Filt. BOD5, mg/l:
SS, mg/l: 29 VSS, mg/l:
pH: 7.7 Alk, mg CaCO3/l: 234

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
11.5	8.2	.000938
NO2+NO3		
3	7.2	.000824
TKN		
15.7	6.8	.000778
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 100682
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.9 D10/DT: .688
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 4
Filt. BOD5, mg/l:
SS, mg/l: 17 VSS, mg/l:
pH: 7.6 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	7.9	5.6	.000631
NO2+NO3	7.4	5.1	.000574
TKN	9.2	6.6	.000743
0.45 micron Filt. TKN			

Source: Sampayo and Metcalf (1984) Date: 100782
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.2 D10/DT: .701
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 12
Filt. BOD5, mg/l:
SS, mg/l: 17 VSS, mg/l:
pH: 7.5 Alk, mg CaCO3/l:

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
10.4	7.9	.000906
NO2+NO3		
3.8	8.3	.000952
TKN		
11.1	7.1	.000815
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 100882
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 22.4 D10/DT: .697
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 6
Filt. BOD5, mg/l:
SS, mg/l: 23 VSS, mg/l:
pH: 7.4 Alk, mg CaCO3/l: 202

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
6.2	4.6	.000525
NO2+NO3		
5.2	6	.000684
TKN		
9.4	5.7	.000650
0.45 micron Filt. TKN		

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Source:  Sampayo and Metcalf (1984) Date:    101182
Avg. Total Flow, l/ sq. m x s:                     1.358
Recycle, percent total flow:                          25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s:                1.358
Media Depth, m:                                    7.315
Media Spec. Surf. Area, sq.m/cu. m:                   98
Onda % Wetted Area:                                   31
Water Temp., C:        20.8         D10/DT:         .727
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l:                                            8
Filt. BOD5, mg/l:
SS, mg/l:        19         VSS, mg/l:
pH:             7.5         Alk, mg CaCO3/l:

Total Applied      Oxidized          10 C Nitrification
Influent Conc.     Nitrogen,         Rate, kg/d/sq. m
mg N/l             mg/l              total surface area

NH4
      4.8               3.6            .000428


NO2+NO3
     10.7               5.9            .000702


TKN
      7.4                 6            .000714


0.45 micron
Filt. TKN
```

Source: Sampayo and Metcalf (1984) Date: 101282
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 20.6 D10/DT: .731
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 15
Filt. BOD5, mg/l:
SS, mg/l: 44 VSS, mg/l:
pH: 7.6 Alk, mg CaCO3/l: 216

Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4		
4.3	1.9	.000227
NO2+NO3		
6.9	3.2	.000383
TKN		
13.6	10.2	.001220
0.45 micron Filt. TKN		

Source: Sampayo and Metcalf (1984) Date: 101382
Avg. Total Flow, l/ sq. m x s: 1.358
Recycle, percent total flow: 25
Periodic Dosing Cycle, sec:
Distribution Time, sec/cycle:
Avg. Distributed Flow, l/sq. m x s: 1.358
Media Depth, m: 7.315
Media Spec. Surf. Area, sq.m/cu. m: 98
Onda % Wetted Area: 31
Water Temp., C: 21.1 D10/DT: .721
COD, mg/l:
0.45 micron Filt. COD, mg/l:
BOD5, mg/l: 13
Filt. BOD5, mg/l:
SS, mg/l: 41 VSS, mg/l:
pH: 7.8 Alk, mg CaCO3/l:

	Total Applied Influent Conc. mg N/l	Oxidized Nitrogen, mg/l	10 C Nitrification Rate, kg/d/sq. m total surface area
NH4	6.6	3.4	.000401
NO2+NO3	10	2.2	.000260
TKN	8.7	2.7	.000319
0.45 micron Filt. TKN			