PREDICTING NITRIFICATION EFFICIENCY FROM DISSIMILAR WASTEWATERS: DESIGN CRITERIA & OPERATION RESULTS

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ABSTRACT

An extended aeration sewage treatment plant on an island camp in Georgian Bay, Ontario, performed fair to well for BOD, TSS and TP removal, but was unable to nitrify ammonium to compliance levels for surface discharge. The raw sewage is from residential and kitchen sources, but is high strength (cBOD >500 mg/L and TKN >100 mg/L), and the alkalinity is low.

A proposal was made to retrofit a Waterloo Biofilter absorbent trickling filter to polish the treated sewage. The influent mass rate to the BIOFILTERS for design purposes was 4.0 kg/d NH_4-N and 0.6 kg/d cBOD (influent design peak of 160 mg/L NH_4-N and 15 mg/L cBOD at 25,000 L/d). The design criteria for the effluent out of the BIOFILTERS were 0.075 kg/d NH_4-N for compliance (3.0 mg/L), and 0.025 kg/d NH_4-N (1.0 mg/L) as a target.

Performance guarantees were requested and field experience polishing this particular wastewater type (low BOD and high NH_4-N) at the required high hydraulic loading rates was not available. To predict how this technology would perform, empirical relationships of influent and effluent data of two different wastewaters were examined, with the intent to interpolate to the expected conditions at the camp and to predict performance.

Polishing data from low-strength secondary clarifier effluent at high hydraulic rates (<1700 L/d per m^3 filter medium) indicated sustainable and complete nitrification. The same could be done with 15 m^3 filter medium at the island camp, easily placed in the limited space available. From this data, an effluent discharge of 0.015 kg/d NH_4-N was predicted at peak flow, less than the target.

From operational data at a high-strength, surface-discharge BIOFILTER, an effluent discharge of 0.0021 kg/d or 2.1 mg/L NH_4-N was predicted, also within target limits. With this performance prediction, the BIOFILTERS were installed in 2002 and the results for BOD, TSS, and NH_4-N were all well within compliance limits and all but one month within target limits. Analysis of empirical relations from operational data from two dissimilar wastewaters such as low BOD/low NH_4-N and high BOD/high TKN can successfully predict the performance of a retrofitted polisher on a third wastewater with low BOD/high NH_4-N.

INTRODUCTION

A package extended aeration sewage treatment plant, consisting of an aerated equalization tank, aeration tank, final clarifier, pressure sand filter, and UV irradiation for surface discharge, was installed in 1999 for the 25 m^3/d design flow from a YMCA camp on Beausoleil Island in Georgian Bay (Figs. 1a, 1b). Alum and sodium bicarbonate (alkalinity) addition are used for phosphorus and ammonium removal. The plant performed well for BOD removal, fair for TSS and phosphorous removal, but was not able to nitrify ammonium to compliance levels for surface discharge to Georgian Bay.

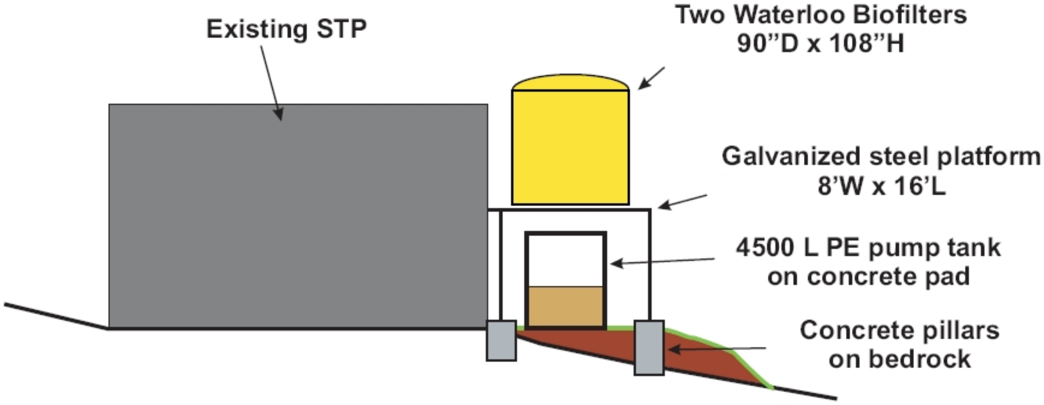

FIGURE 1a.

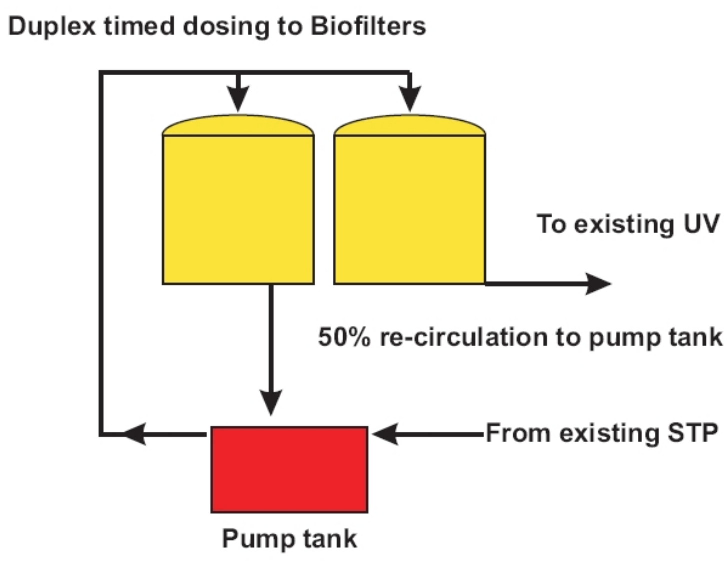

FIGURE 1b.
Schematic of retrofit Waterloo polishers, showing re-circulation and discharge.

A proposal was put forward to retrofit the existing plant with a Waterloo Biofilter absorbent trickling filter (Jowett and McMaster, 1995) as a polishing unit primarily to nitrify ammonium (Masaud et al., in prep; Figs. 1b, 2), but assurance was requested that the retrofit would succeed in meeting compliance. The difficulty was that the type of wastewater expected at this site, being low BOD/high NH_4-N, was not the type that Waterloo had experience with at the required high hydraulic loading rates.

FIGURE 2.
Polyethylene Biofilter tanks on platform designed as polishers for 12,500 L/day each. One tank drains back to polyethylene pump tank below; other goes to UV and lake discharge.

This paper describes calculations for efficiencies of removal of organics and ammonium from actual field data for; (a) low BOD/low NH_4-N wastewater at high hydraulic rates, and (b) high BOD/high NH_4-N wastewater at low hydraulic rates. The empirical relationships between BOD and NH_4-N removal rates are determined and then combined. Then, with the expected loading rates of BOD and NH_4-N at the new site, the treatment performance of the retrofitted polishing BIOFILTER is predicted for the low BOD/high

NH_4-N wastewater type at high hydraulic rates. The predicted effluent quality compares favourably with the actual operational data.

SITE WASTEWATER CHARACTERISATION

Nitrification is typically impeded by high-strength wastewater, low alkalinity, cold temperature, high hydraulic loading rates (low retention time), and disinfectants (e.g., Table 7-6 Crites and Tchobanoglous, 1998). The raw sewage at Beausoleil is from residential and kitchen sources, but is strong in organic matter (average cBOD >500 mg/L) and nitrogen (average TKN >100 mg/L). In addition, the soft lake water required close scrutiny of alkalinity levels.

The peak design criteria for the partially treated sewage to be polished were 160 mg/L NH_4-N and 15 mg/L cBOD at 25,000 L/d, or a mass loading of 4.0 kg/d NH_4-N and 0.6 kg/d cBOD. The design criteria for the effluent out of the BIOFILTERS were 0.075 kg/d NH_4-N for compliance (3.0 mg/L), and 0.025 kg/d NH_4-N (1.0 mg/L) as a target.

The BIOFILTERS have experience in polishing wastewater with low BOD and low TKN at high hydraulic loading rates, and they often treat high BOD and high TKN at lower hydraulic loading rates, but there was no experience with low BOD and high TKN at high hydraulic loading rates. To predict how the technology would perform, empirical relationships of influent and effluent data of past operational data of the BIOFILTER were examined, with the intent to interpolate to the expected conditions at Beausoleil.

LOW-STRENGTH, HIGH-FLOW DATA

For a 12-month period in 1994-95, secondary clarifier effluent at the Waterloo sewage treatment plant was loaded onto a 4.2 m^3 sized, single-pass BIOFILTER at a wide variety of hydraulic rates up to 2600 L/d/m^3 (litres per day per m^3 of filter medium), and the mass loads of kg/d BOD and NH_4-N in both influent and effluent were calculated.

Correlation for All Flow Rates

For the entire hydraulic range tested (<2600 L/d/m^3), there is an exponential relationship between influent hydraulic flow (L/day) and effluent NH_4-N concentration (Fig. 3a) and with effluent BOD concentration; similarly with influent mass NH_4-N versus effluent NH_4-N (Fig. 3b). There is a distinct visual divide into two populations at the ~7000 L/day rate (<1700 L/d/m^3) and at ~0.10 kg/day NH_4-N in Figures 3a and 3b, respectively, below which the data behave more orderly and predictably. This divide suggests that there is likely an optimal loading rate for thorough nitrification to occur, and above that rate, the results are less predictable.

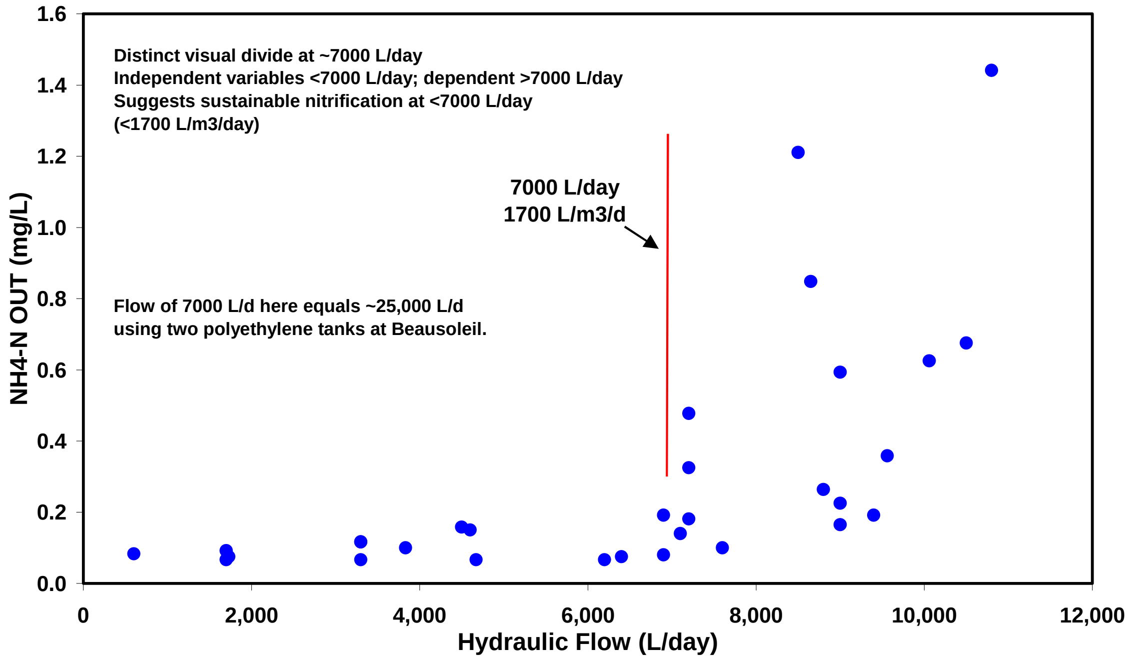

FIGURE 3a.
Low-Strength hydraulic flow vs. mg/L NH4-N – All Flows

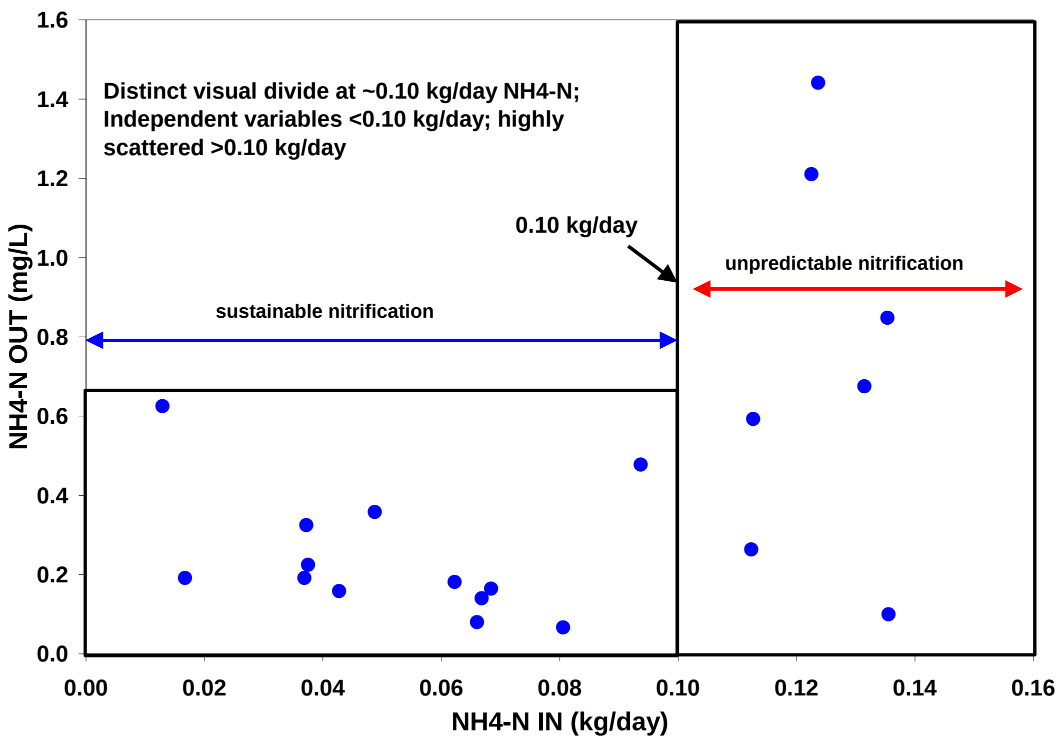

FIGURE 3b.
Low-Strength mass NH4-N vs. mg/L NH4-N – All Flows

Correlation for Lower Flow Rates

When only lower hydraulic loading rates are included (<1700 L/d/m^3), there is a well-formed relationship between influent and effluent BOD mass (Fig. 4a), and is linear above ~0.025 kg/day mass loading. This indicates that, except for very low loading rates, the effluent mass has a slight dependence on the influent mass, increasing slowly at a slope of 0.0103.

There is no correlation at all between influent mass and effluent BOD concentration, indicating that for lower loading rates, the effluent concentration is independent of the influent mass, and does not increase with higher loading rates.

There is good correlation between influent NH_4-N mass and effluent NH_4-N mass (Fig. 4b), indicating a direct dependence. However, when effluent concentration is considered, there is no correlation with mass loading rates (Fig. 4c), and the effluent concentration does not increase with higher loading rates. This independence suggests that within the loading rate range inspected (<1700 L/d/m^3), the effluent quality remains the same regardless of the influent mass loading.

There is no correlation between influent BOD mass and effluent concentration for either NH_4-N or BOD (i.e., increasing the mass at these lower hydraulic loading rates does not increase the effluent concentration). There is a very slight positive correlation between the ratio of influent BOD/NH_4-N masses and effluent NH_4-N mass, but no correlation with effluent NH_4-N concentration. These relationships indicate that at these hydraulic loading rates, the effluent quality is independent of the influent mass of BOD or NH_4-N, and with their ratio, suggesting that this nitrification is sustainable.

Predicting Effluent Quality at Beausoleil (1)

How does this low-strength wastewater analysis relate to Beausoleil? Assuming that the <1700 L/d/m^3 rate would sustain nitrification and adequately polish the existing STP effluent, the volume of BIOFILTER medium needed is 25,000 L/d / 1700 L/d/m^3 = 15 m^3 filter medium, easily placed in two standard 90"D x 108"H tanks within the space available.

At <1700 L/d/m^3, and excluding the very low mass loads, the approximate slope of NH_4-N removal efficiency (ratio of effluent NH_4-N mass to influent NH_4-N mass) is 0.0040 (Fig. 4b), and that for BOD removal efficiency is 0.0103 (Fig. 4a). The ratio 0.0040/0.0103 = 0.39 indicates that BOD removal efficiency is only ~39% that of NH_4-N removal (the reverse is true with high-strength, see below).

When the influent BOD + NH_4-N mass is plotted against effluent NH_4-N mass (Fig. 4d), a slope of 0.000844 and vertical axis intersection of 0.00022 are measured. For a design loading of 4.6 kg/d NH_4-N equivalent (4.0 BOD + 0.6 NH_4-N, and assuming a

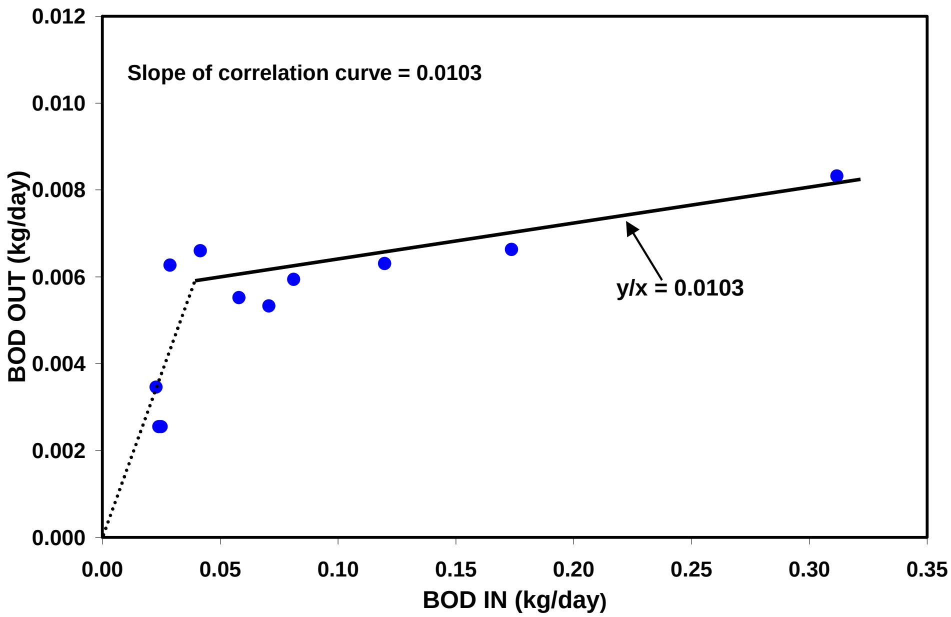

FIGURE 4a.
Low-strength mass BOD IN vs. mass BOD out – Low Flows

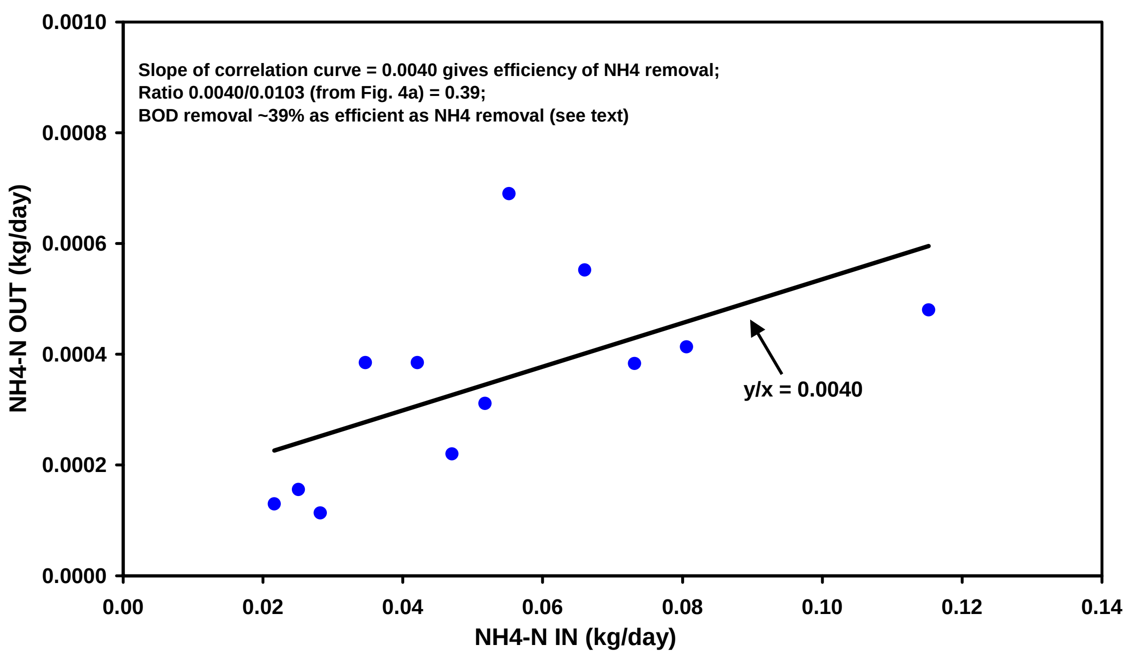

FIGURE 4b.
Low-strength mass NH4-N IN vs. mass NH4-N OUT – Low Flows

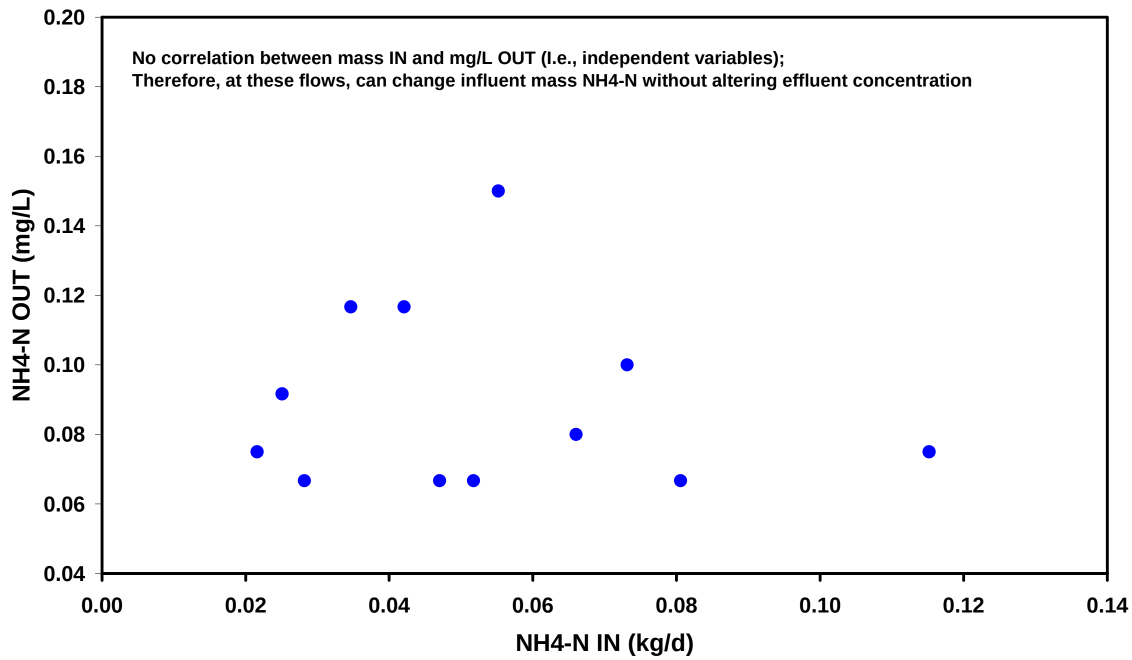

FIGURE 4c.
Low-strength mass NH4-N IN vs. NH4-N OUT – Low Flows

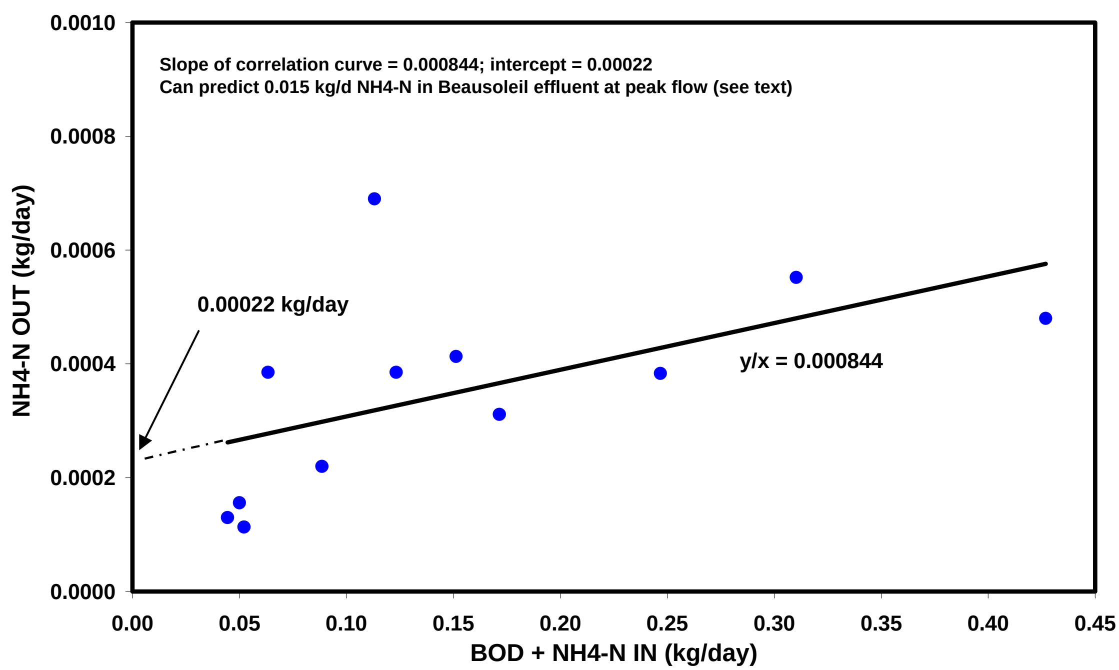

FIGURE 4d.
Low-strength mass BOD + NH4-N IN vs. mass NH4-N OUT – Low Flows

conservative BOD = NH_4-N), an effluent NH_4-N mass of (0.000844 * 4.6 kg/d + 0.00022) / 4.2 m^3 medium = 0.00098 kg NH_4-N per day can be expected for each m^3 of filter medium in the BIOFILTER.

With 15 m^3 of foam medium required for the Beausoleil site, a discharge of 15*0.00098 = 0.015 kg/d NH_4-N can be predicted in the effluent at peak flow, less than both the 0.075 kg/d compliance and the 0.025 kg/d target.

However, these predictions are with relatively low influent NH_4-N values, and at a constant pH of ~8.0. In order to predict what would happen with higher influent NH_4-N values, such as what might occur at Beausoleil if the existing plant did not perform, other data were examined.

HIGH-STRENGTH, LOW-FLOW DATA

This data set uses lower flow rates (design = 500 L/d/m^3) in a double-pass BIOFILTER to treat high-strength wastewater from the Kings Riding clubhouse facilities (see Jowett et al., Env. Sci. Eng., Sept. 2001). With 50% recirculation of treated effluent back to the septic tanks, the actual through-flow is 1000 L/d/m^3 filter medium.

There is good correlation between influent TKN mass and effluent NH_4-N mass (Fig. 5a), with a slope of 0.00806 (i.e., effluent NH_4-N is only ~0.008 (<1%) that of influent TKN). There is also good positive correlation between influent TKN mass and effluent NH_4-N concentration (i.e., effluent quality is dependent on mass loading, unlike the low-strength wastewater above). This dependence on influent mass is likely due to the difficulty of complete nitrification at high BOD, and also to the high effective hydraulic load (i.e., 1000 L/d/m^3 for high-strength wastewater). There is good correlation between influent BOD mass and effluent BOD mass (Fig. 5b), with a slope of 0.0032, and with effluent BOD concentration. Both these graphs converge on the origin (0,0), unlike the low-strength graphs.

It is evident that effluent quality is dependent on influent mass of BOD and TKN with this high-strength wastewater, unlike low-strength wastewater, and that BOD removal efficiency is ~2.52 times that of NH_4-N removal efficiency (0.00806/0.0032 = 2.52), also unlike low-strength wastewater. We can assume then, when treating high-strength wastewater, that one kg/d of NH_4-N is equivalent to ~2.52 kg/d BOD.

Predicting Effluent Quality at Beausoleil (2)

The influent Beausoleil parameters of 4.0 kg/d NH_4-N and 0.6 kg/d BOD are now assumed equivalent to 4.0*2.52 + 0.6 = 10.68 kg/d BOD + NH_4-N loading. Using the correlation between influent BOD + NH_4-N mass and effluent NH_4-N mass, the total load of 10.68 kg/d (instead of 4.6 since one NH_4-N is equivalent to 2.52 BOD) gives an

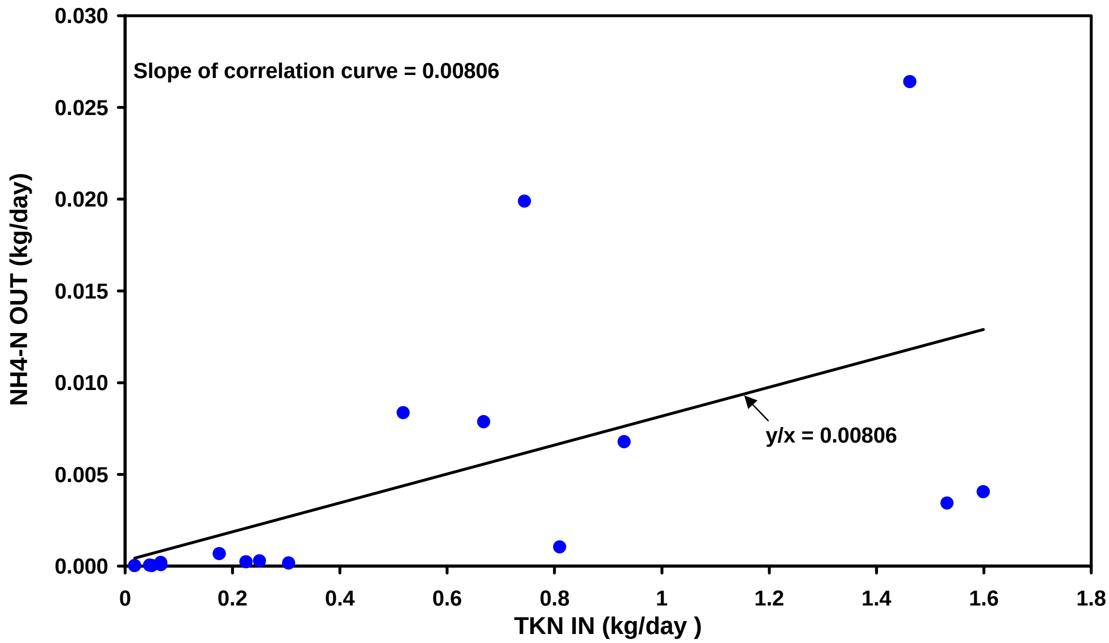

FIGURE 5a.
High-strength mass TKN IN vs. mass NH4-N OUT

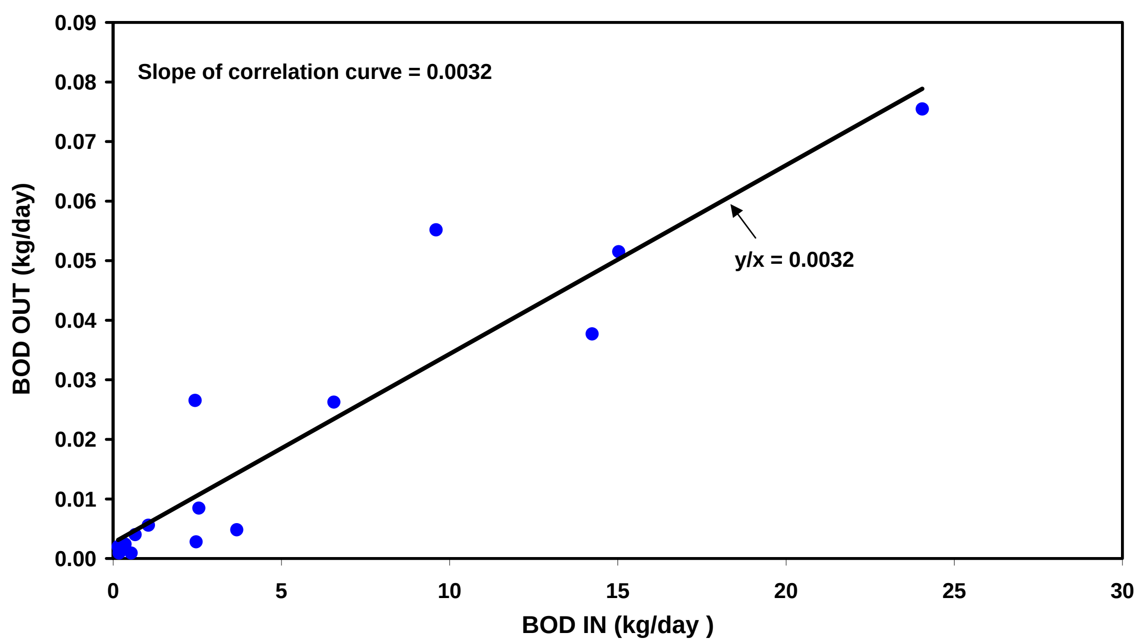

FIGURE 5b.
High-strength mass BOD IN vs. mass BOD OUT

effluent mass load of 0.0077 kg/d NH_4-N. With 56 m^3 medium in the ClubLink site, this results in 0.0077/56 = 0.0001375 kg/d per m^3 medium.

Using the proposed 15 m^3 medium at Beausoleil, this would be 15*0.0001375 = 0.0021 kg/d NH_4-N in the effluent, less than the 0.075 kg/d compliance and 0.025 kg/d target set for the polishing BIOFILTER. Even considering the higher peak loading of 1700 L/d/m^3 (25,000 L/d/15 m^3) compared to the actual 1000 L/d/m^3, the predicted effluent quality should be within the target limits.

Again comparing influent BOD + TKN mass versus effluent NH_4-N concentration (Fig. 5c), a loading of 10.68 kg/d corresponds to a value of 0.60 mg/L NH_4-N in the effluent at Kings Riding. Converting that mass loading on 56 m^3 of filter medium at Kings Riding to 15 m^3 at Beausoleil, the effluent concentration at peak loading can be expected to be 0.60*56/15 = 2.2 mg/L NH_4-N. Although a rough estimate, it lies nicely between the compliance of 3.0 mg/L and the target of 1.0 mg/L.

This analysis of two dissimilar wastewaters appears to provide a reasonable comfort level that the system would work under the expected wastewater conditions of low BOD, high NH_4-N, and high hydraulic loading rates.

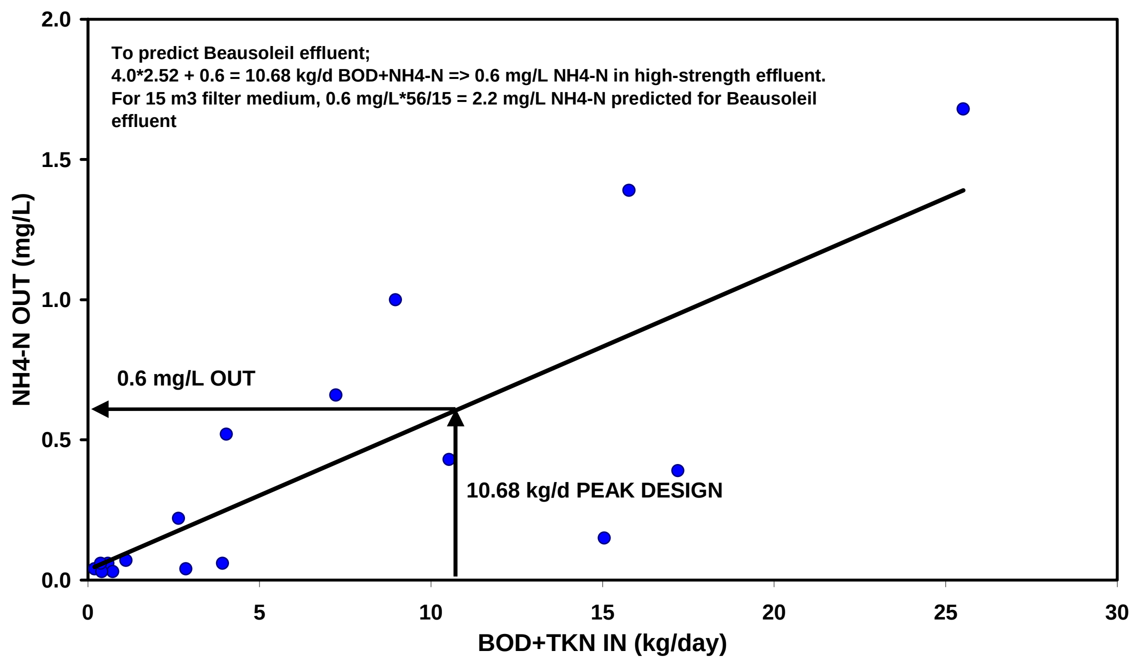

FIGURE 5c.
High-strength mass BOD+TKN IN vs. mg/L NH4-N OUT

FIELD RESULTS OF NITRIFYING POLISHER

The Waterloo Biofilter polishing system was installed and commissioned in May 2002. The results are provided in Table 1 below and show that the retrofitted system was within compliance in every parameter throughout the summer. Better than that, the effluent concentration was within target limits in every situation but NH_4-N in July when the system was at its peak usage, with the 2.3 mg/L correlating closely with the peak of 2.2 mg/L NH_4-N predicted above. No results for 2003 are available, but no phone calls have been received.

Parameter	**cBOD**	**TSS**	**NH_4-N**
Compliance/Target	*15/10*	*15/10*	*3.0/1.0*
May	**2.5**	**7.0**	**0.35**
June	**2.8**	**3.0**	**0.1**
July	**7.2**	**3.8**	**2.29**
August	**5.0**	**4.3**	**0.22**

TABLE 1.
Effluent values in 2002 after polishing (monthly averages in mg/L)

CONCLUSIONS

Sewage treatment systems having difficulty meeting compliance can be retrofitted with a high-rate BIOFILTER polisher to remove residual solids, organics, and ammonium. The analysis of operational data from two dissimilar wastewaters such as low BOD/low NH_4-N and high BOD/high NH_4-N can successfully predict the performance of a retrofitted polisher on a third wastewater with low BOD/high NH_4-N.

ACKNOWLEDGEMENTS

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