Appendix G

Aero-Mod
Treatment Process
Support Documentation

G-6: Cost Effectiveness Study of the Aero-Mod System

COST-EFFECTIVE BIOLOGICAL NITROGEN REMOVAL: AERO-MOD SEQUOX-PLUS

Brooks Newbry*, John McNellis**, Rob Mahan**, Todd Steinbach**

*Aero-Mod, Inc., 1028 N 24th St., Mesa, AZ 85213 (brooks@aeromod.com)

**Aero-Mod, Inc., 7927 U.S. Highway 24, Manhattan, KS 66502

ABSTRACT

Municipal wastewater treatment plants are increasingly faced with achieving very low effluent total nitrogen (TN) concentrations. Discharge limits are now typically 5 mg/L or less. While some technologies have been shown to be capable of this level of performance, a significant challenge is the complexity of the proven treatment systems. In general, these systems require significant manual operation and maintenance and have higher capital and operating costs than their "conventional" counterparts. The Sequential Oxidation (SEQUOX) activated sludge process, developed by Aero-Mod, has proven its ability to achieve low TN effluent and to do so reliably, cost-effectively and with minimal operator attention using extended aeration with post-denitrification and sequential oxidation.

KEYWORDS

Nitrogen removal, BNR, denitrification, aeration, DO control

INTRODUCTION

Nitrogen is a necessary biological nutrient and a known contributor to water quality degradation when present in sufficient concentrations. To protect the quality of receiving waters, nitrogen removal from wastewater prior to its return to the environment has become standard practice. Effluent limits on wastewater treatment plants (WWTPs) are steadily becoming more stringent.

For the purposes of wastewater treatment, nitrogen compounds are typically grouped as illustrated in Figure 1 (more comprehensive descriptions are available elsewhere – e.g. Stensel et al., 2008). Particulate nitrogen is removed by sedimentation (as part of the waste sludge stream) and by conversion to soluble forms, primarily DON and NH_3-N. NH_3-N is converted to NO_2-N and NO_3-N by nitrification; these compounds are subsequently removed by denitrification.

A nitrogen compound class of particular interest is "recalcitrant DON," or rDON, which is not removed by biological wastewater treatment. This group is not easily measured alone but is included as TKN and TN. Concentrations in "typical" municipal wastewater are estimated to be in the range of 0.5 to 2.0 mg/L (Stensel et al., 2008). Accordingly, discharge permit limits written for TN inherently include rDON, which cannot be removed by biological treatment.

A decade ago <u>TIN</u> limits of 10 mg/L were being implemented; today <u>TN</u> limits of 5 mg/L or less are becoming common. The purported "limit of technology" for TN removal by biological treatment is approximately 3 mg/L; however, few technologies have been identified as being able to meet this limit reliably, based on observed performance of various wastewater treatment technologies (USEPA, 2008); rDON plays a role in performance limits and variability.

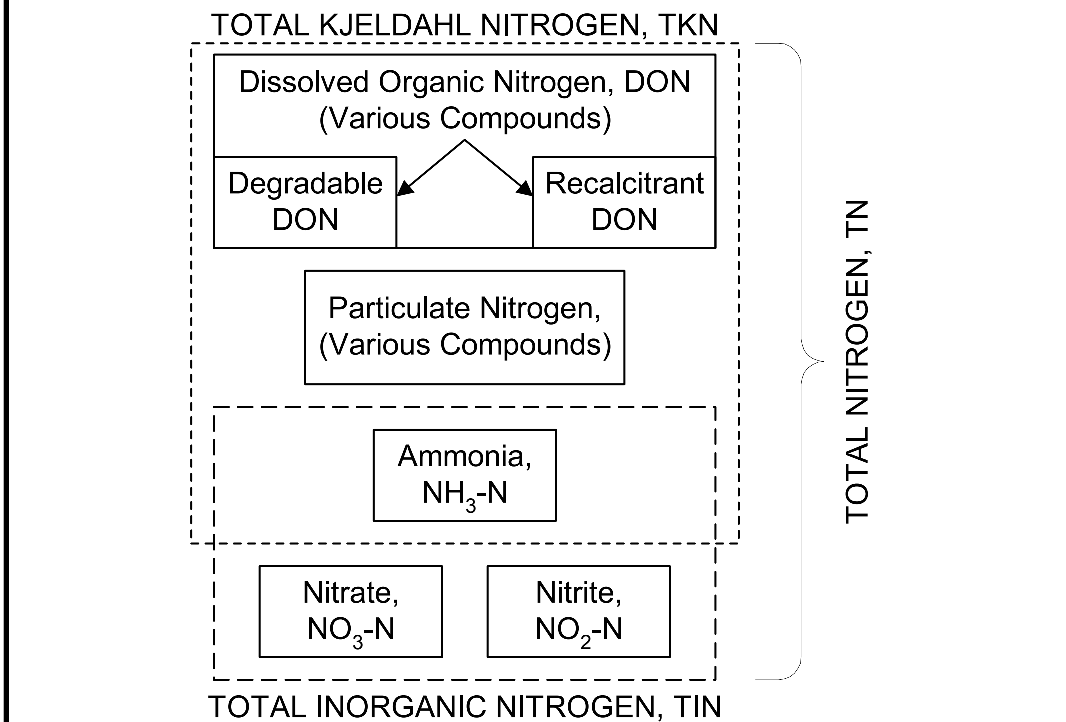


Figure 1 – Typical Nitrogen Compound Speciation in Wastewater Treatment

To assist regulators in applying appropriate limits and to assist WWTP managers in meeting those limits, the USEPA conducted a survey of wastewater treatment plants providing biological nutrient removal (USEPA, 2008). Performance results from this survey are summarized in Table 1. This table excludes results from denitrifying tertiary filters following nitrifying activated sludge; denitrifying filters can provide additional TIN (and therefore TN) removal.

Subsequently, a collaborative research program was implemented under the auspices of the Water Environment Research Federation to better define the limits of technology (Neethling et al., 2010; Bott et al., 2012). Performance results from this work are summarized in Table 2.

As part of the USEPA survey, estimates were made of capital costs and operation and maintenance (O&M) costs attributable to nitrogen removal. Figure 1 summarizes the data for plants reporting TN removal and costs. Capital costs were for plant upgrades, so are variable (but still indicate a trend to lower costs with less extensive treatment)[1]. Unit capital costs were roughly \$1.00-\$2.50/gpd capacity. The trend in O&M costs was more consistent.

These results indicate that meeting low TN limits remains a challenge. Those plants achieving low TN results tend to be those that have relatively complex activated sludge processes followed by tertiary treatment, with associated higher costs. This paper describes and presents performance results for an alternative, low cost, high efficiency nitrogen removal process, SEQUOX™.

[1] The lowest cost was for a facility requiring only denitrifying filters to meet a permit revision from 8 to 3 mg/L TN.

Table 1 – Nitrogen Removal WWTP Summary (USEPA, 2008)				
Nominal TN, mg/L	**Technology**	**Location**	**Concentration, mg/L**	
			Annual Average (50%)	**Maximum Month (92%)**
10	Johannesburg	Maryland	7.86	10.41
	Step-Feed Activated Sludge	Maryland	6.70	8.62
5	Modified Ludzak-Ettinger (MLE)	Maryland	4.35	5.54
	Phase Isolation Ditch (PID)	North Carolina	3.67	4.46
	PID	Connecticut	4.2	7.3
	Sequencing Batch Reactor (SBR)	Connecticut	4.59	6.84
	Cyclic Aeration	Connecticut	4.59	6.15
	Westbank	British Columbia	4.38	4.9
	Step-Feed Activated Sludge	Virginia	5.25	6.15
3	Biological Aerated Filter	Connecticut	3.61	7.13
	Concentric Oxidation Ditch	New Jersey	3.0	4.24
	Step-Feed Activated Sludge	Maryland	2.58	4.30
	Five-Stage Bardenpho	Florida	2.32	3.10
	Five-Stage Bardenpho	Florida	2.04	3.10
	Denitrifying Activated Sludge	Maryland	1.63	2.46

SEQUOX™ PROCESS OVERVIEW

The SEQUOX™ process, developed by AeroMod, Inc., has been implemented in over 250 wastewater treatment plants across the United States and around the world. Originally developed as a low-cost, operator-friendly solution for wastewater treatment, it has increasingly found application for nutrient removal where effluent limits are stringent and operators are “on a steep learning curve.”

SEQUOX™ is generally implemented as extended aeration activated sludge in a two-stage aeration basin design. It incorporates an initial anoxic selector but uses post-denitrification as the primary means for nitrogen removal. In most applications the selector, aeration basins, clarifiers and aerobic digesters are constructed in a single common-wall structure. Airlift pumps for return activated sludge (RAS) and waste activated sludge (WAS) pumping. The process is illustrated schematically in Figures 3 and 4. Significantly, there are no moving parts under the water and no mechanical equipment to maintain other than blowers and a compressor system.

Early applications of the technology involved continuous aeration of the first-stage basins and intermittent aeration of the second stage basins. More recently, several enhancements have been made. One is intermittent aeration of the first stage basins under suitable loading conditions, to reduce energy consumption and improve nitrogen removal. This operational strategy is called SEQUOX-PLUS™. Another significant enhancement is dissolved oxygen control of the blowers, using a broad band “operating range” rather than a target setpoint. This system is called DO_2PTIMIZER™.

Solids Retention Time (SRT) is the key biological control parameter, as with all activated sludge systems. In both SEQUOX™ and SEQUOX-PLUS™ solids wasting is from the aeration basin. This eliminates the need for laboratory analyses and solids inventory calculations to determine the required wasting volume. The required daily wasting volume is the volume of the aeration basins divided by the target SRT. The WAS airlift pumps have no moving parts, so once calibrated the operating point will not change. Therefore, the required wasting period does not change as long as the target SRT does not change, regardless of changes in influent flows and loads and aeration basin mixed liquor suspended solids (MLSS) concentrations.

Table 2 – Advanced WWTP Nitrogen Removal Summary (Bott et al., 2012)

Location	**Treatment Process**		**TN Permit Limit, mg/L[(1)]**	**TN Probability (mg/L)**	
	Secondary Treatment	**Tertiary Treatment**		**50% (Annual Ave)**	**95%**
Michigan	Act. Sludge with Methanol Addition	(Not Described)	5 (TIN) (W)	0.75	2.40
Florida	Multi-Stage Oxidation Ditch	Denitrifying Filters	3 (M)	1.03	2.71
Nevada	Activated Sludge	Nitrifying Trickling Filters; Denitrifying Filters	2 (M)	1.57	2.85
Florida	Three-Stage Act. Sludge	Denitrifying Filters	3 (A)	1.45	2.92
Maryland	Three-Stage Act. Sludge	Denitrifying Filters	3 (M)	1.47	3.20
Nevada	High Purity Oxygen Act. Sludge	Lime Softening; Biological Aerated Filters; Tertiary Filters	3 (M)	2.5	3.37
Massachusetts	Activated Sludge	Denitrifying Filters	4 (M)	2.37	4.22
Maryland	Step-Feed Act. Sludge	Tertiary Filters	8 (M)	3.00	8.00
Florida	Five-Stage Bardenpho	Tertiary Filters	3 (A)	3.64	8.56
Maryland	Four-Stage Bardenpho	None	7 (M)	3.40	6.40

1) Averaging Period: W=Weekly, M=Monthly, A=Annual

The entire system is controlled by routing air to proper locations (for aeration, mixing and pumping) using timers and pneumatically operated valves. A PLC control system is used, through which operators set operating parameters such as length of aeration cycles, RAS pumping frequency and duration, WAS pumping frequency and duration and the upper and lower end of the DO operating range. Once established, these settings rarely require adjustment (seasonally at most; often they are never changed). Further, when the PLC fails (as all PLCs do!) the system automatically reverts to physical timer control. The only functionality that is lost is ramping of the blower speeds in response to DO readings.

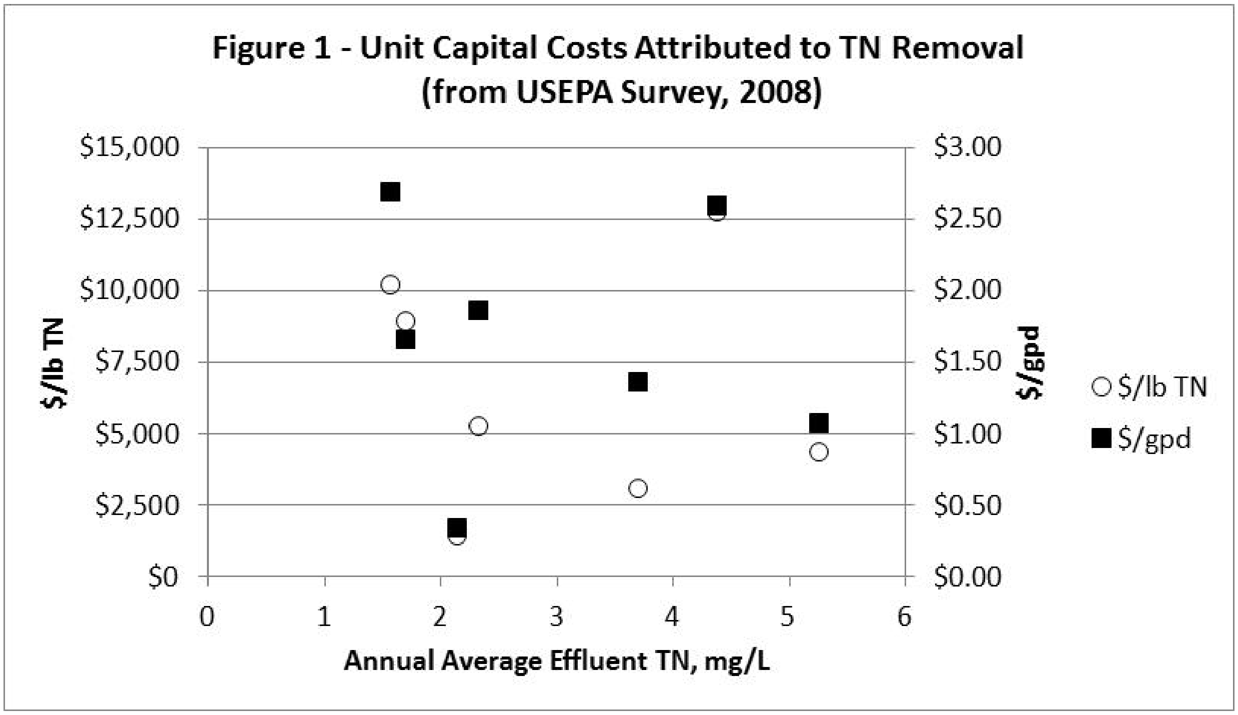


Figure 1 - Unit Capital Costs Attributed to TN Removal
(from USEPA Survey, 2008)
$15,000
$12,500
$10,000
$7,500
$5,000
$2,500
$0
$/lb TN
$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$0.00
$/gpd
0
1
2
3
4
5
6
Annual Average Effluent TN, mg/L
$/lb TN
$/gpd

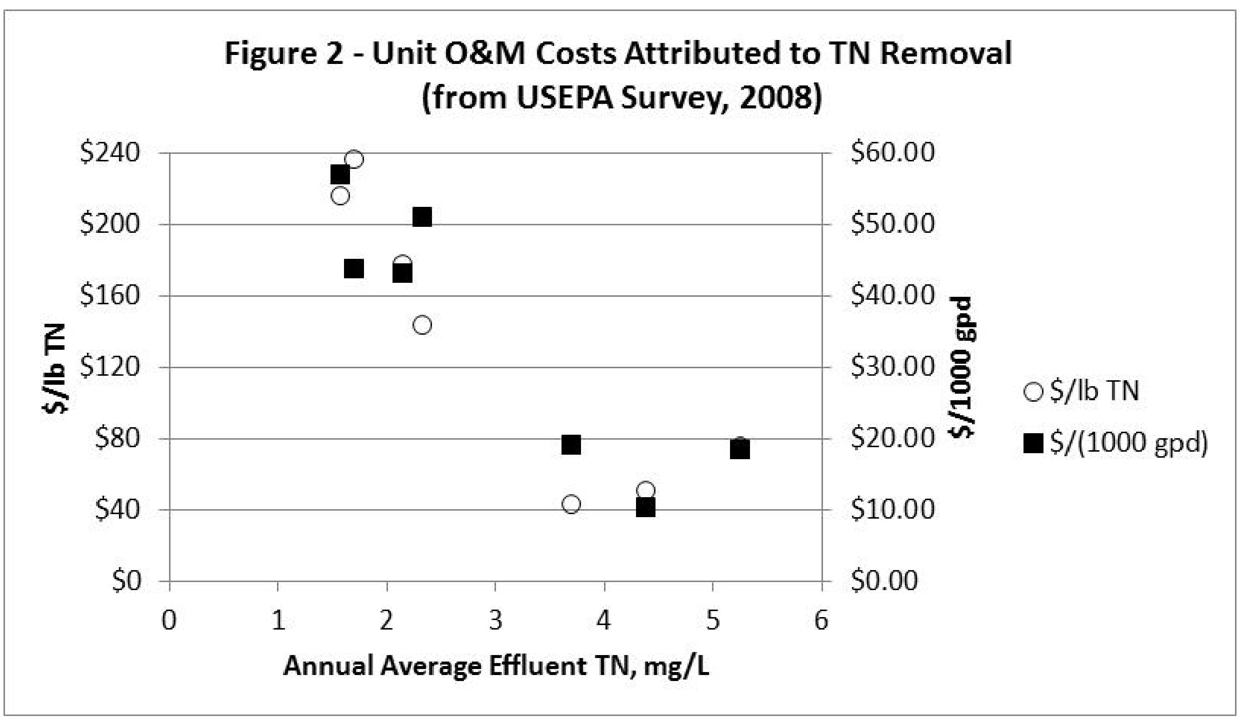


Figure 2 - Unit O&M Costs Attributed to TN Removal
(from USEPA Survey, 2008)
$240
$200
$160
$120
$80
$40
$0
$/lb TN
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$0.00
$/1000 gpd
0
1
2
3
4
5
6
Annual Average Effluent TN, mg/L
$/lb TN
$/(1000 gpd)

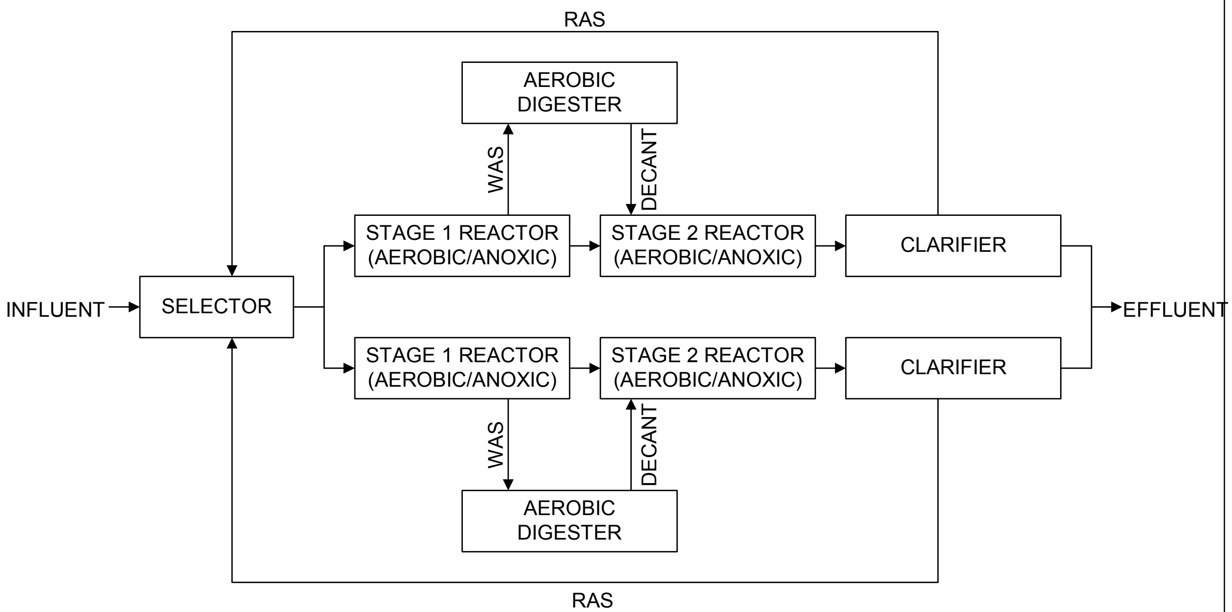


Figure 3 – SEQUOX™ Schematic

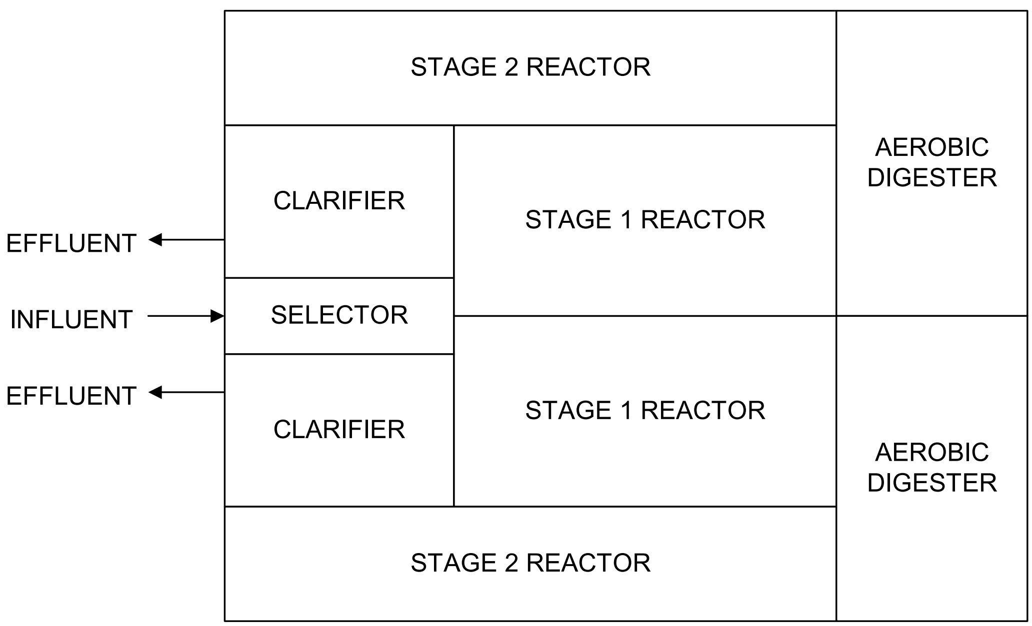


Figure 4 – SEQUOX™ Typical Layout

PERFORMANCE ASSESSMENT

Periodic surveys of plant performance have indicated that the SEQUOX™ process is capable of achieving very low effluent TIN concentrations. More recently, surveys of the SEQUOX-PLUS™ have indicated even lower TIN concentrations. Few of these plants are yet faced with very low effluent TIN (or TN) limits, so extensive monitoring data are limited.

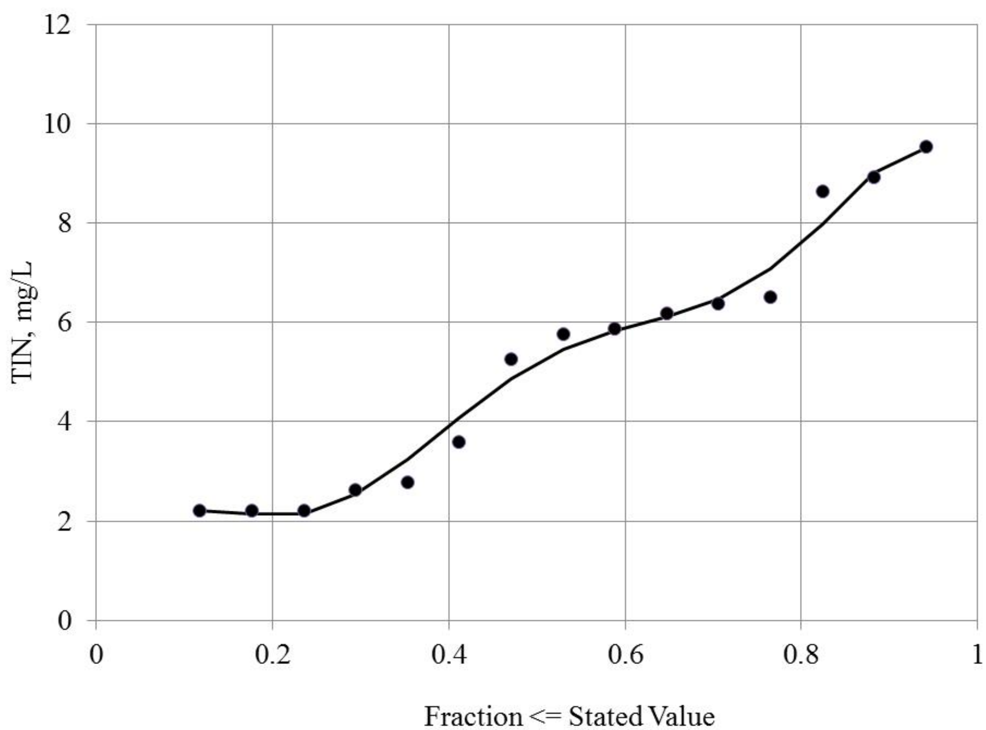
The objectives of this study were to (a) assess biological nitrogen removal characteristics of these processes, where data are available to characterize performance and (b) relate observed performance to widely accepted biokinetics (using Biowin as the modeling tool) as a basis for further process enhancements.

Database Summary

Performance data for the initial assessment were collected from thirty-two facilities. The period of record averaged approximately one year. The plant flows ranged from 0.02 to 2.4 mgd and represent plants in twelve states, from northern climates (such as Michigan and Indiana) to southern climates (such as Texas and Florida).

TIN data for SEQUOX™ plants for which sufficient performance results were available are presented in Figure 5. TN data were not available for a sufficient number of plants to present here. However, TIN is indicative of performance. Although these plants do not have stringent TIN or TN limits (some have no nitrogen limits at all), in general, they have achieved effluent TIN concentrations less than 9 mg/L ninety percent of the time and less than 6 mg/L fifty percent

Figure 5 - TIN Frequency Distribution (Available Sequox Data)



of the time – remarkable performance compared with other process options and considering the level of operator sophistication at many of these facilities.

Representative Case Study 1

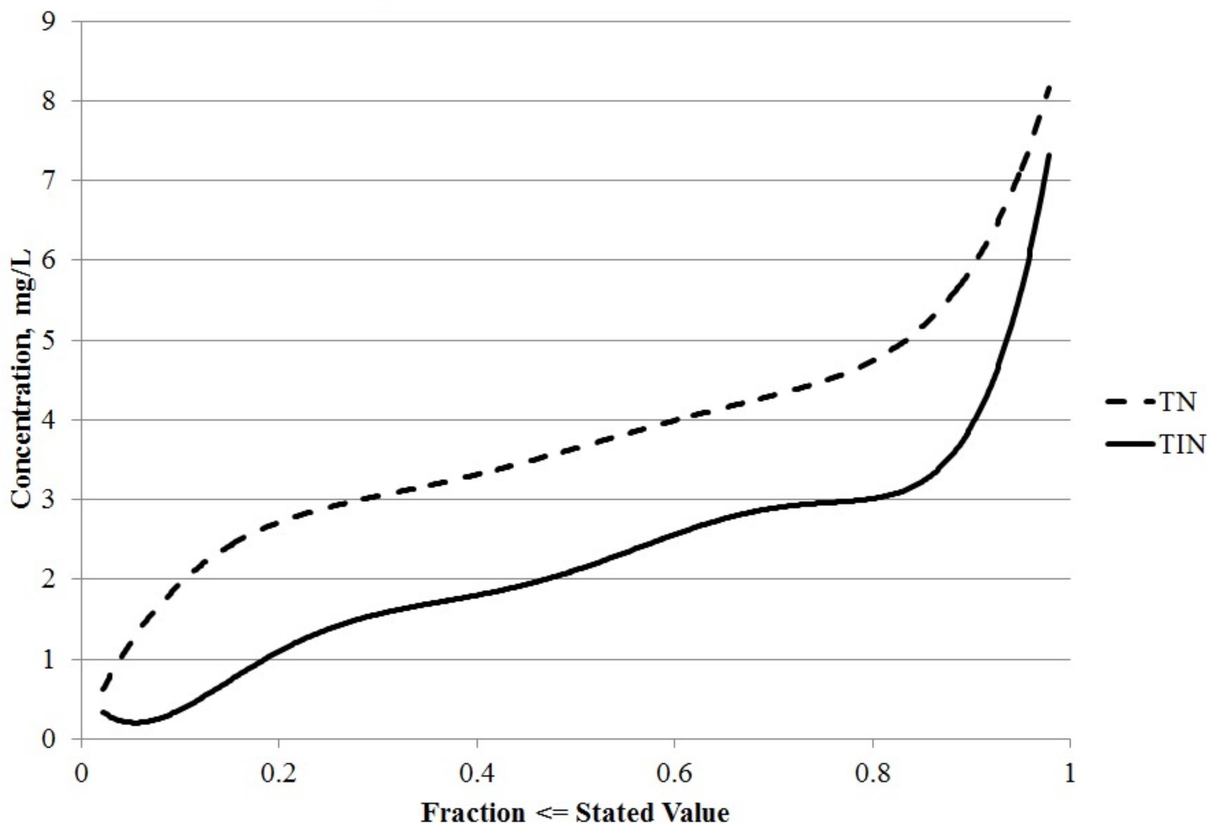
The Aztec, NM plant was designed to meet a stringent TN limit (approximately 3 mg/L). It includes the SEQUOX-PLUS™ operating strategy and the DO_2PTIMIZER™ aeration control system. It was designed to treat a flow of 1.5 mgd and an influent TKN of approximately 80 mg/L.

Effluent nitrogen results are presented as a frequency distribution in Figure 6. They include:

- 50 percentile: 2.1 mg/L TIN, 3.7 mg/L TN
- 92 percentile: 3.6 mg/L TIN, 5.7 mg/L TN

These results are comparable to those in the “nominal 5 mg/L TN” category from the USEPA survey, cited earlier.

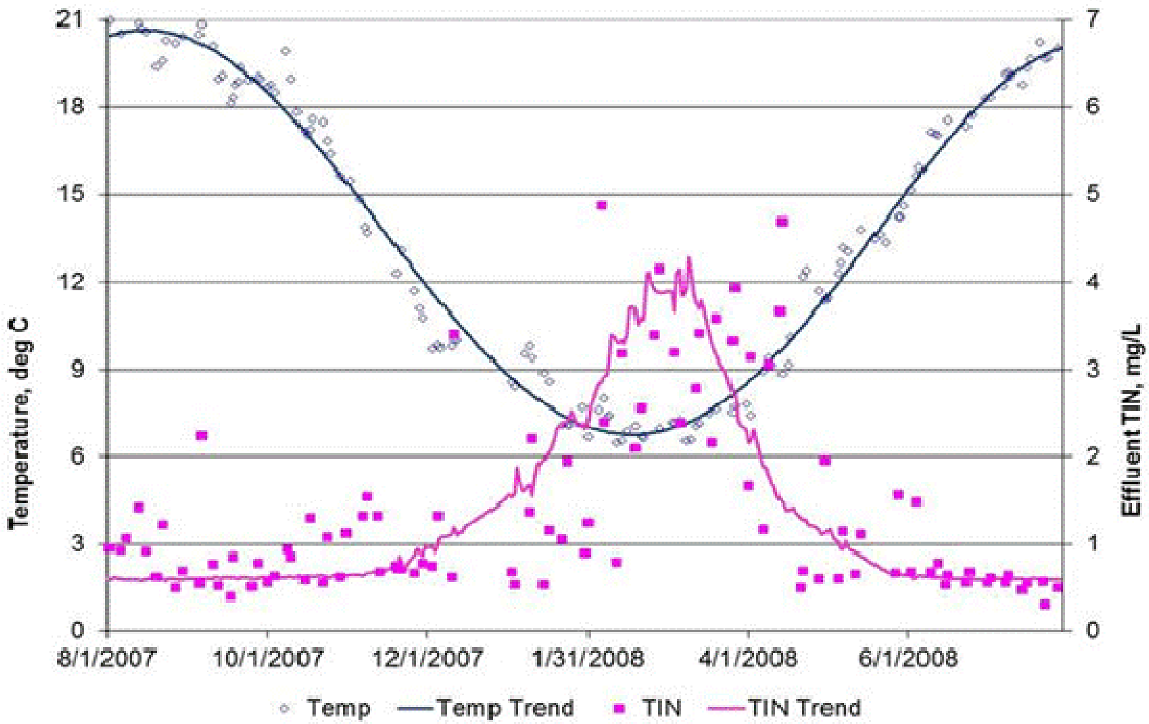
Figure 6 - Nitrogen Data from Aztec, NM



Representative Case Study 2 and Process Model Development

To further examine process performance characteristics and to develop a basis for process modeling, specific facilities were examined in more detail. One representative twelve-month data set is presented in Figure 7, which shows measured and predicted TIN concentrations for a plant in Michigan. The solid lines represent simulated temperatures and predicted TIN values, respectively, while and the data points represent results of discrete samples. As indicated, the plant consistently produced effluent TIN concentrations less than 5 mg/L, even in the coldest months (the high values during January through March are the result of decreased nitrification). The predicted values in this figure were developed using Biowin.

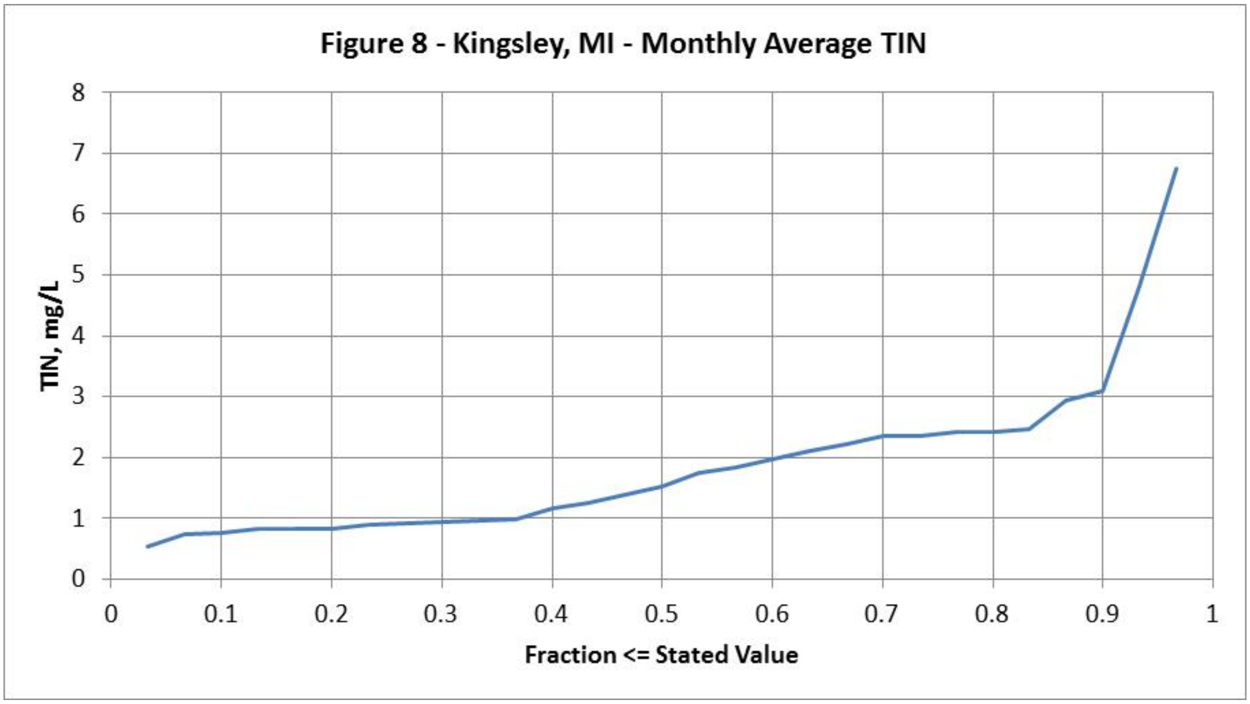
Figure 7 – Kingsley, MI Predicted and Observed Performance



The TIN data for this period are also presented in Figure 8 as a frequency distribution. The 50-percentile and 92-percentile values are approximately 1.5 and 3.2 mg/L, respectively. Assuming an rDON concentration of 1 mg/L (a typical value, as discussed earlier), the corresponding estimated TN concentrations are 2.5 and 4.2 mg/L, respectively. These values compare with those in the "nominal 3 mg/L TN" category in the USEPA survey.

<u>Application of Results</u>

Performance data from full-scale plants have demonstrated the capabilities of this innovative process. Although not presented in this paper, the construction and O&M costs for Sequox-Plus™ are comparable to (or less than) costs for conventional activated sludge facilities. As effluent nutrient limits continue to trend lower, approaching the lower bound on what can be achieved biologically (and in some cases even dropping below that lower bound), having cost-effective biological treatment systems that can meet these limits becomes increasingly important. This performance assessment, aided by process modeling, has demonstrated that the Sequox-Plus™ process is one such cost-effective system.



Stensel, H.D. et al., "Dissolved Organic Nitrogen (DON) in Biological Nutrient Removal Wastewater Treatment Processes," Water Environment Research Foundation, November (2008)

USEPA, "Municipal Nutrient Removal Technologies Reference Document, Volume 1 – Technical Report," EPA 832-R-08-006 (2008)

Bott, C.B. et al., "WEF/WERF Study of BNR Plants Achieving Very Low N and P Limits: Evaluation of Technology Performance and Process Reliability," Water Science and Technology, Vol. 65, No. 5 (2012)

Neethling, J.B. et al., "WERF Nutrient Challenge investigates limits of nutrient removal technologies", Water Science and Technology, Vol. 61, No. 4 (2010)