Biotool 1.1
Model and User Guide

February 12, 2015

Daniel P. Smith, Ph.D., P.E., DEE

Applied Environmental Technology
Tampa, FL 33592

AET

Table of Contents

Page

List of Tables

Page

Objective of Report

Biotool 1.1 is computer model that provides guidance for the process design of passive, two-stage biofilter systems that remove nitrogen from onsite wastewater. This report summarizes the background of Biotool 1.1, describes the structure of the model, and provides a user guide for model application.

Biotool 1.1 Background

Passive nitrogen removal systems for onsite wastewater employ unsaturated biofilters for ammonia oxidation (Stage 1) followed by saturated biofilters with reactive media for denitrification (Stage 2). The Passive Nitrogen Removal Study (PNRS) was conducted to experimentally evaluate a variety of Stage 1 and Stage 2 biofilters. Nitrogen removal performance data was generated for numerous Stage 1 and Stage 2 biofilters that were operated continuously for over eighteen months. The wastewater supply for all studies was onsite wastewater primary effluent. The Stage 1 biofilters evaluated in PNRS included single-pass and recycle systems and three biofilter media: expanded clay, clinoptilolite and sand. The Stage 2 systems evaluated in PNRS were single-pass biofilters with two reactive media: lignocellulosic and elemental sulfur.

Biotool 1.1 is a computer model that provides process design guidance for two-stage biofilter systems for nitrogen removal from onsite wastewater. The basis of the Biotool 1.1 model is performance data generated in the Passive Nitrogen Removal Study. The Biotool 1.1 model is relatively easy to use with limited input requirements, and its results are straightforward to comprehend. The output of Biotool 1.1 includes biofilter sizes, loading rates, nitrogen removal efficiency, and effluent nitrogen concentrations. Biotool 1.1 provides process design guidance prior to detailed physical design of two-stage biofilter systems.

Biotool 1.1 Model Structure

Two-Stage Passive Nitrogen Removal Processes in Biotool 1.1 Eighteen two-stage biofilter processes are represented in Biotool 1.1. Each two-stage process includes one Stage 1 biofilter and one Stage 2 biofilter (Table 1). Stage 1 processes include two hydraulic options (single-pass or recycle) and three biofilter media, for a total of six system options. Biotool 1.1 includes three Stage 2 media configurations: lignocellulosic (LS), elemental sulfur (ES), and lignocellulosic followed by elemental sulfur (LS/ES). Coupling of six Stage 1 options with three Stage 2 options yields eighteen distinct process options. Biotool 1.1 simulates effluent nitrogen concentrations for Stage 1, Stage 2 LS, and Stage 2 ES processes, and for the total two-stage process (System 1 + System 2). The Biotool 1.1 simulations are based on PNRS results. The functional relationships between effluent nitrogen concentration predictions and system parameters that are embedded in the Biotool 1.1 equations are summarized in Table 2.

Stage 1 Systems The depth of Stage 1 media is specified by the user, with a minimum depth of 15 in. corresponding to the lowest experimentally tested depth for which data are available. The Surface Loading Rate (SLR) is 3.0 gal./ft^2-day, a loading rate at which

Table 1. Biotool 1.1 Two-Stage Biofilter Processes

System	Hydraulics	Stage 1 Media	Stage 2 Media
1	Single Pass	Expanded Clay	Lignocellulosic
2			Sulfur
3			Lignocellulosic/ Sulfur
4		Clinoptilolite	Lignocellulosic
5			Sulfur
6			Lignocellulosic/ Sulfur
7		Sand	Lignocellulosic
8			Sulfur
9			Lignocellulosic/ Sulfur
10	Recycle	Expanded Clay	Lignocellulosic
11			Sulfur
12			Lignocellulosic/ Sulfur
13		Clinoptilolite	Lignocellulosic
14			Sulfur
15			Lignocellulosic/ Sulfur
16		Sand	Lignocellulosic
17			Sulfur
18			Lignocellulosic/ Sulfur

unsaturated biofilters have been successfully operated without surface clogging in PNRS. The Stage 1 SLR is not adjustable. Biotool 1.1 computes derived parameters including the biofilter entry surface area, empty bed volume, empty bed residence time, and loading rate of Total Kjeldahl Nitrogen per empty bed volume. Biotool 1.1 outputs the concentrations of effluent organic nitrogen, effluent ammonia nitrogen, and effluent nitrate+nitrate nitrogen.

For Stage 1, Biotool 1.1 uses derived parameters of the system to predict effluent nitrogen concentration for three nitrogen species: organic nitrogen, ammonia nitrogen, and nitrate+nitrate nitrogen. For the three nitrogen species, effluent nitrogen concentration equations were developed for each of the six Stage 1 systems listed in Table 3 (total of 18 candidate equations were evaluated using experimental data from a multitude of experimental biofilters. The PNRS experimental data sets and candidate equations are

Table 2. Functionality of Nitrogen Equations in Biotool 1.1

System	Biotool 1.1 Equation (*Nitrogen Equations* Worksheet)		Argument Dependencies
	Effluent Conc. Result	Argument	
Stage 1 System 1 - 6	Organic N	TKN Loading Rate	Influent TKN Conc. (Input), Media Residence Time (Flowrate, Media Depth)
	NH_3-N	Effective NH_3-N Removal Efficiency	TKN Loading Rate (Influent TKN Conc. (Input), Media Residence Time (Flowrate, Media Depth))
		Effective Influent NH_3-N Conc.[1]	Influent TKN Conc. (Input), Influent NH_3 Conc. (Input), Effluent Organic N Conc. (Predicted by Biotool 1.1)
	NO_x-N	Influent TKN	Influent TKN Conc. (Input)
Stage 2 System 1 - 2	NO_x-N	NO_x-N Loading Rate	Influent NO_x Conc. (Predicted by Biotool 1.1), Media Residence Time (Flowrate, Media Volume)

[1]Calculated in Biotool 1.1 *Nitrogen Equations* worksheet

included in Appendix A. For each of the 18 cases, analysis and best judgment were used to specify a single equation for use in Biotool 1.1 that provided a conservation predictor of effluent nitrogen concentration. The *selected equations included in the red highlighted plots* in Appendix A and are directly included or used within the *Nitrogen Equations* worksheet of Biotool 1.1. Note that Appendix A includes numerous nitrogen equations that were not selected for use in Biotool 1.1. Effluent organic nitrogen was simulated based on the Total Kjeldahl Nitrogen (TKN) loading rate per empty bed volume of the biofilter. Effluent ammonia nitrogen was simulated based on the effective influent ammonia concentration, the effective ammonia removal efficiency, and the TKN loading rate per empty bed volume of the biofilter. Effluent nitrate+nitrite nitrogen in Stage 1 was simulated based on the influent Total Kjeldahl Nitrogen (TKN) concentration. The rational for basing Stage 1 effluent NO_x solely on influent TKN is related to the conservative nature of real-world engineering. For a practical two-stage biofilter design, Stage 1 will *de facto* operate in a loading region where ammonification and ammonium oxidation are afforded a high degree of completion. In this regime, influent TKN, equivalent to Total Nitrogen, will highly influence effluent NO_x, as modified by denitrification in the unsaturated Stage 1 biofilters and pre-denitrification in Statge 1 recycle systems. Nitrogen equations for single-pass biofilters with sand were estimated by adjusting single-pass expanded clay results based on the relative performance of recycle biofilters with sand and expanded clay media. The organic and ammonia nitrogen concentrations in Stage 1 effluent are the total system (Stage 1 & 2) effluent concentrations for these parameters.

Table 3. Passive Nitrogen Removal Study: Stage 1 Systems

System	Hydraulics	Stage 1 Media	PNRS II Biofilters	Surface Loading Rate, gal./ft^2-day	Media Depth, inch
1	Single Pass	Expanded Clay	UNSAT-EC1 UNSAT-EC3	3	15 - 30
2		Clinoptilolite	UNSAT-CL1 UNSAT-CL3 UNSAT-CL5	3	15 - 30
3		Sand	-	3	15 - 30
4	Recycle	Expanded Clay	UNSAT-EC4	3	15 - 30
5		Clinoptilolite	UNSAT-CL2 UNSAT-CL4	3	15 - 30
6		Sand	UNSAT-SA2	3	15 - 30

Stage 2 Systems For both lignocellulosic and sulfur media Stage 2 biofilters, the user specifies the media depth, surface loading rate, and percent of reactive media. Biotool 1.1 computes derived parameters including the biofilter entry surface area, empty bed volume, and empty bed residence time. The Reactive Media Volume (RMV) is calculated as the product of the empty bed volume and the fraction of the biofilter media that is reactive. The loading rate of nitrate+nitrite nitrogen per RMV volume is computed. Effluent nitrate+nitrite nitrogen concentration equations were developed for each Stage 2 process based on PNRS data (Table 4). For nitrate+nitrite, effluent concentration equations were developed for two denitrification electron donors: lignocellulosic media and elemental sulfur (total of 2 equations). For each of 2 electron donor cases, various candidate equations were evaluated using experimental data from a multitude of experimental biofilters. The PNRS experimental data sets and candidate equations are included in Appendix A. A single equation was selected for each electron donor for use in Biotool 1.1 using best judgment. The *selected equations are highlighted in red* in the plots in Appendix A and are included in the *Nitrogen Equations* worksheet of Biotool 1.1. Biotool 1.1 simulates the effluent nitrate+nitrite nitrogen concentration based on nitrogen equations based on the loading rate of nitrate+nitrite nitrogen per reactive media volume (RMV).

Stage 1 + Stage 2 Systems Biotool 1.1 represents nitrogen removal in total two-stage biofiltration systems as the resultant of organic and ammonia nitrogen removal in Stage 1, the production of nitrate+nitrite in Stage 1, and the removal of nitrate+nitrite in Stage 2. Organic nitrogen and ammonia nitrogen changes in Stage 2 are relatively minor and not considered in the model. Total Nitrogen in the final effluent is equal to the sum of organic and ammonia nitrogen in Stage 1 effluent and nitrate+nitrite in Stage 2 effluent.

Table 4. Passive Nitrogen Removal Study: Stage 2 Systems

System	Hydraulics	Stage 2 Media	PNRS II Biofilters	Surface Loading Rate, gal/ft^2-day	Empty Bed Residence Time, hour
1	Single Pass	Lignocellulosic	DENIT-LS1 DENIT-LS2 DENIT-LS3 DENIT-LS4 DENIT-LS5	5.6 - 10	64 - 108
2	Single Pass	Sulfur	DENIT-SU1 DENIT-SU2 DENIT-SU3 DENIT-SU4	5.6 - 10	64 - 108
3	Single Pass	Lignocellulosic / Sulfur	Stage 2 Systems 1 & 2	5.6 - 10	64 - 108

Biotool 1.1 Application

Biotool 1.1 is applied as a discrete simulation. The user enters data for wastewater characteristics and biofilter process specifications in input fields. Biotool 1.1 automatically predicts performance for the two-stage system, which is included in output fields. The user may then save the Biotool file with a specific name, extract simulation results, or evaluate other model cases by changing the input fields. Biotool 1.1 contains two worksheets: *Input & Output* and *Nitrogen Equations*. *Input & Output* contains fields for input of wastewater quantity and quality, design of the two-stage nitrogen removal process, and output fields for nitrogen input and effluent concentrations for each stage, loading rates and removal efficiencies for each stage, and effluent concentrations and for the two-stage process as a whole. The *Nitrogen Equations* worksheet contains the embedded nitrogen equations and calculation results of intermediate parameters and effluent nitrogen concentrations. The user is only required to interact with *Input & Output* to use Biotool 1.1.

The *Input & Output* fields in Biotool 1.1 are summarized as follows.

Wastewater Input Fields

Cell C13: select 1 if wastewater characteristics are based on user supplied per capita equivalents (Option 1) or select 2 for user supplied values (Option 2)

Cell C17: capita equivalents of wastewater influent (for Option 1)

Cell C20: daily wastewater volume, gallon (for Option 2)

Cell C21: C-BOD_5 concentration, mg/L (for Option 2)

Cell C22: Total Nitrogen Concentration, mg/L (for Option 2)

Cells C24, C25 and C26 provide default values for per capita loading factors and can be optionally modified.

Cell C24: per capita daily wastewater volume generation rate, gallon (for Option 1)

Cell C25: per capita C-BOD_5 generation rate, gram/capita-day (for Option 1)

Cell C26: per capita nitrogen generation rate, gram/capita-day (for Option 1)

Wastewater Output Fields

Cell C29: daily wastewater volume, gallon

Cell C30: C-BOD_5 concentration, mg/L

Cell C31: Total Nitrogen Concentration, mg/L

Nitrogen removals are not affected by the influent C-BOD_5 concentration in Biotool 1.1.

Passive Nitrogen Removal System Input Fields

Stage 1

Cell C52: select 1 for single-pass biofilter or select 2 for recycle biofilter

Cell C56: select 1 for expanded clay, 2 for clinoptilolite, or 3 for sand media

Cell C60: specify depth of media in inches (minimum depth is 15 inch)

The surface loading rate to Stage 1 biofilters is 3 gal/ft^2-day, as per PNRS Stage 1 biofilters.

Stage 2

Cell F52: select 1 for lignocellulosic media, 2 for elemental sulfur media, or 3 for a lignocellulosic media biofilter followed by a sulfur media biofilter

Cell F57: specify media depth of lignocellulosic (LS) biofilter

Cell F58: specify % of lignocellulosic in the biofilter media

Cell F59: specify surface loading rate to LS biofilter

Cell F62: specify media depth of elemental sulfur (ES) biofilter

Cell F63: specify % of elemental sulfur in the biofilter media

Cell F64: specify surface loading rate to ES biofilter

Guidance for biofilter process design is taken from the Passive Nitrogen Removal Study (PNRS) results. The surface loading rate to Stage 1 biofilters, based on PNRS, is 3 gal/ft^2-min. Media depth for Stage 1 biofilters is within or greater that 24 to 40 in. (5 to 8.3 day empty bed contact time). The surface loading rates to Stage 2 lignocellulosic (LS) and elemental sulfur (ES) biofilters are within or less than 5 to 12 gal./ft^2-day. The percent

reactive media for LS and ES biofilters are 50 to 100% and 80 to 100%, respectively. Stage 2 media contact times are within or greater than 100 and 20 hours for LS and ES, respectively. Shorter media contact times may be employed for Stage 2 systems with an LS biofilter followed by an ES biofilter (LS/ES).

Passive Nitrogen Removal System Output Fields The output fields provide a complete summary of the Biotool 1.1 simulation, including influent wastewater characteristics and biofilter designs.

Wastewater Influent

Cell C68: daily wastewater volume, gallon

Cell C69: C-BOD_5 concentration, mg/L

Cell C70: Total Nitrogen Concentration, mg/L

Stage 1

Cell C73: Hydraulics

Cell C74: Media

Cell C75: Media depth

Cell C76: Surface Loading Rate to biofilter

Cell C77: area of biofilter entry surface

Cell C78: empty bed volume

Cell C79: empty bed residence time

Cell C80: TKN loading rate per empty bed volume

Cell C81: effective influent NH_3-N (= influent NH_3-N + change in organic nitrogen)

Cell C82 to F86: effluent nitrogen concentrations

Cell C87: Total Nitrogen reduction efficiency

Cell C88: Effective NH_3-N reduction efficiency

Stage 2 Lignocellulosic (LS)

Cell F73: biofilter media depth

Cell F74: % reactive media

Cell F75: surface loading rate

Cell F76: influent NO_x-N

Cell F77: area of biofilter entry surface

Cell F78: empty bed volume

Cell F79: empty bed residence time

Cell F80: reactive media volume (= empty bed volume x % reactive media / 100)

Cell F81: reactive media residence time

Cell F82: NO_x-N loading per reactive media volume

Cell F83: effluent NO_x-N

Cell F84: NO_x-N removal efficiency

Stage 2 Elemental sulfur (ES)

Cell I73: biofilter media depth

Cell I74: % reactive media

Cell I75: surface loading rate

Cell I76: influent NO_x-N

Cell I77: area of biofilter entry surface

Cell I78: empty bed volume

Cell I79: empty bed residence time

Cell I80: reactive media volume (= empty bed volume x % reactive media / 100)

Cell I81: reactive media residence time

Cell I82: NO_x-N loading per reactive media volume

Cell I83: effluent NO_x-N

Cell I84: NO_x-N removal efficiency

Stage 1 + Stage 2

Cell L73: Total Nitrogen removal efficiency

Cell L74 to L 78: effluent nitrogen concentrations

Example Application An example application of Biotool 1.1 is presented in Table 5. The wastewater in this example has a daily volume of 105 gallon and Total Nitrogen of 54.7 mg/L, which is similar to that of a full scale home site in which a two-stage nitrogen removal system is being evaluated (BHS2). The Stage 1 process in the Biotool 1.1 simulation is a recycle system with 30 in. of expanded clay media, and Stage 2 is a lignocellulosic biofilter followed by a sulfur biofilter. Biotool 1.1 predicts a nitrogen removal efficiency of 94.0% and an effluent total nitrogen of 3.3 mg/L (Table 5).

Biotool 1.1 predictions are based on extensive operation of a multitude of unsaturated biofilters (Stage 1) and saturated biofilters (Stage 2). Biotool 1.1 results show a similarity of performance for Stage 1 biofilters when operating within the PNRS design ranges. The

Table 5. Biotool 1.1 Example Application

Input Fields Wastewater Primary Effluent	
Input Options	Enter 1 or 2
1. User Supplied Capita equivalents	2
2. User Supplied Flow, C-BOD_5 & Total N Conc.	
Option 1	
Capita equivalents	3.5
Option 2	
Daily wastewater volume, gallon	104.5
C-BOD_5 conc., mg/L	192.3
Total Nitrogen conc., mg/L	54.7
Wastewater volume, gallon/capita-day	60
C-BOD_5 Loading Rate, gram/capita-day	42.5
Nitrogen Loading Rate, gram/capita-day	11.2

Output Fields Wastewater Primary Effluent	
Daily volume, gallon	105
C-BOD_5 conc., mg/L	192
Total Nitrogen conc., mg/L	54.7

Input Fields Passive Nitrogen Removal System				
Stage 1			**Stage 2**	
Hydraulics	Enter 1 or 2		Media Configuration	Enter 1,2 or 3
1. Single Pass	2		1. Lignocellulosic (LS)	3
2. Recycle			2. Elemental sulfur (ES)	
			3. Lignocellulosic/ sulfur (LS/ES)	
Media Type	Enter 1, 2 or 3			
1. Expanded Clay	1		**Lignocellulosic (LS)**	
2. Clinoptilolite			Biofilter media depth, in.	42.0
3. Sand			% Reactive Media	100.0
			Surface Loading Rate, gal/ft^2-day	3.2
Media Depth, in.	30.0			
			Elemental Sulfur (ES)	
			Biofilter media depth, in.	24.0
			% Reactive Media	80.0
			Surface Loading Rate, gal/ft^2-day	6.8

Output Fields
Passive Nitrogen Removal System

Wastewater Characteristics	
Daily volume, gallon	104.5
C-BOD5 conc., mg/L	192.3
Total Nitrogen conc., mg/L	54.7

Stage 1	
Hydraulics	Recycle
Media	Expanded Clay
Media depth, in.	30.0
SLR, gal/ft^2-day	3.0
Biofilter entry surface area, ft^2	34.8
Empty bed volume, ft^3	87.1
Empty bed residence time, day	6.2
TKN loading rate, gram/m^3 media EBV-day	8.77
Effective Influent NH_3-N, mg/L	52.0
Effluent Total N, mg/L	34.3
Effluent TKN, mg/L	2.8
Effluent Organic N, mg/L	2.7
Effluent NH_3-N, mg/L	0.12
Effluent NO_x-N, mg/L	31.5
Total Nitrogen Reduction Efficiency, %	37.4
Effective NH_3-N Reduction Efficiency, %	99.8

Stage 2 Lignocellulosic (LS)	
Biofilter media depth, in.	42.0
% Reactive Media	100.0
Surface Loading Rate, gal/ft2-day	3.2
Influent NO_x-N, mg/L	31.5
Biofilter entry surface area, ft^2	32.7
Empty bed volume, ft^3	114.3
Empty bed residence time, day	8.18
Reactive media volume (RMV), ft^3	114.3
Reactive media residence time, day	8.18
NO_x-N loading rate, gram/m^3 RMV-day	3.8
Effluent NO_x-N, mg/L	1.62
NO_x-N Reduction Efficiency, %	94.8

Stage 2 Elemental Sulfur (ES)	
Biofilter media depth, in.	24.0
% Reactive Media	80.0
Surface Loading Rate, gal/ft2-day	6.8
Influent NO_x-N, mg/L	1.62
Biofilter entry surface area, ft^2	15.4
Empty bed volume, ft^3	30.7
Empty bed residence time, day	2.20
Reactive media volume (RMV), ft^3	24.6
Reactive media residence time, day	1.76
NO_x-N loading rate, gram/m^3 RMV-day	0.9
Effluent NO_x-N, mg/L	0.15
NO_x-N Reduction Efficiency, %	90.7

Stage 1 + Stage 2	
Total Nitrogen Removal Efficiency, %	94.6
Effluent Total Nitrogen, mg/L	2.9
Effluent TKN, mg/L	2.8
Effluent Organic N, mg/L	2.7
Effluent NH_3-N, mg/L	0.12
Effluent NO_x-N, mg/L	0.15

Biotool 1.1 model may be used with confidence for Stage 1 design. Biotool 1.1 results show significant differences in NO_x removal for Stage 2 biofilters, with longer residence times and larger biofilter sizes required for lignocellulosic media versus elemental sulfur. Biotool 1.1 may be used with confidence for Stage 2 design for either electron donor media. Biotool 1.1 also supports the simulation of a combined Stage 2 system with a lignocellulosic biofilter followed in series by an elemental sulfur biofilter.

Summary

Biotool 1.1 provides guidance for process design of passive two-stage biofiltration systems for nitrogen removal from onsite wastewater. For systems with proper physical design, nitrogen removal should generally approximate or exceed performance predicted by the model. A significant caution should be exercised when applying Biotool 1.1 for wastewater temperatures that are lower than those of the Passive Nitrogen Removal Study. The Biotool 1.1 model is based on biofilters that operated between 18 and 29C, and colder temperature operation was not verified.

Appendix A

Performance Curve Generation

Numerous candidate equations are shown on this sheet. The equations highlighted in red in the plots were selected for use in Biotool 1.1 as conservative nitrogen predictors.

Predicted Effluent Organic-N	
b	3.36
m	0.0453

Predicted Effective NH_3-N Removal Efficiency, %	
b	99.5
m	-0.10

Predicted Effluent NO_x-N, mg/L	
a	7.13287
b	0.02720
f	0.10

Predicted Effluent NO_x-N, mg/L	
b	27.50
m	1.6710

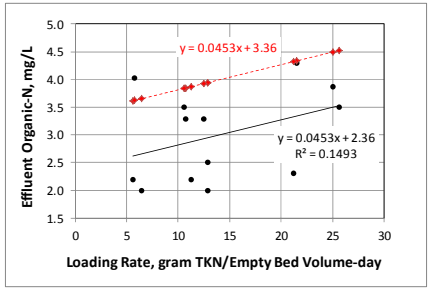
Stage 1

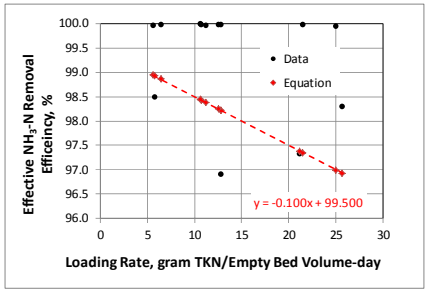
System	1
Hydraulics	Single Pass
Media	Expanded Clay
SLR, gal/ft^2-day	3.0

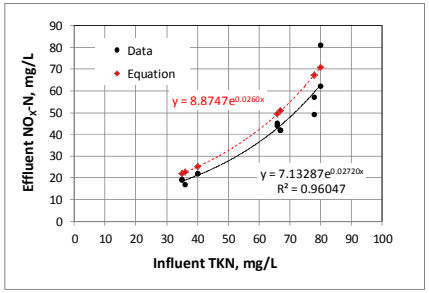
Mean EC-1	3.53	3.02	0.51	41.2	19.6	94.2	5.8	58.0	18.6	99.3	4.25	97.5	47.6	60.2
Mean EC-3	3.39	2.97	0.42	39.1	9.2	93.7	6.3	54.5	8.7	99.3	3.78	98.6	44.0	42.9

Mean	60.8	59.1	1.0	3.5	3.0	0.46	40.1	14.0	93.9	6.1	56.1	13.3	99.3	3.99	98.1	45.7	50.9
Minimum	22.0	35.0	0.4	2.0	2.0	0.01	17.0	5.6	87.5	4.2	32.0	5.1	96.9	3.61	96.9	22.0	36.9
Maximum	93.0	80.0	2.1	4.9	4.3	2.40	81.0	25.7	95.8	12.5	77.5	24.5	100.0	4.52	98.9	70.8	70.4

PNRS II Sample Event	Biofilter	Media depth, inch	EBCT, hours	Influent C-BOD_5, mg/L	Influent TKN, mg/L	Influent C-BOD_5 / TKN, g/g	Effluent TKN, mg/L	Effluent Org N, mg/L	Effluent NH_3-N, mg/L	Effluent NO_x-N, mg/L	TKN Loading Rate, g/m^3 EBV-day	TKN Removal Efficiency, %	TKN Removal Inefficiency, %	Effective Influent NH_3-N, mg/L	Effective Influent NH_3-N Loading rate, g/m^3-day	Effective NH_3 Removal Efficiency, %	Predicted Effluent Organic N, mg/L	Predicted Effective NH_3-N Removal Efficiency, %	Predicted Effluent NO_x-N, mg/L	Predicted Effluent NO_x-N, mg/L
1	UNSAT-EC1	15	75	22.0	35.0	0.63	2.2	2.19	0.01	19.0	11.2	93.7	6.3	32.8	10.5	100.0	3.87	98.4	22.0	46.27
2	UNSAT-EC1	15	75	27.0	67.0	0.40	4.3	4.29	0.01	42.0	21.5	93.6	6.4	62.7	20.1	100.0	4.33	97.4	50.8	63.42
3	UNSAT-EC1	15	75	91.0	80.0	1.14	4.8	3.50	1.30	62.0	25.7	94.0	6.0	76.5	24.5	98.3	4.52	96.9	70.8	70.39
4	UNSAT-EC1	15	75	78.0	66.0	1.18	4.0	2.30	1.70	45.1	21.2	93.9	6.1	63.7	20.4	97.3	4.32	97.4	49.5	62.89
5	UNSAT-EC1	15	75	93.0	78.0	1.19	3.9	3.87	0.04	57.0	25.0	95.0	5.0	74.1	23.8	100.0	4.49	97.0	67.3	69.32
6	UNSAT-EC1	15	75	47.0	40.0	1.18	2.0	2.00	0.01	22.0	12.8	95.0	5.0	38.0	12.2	100.0	3.94	98.2	25.2	48.95
1	UNSAT-EC3	30	150	22.0	35.0	0.63	2.2	2.19	0.01	19.0	5.6	93.7	6.3	32.8	5.3	100.0	3.61	98.9	22.0	36.88
2	UNSAT-EC3	30	150	27.0	67.0	0.40	3.3	3.29	0.01	42.0	10.7	95.1	4.9	63.7	10.2	100.0	3.85	98.4	50.8	45.46
3	UNSAT-EC3	30	150	91.0	80.0	1.14	4.9	2.50	2.40	81.0	12.8	93.9	6.1	77.5	12.4	96.9	3.94	98.2	70.8	48.95
4	UNSAT-EC3	30	150	78.0	66.0	1.18	3.5	3.50	0.01	44.0	10.6	94.7	5.3	62.5	10.0	100.0	3.84	98.4	49.5	45.19
5	UNSAT-EC3	30	150	93.0	78.0	1.19	3.3	3.29	0.01	49.0	12.5	95.8	4.2	74.7	12.0	100.0	3.93	98.2	67.3	48.41
6	UNSAT-EC3	30	150	47.0	40.0	1.18	2.0	2.00	0.01	22.0	6.4	95.0	5.0	38.0	6.1	100.0	3.65	98.9	25.2	38.22
7	UNSAT-EC3	30	150	75.0	36.0	2.08	4.5	4.02	0.48	17.0	5.8	87.5	12.5	32.0	5.1	98.5	3.62	98.9	22.6	37.15







Performance Curve Generation

Numerous candidate equations are shown on this sheet. The equations highlighted in red in the plots were selected for use in Biotool 1.1 as conservative nitrogen predictors.

Stage 1

System	2
Hydraulics	Single Pass
Media	Clinoptilolite
SLR, gal/ft^2-day	3.0

Predicted Effluent Organic-N	
b	3.06
m	0.0800

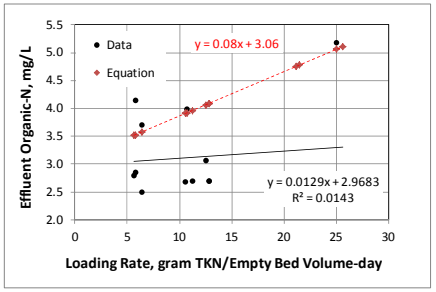
Predicted Effective NH_3-N Removal Efficiency, %	
b	99.8
m	-0.03

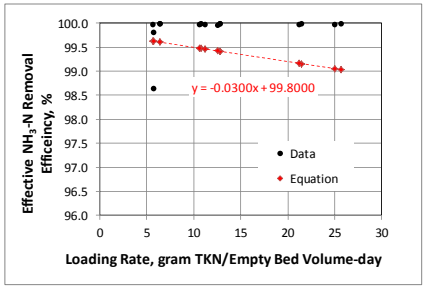
Predicted Effluent NO_x-N, mg/L	
a	4.60690
b	0.03250
f	0.10

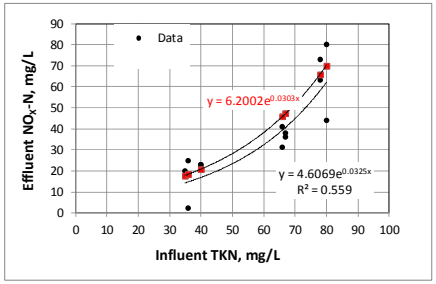
Predicted Effluent NO_x-N, mg/L	
b	34.00
m	1.6230

Mean CL-1	3.12	3.10	0.01	37.9	19.6	94.6	5.4	57.9	18.6	99.98	4.63	99.2	44.7	65.8		
Mean CL-3	3.31	3.29	0.02	41.2	9.2	93.4	6.6	54.1	8.7	99.95	3.80	99.5	40.9	49.0		
Mean CL-5	2.90	2.67	0.23	12.3	6.1	92.3	7.7	35.3	5.7	99.31	3.55	99.6	19.7	43.9		
Mean	60.9	56.3	1.1	3.2	3.1	0.04	36.0	12.9	93.7	6.3	53.1	12.2	99.88	4.10	99.4	39.6	55.0
Minimum	22.0	35.0	0.4	2.5	2.5	0.01	2.5	5.6	88.3	3.3	31.9	5.1	98.64	3.51	99.0	17.9	43.1
Maximum	93.0	80.0	2.1	5.2	5.2	0.45	80.0	25.7	96.8	11.7	77.4	24.8	99.99	5.11	99.6	70.0	75.7

PNRS II Sample Event	Biofilter	Media depth, inch	EBCT, hours	Influent C-BOD_5, mg/L	Influent TKN, mg/L	Influent C-BOD_5 / TKN, g/g	Effluent TKN, mg/L	Effluent Org N, mg/L	Effluent NH_3-N, mg/L	Effluent NO_x-N, mg/L	TKN Loading Rate, g/m^3 EBV-day	TKN Removal Efficiency, %	TKN Removal Inefficiency, %	Effective Influent NH_3-N, mg/L	Effective Influent NH_3-N Loading rate, g/m^3-day	Effective NH_3 Removal Efficiency, %	Predicted Effluent Organic N, mg/L	Predicted Effective NH_3-N Removal Efficiency, %	Predicted Effluent NO_x-N, mg/L	Predicted Effluent NO_x-N, mg/L
1	UNSAT-CL1	15	75	22.0	35.0	0.63	2.7	2.69	0.01	18.0	11.2	92.3	7.7	32.3	10.4	99.97	3.96	99.5	17.9	52.23
2	UNSAT-CL1	15	75	27.0	67.0	0.40	2.8	2.79	0.01	38.0	21.5	95.8	4.2	64.2	20.6	99.98	4.78	99.2	47.4	68.89
3	UNSAT-CL1	15	75	91.0	80.0	1.14	2.6	2.60	0.01	44.0	25.7	96.8	3.3	77.4	24.8	99.99	5.11	99.0	70.0	75.66
4	UNSAT-CL1	15	75	78.0	66.0	1.18	2.7	2.68	0.02	31.2	21.2	95.9	4.1	63.3	20.3	99.97	4.75	99.2	46.0	68.37
5	UNSAT-CL1	15	75	93.0	78.0	1.19	5.2	5.18	0.02	73.0	25.0	93.3	6.7	72.8	23.4	99.97	5.06	99.0	65.9	74.62
6	UNSAT-CL1	15	75	47.0	40.0	1.18	2.7	2.70	0.01	23.0	12.8	93.3	6.8	37.3	12.0	99.99	4.09	99.4	20.9	54.83
1	UNSAT-CL3	30	150	22.0	35.0	0.63	2.8	2.79	0.01	20.0	5.6	92.0	8.0	32.2	5.2	99.97	3.51	99.6	17.9	43.11
2	UNSAT-CL3	30	150	27.0	67.0	0.40	4.0	3.99	0.01	36.0	10.7	94.0	6.0	63.0	10.1	99.98	3.92	99.5	47.4	51.45
3	UNSAT-CL3	30	150	91.0	80.0	1.14	2.7	2.70	0.01	80.0	12.8	96.6	3.4	77.3	12.4	99.99	4.09	99.4	70.0	54.83
4	UNSAT-CL3	30	150	78.0	66.0	1.18	2.7	2.68	0.02	41.1	10.6	95.9	4.1	63.3	10.2	99.97	3.91	99.5	46.0	51.18
5	UNSAT-CL3	30	150	93.0	78.0	1.19	3.1	3.07	0.03	63.0	12.5	96.0	4.0	74.9	12.0	99.96	4.06	99.4	65.9	54.31
6	UNSAT-CL3	30	150	47.0	40.0	1.18	3.7	3.70	0.01	23.0	6.4	90.8	9.3	36.3	5.8	99.99	3.57	99.6	20.9	44.41
7	UNSAT-CL3	30	150	75.0	36.0	2.08	4.2	4.14	0.06	25.0	5.8	88.3	11.7	31.9	5.1	99.81	3.52	99.6	18.4	43.37
6	UNSAT-CL5	30	150	47.0	40.0	1.18	2.5	2.50	0.01	22.0	6.4	93.8	6.3	37.5	6.0	99.99	3.57	99.6	20.9	44.41
7	UNSAT-CL5	30	150	75.0	36.0	2.08	3.3	2.85	0.45	2.5	5.8	90.8	9.2	33.2	5.3	98.64	3.52	99.6	18.4	43.37







Biotool 1.1 Model and User Guide
Dr. Daniel P. Smith
Applied Environmental Technology
February 12, 2015

Performance Curve Generation

The equations highlighted in red in the plots were selected for use in Biotool 1.1 as conservative nitrogen predictors.

Stage 1

System	3
Hydraulics	Single Pass
Media	Sand
SLR, gal/ft^2-day	3.0

Predicted Effluent Organic-N	
b	3.76
m	0.0453

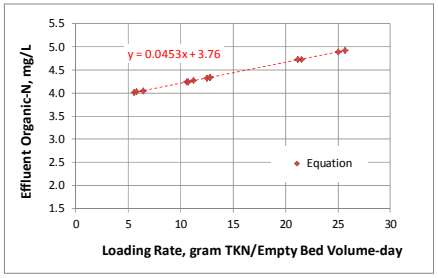
Predicted Effective NH_3-N Removal Efficiency, %	
b	99.1
m	-0.10

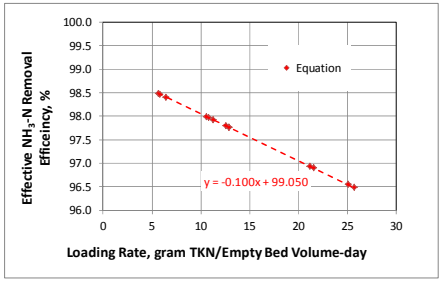
Predicted Effluent NO_x-N, mg/L	
a	7.13287
b	0.02720
f	0.10

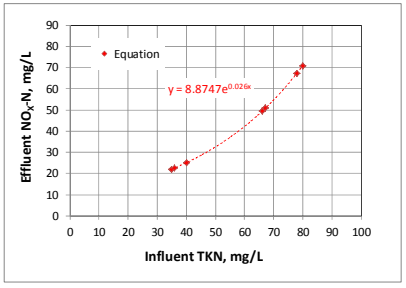
Predicted Effluent NO_x-N	
b	24.50
m	1.7300

		19.6	4.65	97.1	47.6	58.4
		9.2	4.18	98.1	44.0	40.4
Mean	59.1	14.0	4.39	97.7	45.7	48.7
Minimum	35.0	5.6	4.01	96.5	22.0	34.2
Maximum	80.0	25.7	4.92	98.5	70.8	68.9

Influent TKN, mg/L	TKN Loading Rate, g/m^3 EBV-day	Predicted Effluent Organic N, mg/L	Predicted Effective NH_3-N Removal Efficiency, %	Predicted Effluent NO_x-N, mg/L	Predicted Effluent NO_x-N, mg/L
35.0	11.2	4.27	97.9	22.0	43.93
67.0	21.5	4.73	96.9	50.8	61.69
80.0	25.7	4.92	96.5	70.8	68.91
66.0	21.2	4.72	96.9	49.5	61.14
78.0	25.0	4.89	96.5	67.3	67.80
40.0	12.8	4.34	97.8	25.2	46.70
35.0	5.6	4.01	98.5	22.0	34.21
67.0	10.7	4.25	98.0	50.8	43.10
80.0	12.8	4.34	97.8	70.8	46.70
66.0	10.6	4.24	98.0	49.5	42.82
78.0	12.5	4.33	97.8	67.3	46.15
40.0	6.4	4.05	98.4	25.2	35.60
36.0	5.8	4.02	98.5	22.6	34.49







Performance Curve Generation

Numerous candidate equations are shown on this sheet. The equations highlighted in red in the plots were selected for use in Biotool 1.1 as conservative nitrogen predictors.

Predicted Effluent Organic-N	
b	2.34
m	0.0384

Predicted Effective NH_3-N Removal Efficiency, %	
b	99.774
m	-0.0001

Predicted Effluent NO_x-N, mg/L	
a	8.42886
b	0.02081
f	0.10

Predicted Effluent NO_x-N, mg/L	
b	7.20
m	3.7400

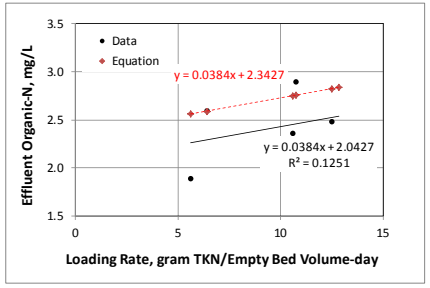
Stage 1

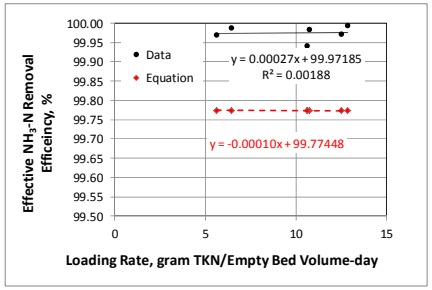
System	4
Hydraulics	Recycle
Media	Expanded Clay
SLR, gal/ft^2-day	3.0

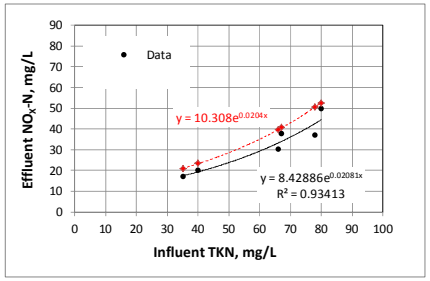
Mean EC-4	2.43	2.42	0.01	32.1	9.8	95.7	4.3	58.6	9.4	99.97	2.72	99.8	38.0	43.80		

Mean	59.7	61.0	1.0	2.4	2.4	0.01	32.1	9.8	95.7	4.3	58.6	9.4	99.97	2.72	99.8	38.0	43.80
Minimum	22.0	35.0	0.4	1.9	1.9	0.01	17.0	5.6	93.5	2.9	33.1	5.3	99.94	2.56	99.8	21.0	28.20
Maximum	93.0	80.0	1.2	2.9	2.9	0.04	50.0	12.8	97.1	6.5	77.7	12.5	99.99	2.84	99.8	52.5	55.20

PNRS II Sample Event	Biofilter	Media depth, inch	EBCT, hours	Influent C-BOD_5, mg/L	Influent TKN, mg/L	Influent C-BOD_5 / TKN, g/g	Effluent TKN, mg/L	Effluent Org N, mg/L	Effluent NH_3-N, mg/L	Effluent NO_x-N, mg/L	TKN Loading Rate, g/m^3 EBV-day	TKN Removal Efficiency, %	TKN Removal Inefficiency, %	Effective Influent NH_3-N, mg/L	Effective Influent NH_3-N Loading rate, g/m^3-day	Effective NH_3 Removal Efficiency, %	Predicted Effluent Organic N, mg/L	Predicted Effective NH_3-N Removal Efficiency, %	Predicted Effluent NO_x-N, mg/L	Predicted Effluent NO_x-N, mg/L
1	UNSAT-EC4	30	150	22.0	35.0	0.63	1.9	1.89	0.01	17.0	5.6	94.6	5.4	33.1	5.3	99.97	2.56	99.8	21.0	28.20
2	UNSAT-EC4	30	150	27.0	67.0	0.40	2.9	2.89	0.01	38.0	10.7	95.7	4.3	64.1	10.3	99.98	2.76	99.8	40.7	47.40
3	UNSAT-EC4	30	150	91.0	80.0	1.14	2.3	2.30	0.01	50.0	12.8	97.1	2.9	77.7	12.5	99.99	2.84	99.8	52.5	55.20
4	UNSAT-EC4	30	150	78.0	66.0	1.18	2.4	2.36	0.04	30.5	10.6	96.4	3.6	63.6	10.2	99.94	2.75	99.8	39.9	46.80
5	UNSAT-EC4	30	150	93.0	78.0	1.19	2.5	2.48	0.02	37.0	12.5	96.8	3.2	75.5	12.1	99.97	2.82	99.8	50.5	54.00
6	UNSAT-EC4	30	150	47.0	40.0	1.18	2.6	2.60	0.01	20.0	6.4	93.5	6.5	37.4	6.0	99.99	2.59	99.8	23.4	31.20







Performance Curve Generation

Numerous candidate equations are shown on this sheet. The equations highlighted in red in the plots were selected for use in Biotool 1.1 as conservative nitrogen predictors.

Predicted Effluent Organic-N	
b	2.68
m	0.0113

Predicted Effective NH_3-N Removal Efficiency, %	
b	99.780
m	-0.0001

Predicted Effluent NO_x-N, mg/L	
a	5.26380
b	0.02710
f	0.10

Predicted Effluent NO_x-N, mg/L	
b	28.50
m	0.9550

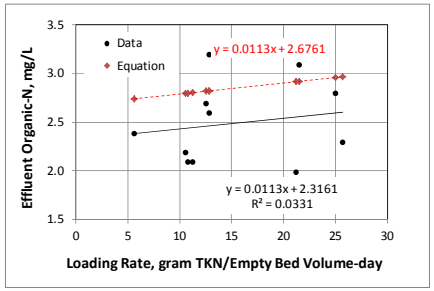
Stage 1

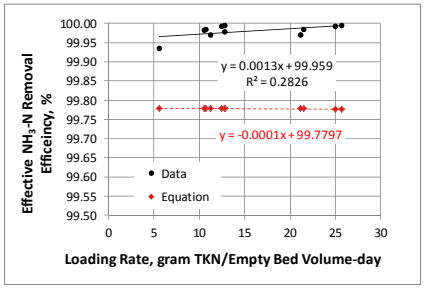
System	5
Hydraulics	Recycle
Media	Clinoptilolite
SLR, gal/ft^2-day	3.0

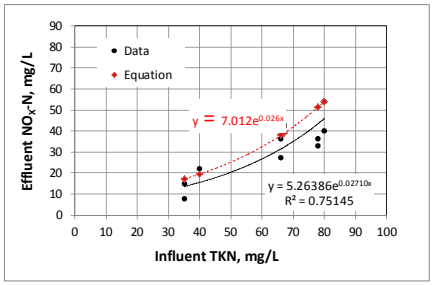
Mean CL-2	2.58	2.57	0.01	32.7	19.6	95.3	4.7	58.4	18.7	99.98	2.90	99.8	36.5	47.19			
Mean CL-4	2.40	2.39	0.01	32.0	10.5	96.0	4.0	62.8	10.1	99.98	2.79	99.8	39.9	38.49			

Mean	60.8	62.9	0.9	2.5	2.5	0.01	32.4	15.4	95.6	4.4	60.4	14.8	99.98	2.85	99.8	38.1	43.24
Minimum	22.0	35.0	0.4	2.0	2.0	0.01	7.9	5.6	92.0	2.9	32.6	5.2	99.94	2.74	99.8	17.1	33.86
Maximum	93.0	80.0	1.2	3.2	3.2	0.02	54.0	25.7	97.1	8.0	77.7	24.9	99.99	2.97	99.8	54.0	53.01

PNRS II Sample Event	Biofilter	Media depth, inch	EBCT, hours	Influent C-BOD_5, mg/L	Influent TKN, mg/L	Influent C-BOD_5 / TKN, g/g	Effluent TKN, mg/L	Effluent Org N, mg/L	Effluent NH_3-N, mg/L	Effluent NO_x-N, mg/L	TKN Loading Rate, g/m^3 EBV-day	TKN Removal Efficiency, %	TKN Removal Inefficiency, %	Effective Influent NH_3-N, mg/L	Effective Influent NH_3-N Loading rate, g/m^3-day	Effective NH_3 Removal Efficiency, %	Predicted Effluent Organic N, mg/L	Predicted Effective NH_3-N Removal Efficiency, %	Predicted Effluent NO_x-N, mg/L	Predicted Effluent NO_x-N, mg/L
1	UNSAT-CL2	15	75	22.0	35.0	0.63	2.1	2.09	0.01	15.0	11.2	94.0	6.0	32.9	10.6	99.97	2.80	99.8	17.1	39.22
2	UNSAT-CL2	15	75	27.0	67.0	0.40	3.1	3.09	0.01	42.0	21.5	95.4	4.6	63.9	20.5	99.98	2.92	99.8	39.0	49.03
3	UNSAT-CL2	15	75	91.0	80.0	1.14	2.3	2.30	0.01	54.0	25.7	97.1	2.9	77.7	24.9	99.99	2.97	99.8	54.0	53.01
4	UNSAT-CL2	15	75	78.0	66.0	1.18	2.0	1.98	0.02	27.2	21.2	97.0	3.0	64.0	20.5	99.97	2.92	99.8	38.1	48.72
5	UNSAT-CL2	15	75	93.0	78.0	1.19	2.8	2.79	0.01	36.2	25.0	96.4	3.6	75.2	24.1	99.99	2.96	99.8	51.4	52.40
6	UNSAT-CL2	15	75	47.0	40.0	1.18	3.2	3.19	0.01	22.0	12.8	92.0	8.0	36.8	11.8	99.98	2.82	99.8	19.6	40.76
1	UNSAT-CL4	30	150	22.0	35.0	0.63	2.4	2.38	0.02	7.9	5.6	93.1	6.9	32.6	5.2	99.94	2.74	99.8	17.1	33.86
2	UNSAT-CL4	30	150	27.0	67.0	0.40	2.1	2.09	0.01	43.0	10.7	96.9	3.1	64.9	10.4	99.98	2.80	99.8	39.0	38.76
3	UNSAT-CL4	30	150	91.0	80.0	1.14	2.6	2.60	0.01	40.0	12.8	96.8	3.3	77.4	12.4	99.99	2.82	99.8	54.0	40.76
4	UNSAT-CL4	30	150	78.0	66.0	1.18	2.2	2.19	0.01	36.2	10.6	96.7	3.3	63.8	10.2	99.98	2.80	99.8	38.1	38.61
5	UNSAT-CL4	30	150	93.0	78.0	1.19	2.7	2.69	0.01	33.0	12.5	96.5	3.5	75.3	12.1	99.99	2.82	99.8	51.4	40.45







Performance Curve Generation

Numerous candidate equations are shown on this sheet. The equations highlighted in red in the plots were selected for use in Biotool 1.1 as conservative nitrogen predictors.

Predicted Effluent Organic-N	
b	2.40
m	0.0384

Predicted Effective NH_3-N Removal Efficiency, %	
b	99.3215
m	-0.00010

Predicted Effluent NO_x-N, mg/L	
a	9.73223
b	0.01656
f	0.10

Predicted Effluent NOx-N, mg/L	
b	5.65
m	3.3300

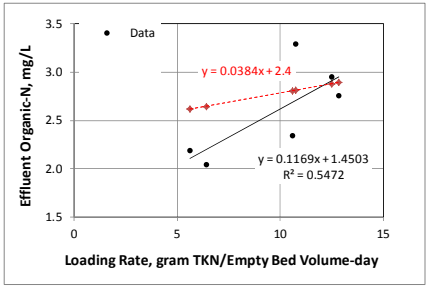
Stage 1

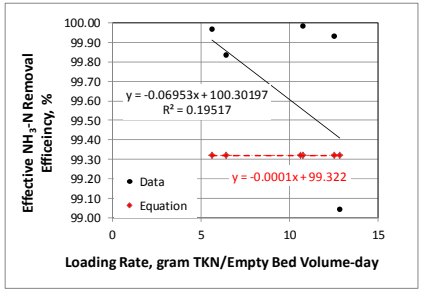
System	6
Hydraulics	Recycle
Media	Sand
SLR, gal/ft^2-day	3.0

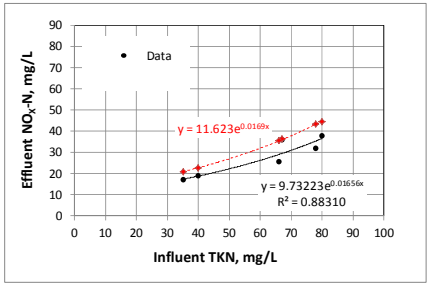
Mean SA-2	2.85	2.59	0.26	28.0	9.8	95.1	4.9	58.4	9.4	99.62	2.78	99.3	33.9	38.2			

Mean	59.7	61.0	1.0	2.9	2.6	0.26	28.0	9.8	95.1	4.9	58.4	9.4	99.62	2.78	99.3	33.9	38.2
Minimum	22.0	35.0	0.4	2.1	2.0	0.01	17.0	5.6	93.7	3.8	32.8	5.3	98.96	2.62	99.3	20.9	24.3
Maximum	93.0	80.0	1.2	3.5	3.3	0.74	38.0	12.8	96.2	6.3	77.2	12.4	99.98	2.89	99.3	44.6	48.4

PNRS II Sample Event	Biofilter	Media depth, inch	EBCT, hours	Influent C-BOD_5, mg/L	Influent TKN, mg/L	Influent C-BOD_5 / TKN, g/g	Effluent TKN, mg/L	Effluent Org N, mg/L	Effluent NH_3-N, mg/L	Effluent NO_x-N, mg/L	TKN Loading Rate, g/m^3 EBV-day	TKN Removal Efficiency, %	TKN Removal Inefficiency, %	Effective Influent NH_3-N, mg/L	Effective Influent NH_3-N Loading rate, g/m^3-day	Effective NH_3 Removal Efficiency, %	Predicted Effluent Organic N, mg/L	Predicted Effective NH_3-N Removal Efficiency, %	Predicted Effluent NO_x-N, mg/L	Predicted Effluent NO_x-N, mg/L
1	UNSAT-SA-2	30	150	22.0	35.0	0.63	2.2	2.19	0.01	17.0	5.6	93.7	6.3	32.8	5.3	99.97	2.62	99.3	20.9	24.35
2	UNSAT-SA-2	30	150	27.0	67.0	0.40	3.3	3.29	0.01	36.0	10.7	95.1	4.9	63.7	10.2	99.98	2.81	99.3	36.2	41.44
3	UNSAT-SA-2	30	150	91.0	80.0	1.14	3.5	2.76	0.74	38.0	12.8	95.6	4.4	77.2	12.4	99.04	2.89	99.3	44.6	48.39
4	UNSAT-SA-2	30	150	78.0	66.0	1.18	3.0	2.34	0.66	25.7	10.6	95.5	4.5	63.7	10.2	98.96	2.81	99.3	35.6	40.91
5	UNSAT-SA-2	30	150	93.0	78.0	1.19	3.0	2.95	0.05	32.0	12.5	96.2	3.8	75.1	12.0	99.93	2.88	99.3	43.2	47.32
6	UNSAT-SA-2	30	150	47.0	40.0	1.18	2.1	2.04	0.06	19.0	6.4	94.8	5.3	38.0	6.1	99.84	2.65	99.3	22.9	27.02







Performance Curve Generation

Numerous candidate equations are shown on this sheet. The equation highlighted in red in the plot was selected for use in Biotool 1.1 as a conservative nitrogen predictor.

Stage 2

System	1
Hydraulics	Single Pass
Media	Lignocellulosic

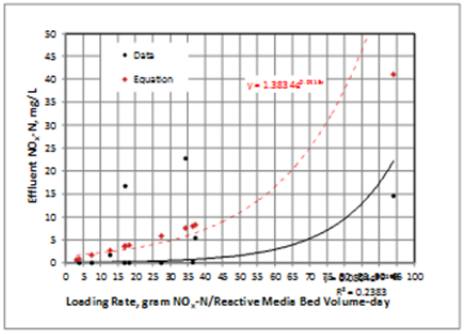
Predicted Effluent NO_x-N, mg/L	
a	0.080
b	0.0598
f	0.200

Predicted NO_x-N Removal Efficiency, %	
b	97.000
m	-0.3000

Mean LS-1	21.24	0.020	9.5	99.9	9.5	2.04	92.3
Mean LS-2	37.01	14.220	55.2	52.2	34.0	18.89	69.4
Mean LS-3	29.67	6.177	22.1	72.3	17.5	4.80	85.9
Mean LS-4	13.07	0.217	16.2	91.9	16.0	3.50	90.6

Mean	25.25	5.158	25.8	79.1	19.2	7.31	84.5
Minimum	2.50	0.010	3.1	1.1	0.4	0.72	50.0
Maximum	63.01	22.760	94.0	99.9	72.4	40.98	95.4

PNRS II Sample Event	Biofilter	Media depth, inch	Entrance Surface Area, ft^2	Empty Bed Volume, ft^3	% Reactive Media	Reactive Media Bed Volume (RMBV), ft^3	Surface Loading Rate, $gal./ft^2$-day	Empty Bed Contact Time, hours	Reactive Media Contact Time, hours	Influent NO_x-N, mg/L	Effluent NO_x-N, mg/L	NO_x-N Loading Rate, g/m^3 RMBV-day	NO_x-N Removal Efficiency, %	NO_x-N Removal Rate, g/m^3 RMBV-day	Predicted Effluent NO_x-N, mg/L	Predicted NO_x-N Removal Efficiency, mg/L
5	DENIT-LS1	72	0.196	1.18	50	0.59	10.00	107.7	53.9	38.01	0.020	16.94	99.9	16.9	3.61	88.5
6	DENIT-LS1	72	0.196	1.18	50	0.59	10.00	107.7	53.9	17.01	0.030	7.58	99.8	7.6	1.64	93.2
7	DENIT-LS1	72	0.196	1.18	50	0.59	10.00	107.7	53.9	8.70	0.010	3.88	99.9	3.9	0.88	95.1
5	DENIT-LS2	24	2.638	5.28	25	1.32	5.58	64.4	16.1	63.01	14.500	93.98	77.0	72.4	40.98	50.0
6	DENIT-LS2	24	2.638	5.28	25	1.32	5.58	64.4	16.1	23.01	22.760	34.32	1.1	0.4	7.49	79.8
7	DENIT-LS2	24	2.638	5.28	25	1.32	5.58	64.4	16.1	25.00	3.400	37.29	78.4	29.2	8.21	78.4
5	DENIT-LS3	24	2.638	5.28	50	2.64	5.58	64.4	32.2	49.01	0.070	36.55	99.9	36.5	8.03	78.7
6	DENIT-LS3	24	2.638	5.28	50	2.64	5.58	64.4	32.2	23.01	16.760	17.16	27.2	4.7	3.66	88.4
7	DENIT-LS3	24	2.638	5.28	50	2.64	5.58	64.4	32.2	17.00	1.700	12.68	90.0	11.4	2.71	90.7
5	DENIT-LS4	24	2.638	5.28	30	1.58	5.58	64.4	19.3	14.70	0.030	18.27	99.8	18.2	3.89	87.9
6	DENIT-LS4	24	2.638	5.28	30	1.58	5.58	64.4	19.3	22.01	0.020	27.36	99.9	27.3	5.88	88.4
7	DENIT-LS4	24	2.638	5.28	30	1.58	5.58	64.4	19.3	2.50	0.600	3.11	76.0	2.4	0.72	95.4



Biotool 1.1 Model and User Guide
Dr. Daniel P. Smith
Applied Environmental Technology
February 12, 2015

Performance Curve Generation

Numerous candidate equations are shown on this sheet. The equation highlighted in red in the plot was selected for use in Biotool 1.1 as a conservative nitrogen predictor.

Stage 2

System 2
Hydraulics Single Pass
Media Sulfur

Predicted Effluent NO_x-N, mg/L	
b	0.1500
m	0.0009

Predicted NO_x-N Removal Efficiency, %	
b	99.200
m	-0.0004

Mean SU-1	26.35	0.110	7.3	99.5	7.3	0.16	99.20
Mean SU-2	25.02	0.035	18.6	99.8	18.6	0.17	99.19
Mean SU-3	26.35	0.05	12.28	99.78	12.26	0.16	99.20
Mean SU-4	25.02	0.075	31.1	99.7	31.0	0.18	99.19

Mean	25.82	0.069	15.8	99.7	15.8	0.16	99.19
Minimum	16.00	0.010	4.5	98.8	4.4	0.15	99.18
Maximum	40.00	0.350	47.2	99.9	47.2	0.19	99.20

PNRS II Sample Event	Biofilter	Media depth, inch	Entrance Surface Area, ft^2	Empty Bed Volume, ft^3	% Reactive Media	Reactive Media Bed Volume (RMBV), ft^3	Surface Loading Rate, $gal./ft^2$-day	Empty Bed Contact Time, hours	Reactive Media Contact Time, hours	Influent NO_x-N, mg/L	Effluent NO_x-N, mg/L	NO_x-N Loading Rate, g/m^3 RMBV-day	NO_x-N Removal Efficiency, %	NO_x-N Removal Rate, g/m^3 RMBV-day	Predicted Effluent NO_x-N, mg/L	Predicted Effluent NO_x-N, mg/L
1	DENIT-SU1	72	0.196	1.18	80	0.94	10.00	107.7	86.2	18.00	0.010	5.01	99.9	5.0	0.15	99.20
2	DENIT-SU1	72	0.196	1.18	80	0.94	10.00	107.7	86.2	40.00	0.040	11.14	99.9	11.1	0.16	99.20
3	DENIT-SU1	72	0.196	1.18	80	0.94	10.00	107.7	86.2	16.00	0.140	4.46	99.1	4.4	0.15	99.20
4	DENIT-SU1	72	0.196	1.18	80	0.94	10.00	107.7	86.2	29.06	0.350	8.09	98.8	8.0	0.16	99.20
5	DENIT-SU1	72	0.196	1.18	80	0.94	10.00	107.7	86.2	38.01	0.060	10.59	99.8	10.6	0.16	99.20
6	DENIT-SU1	72	0.196	1.18	80	0.94	10.00	107.7	86.2	17.01	0.060	4.74	99.6	4.7	0.15	99.20
3	DENIT-SU2	72	0.196	1.18	30	0.35	10.00	107.7	32.3	16.00	0.030	11.88	99.8	11.9	0.16	99.20
4	DENIT-SU2	72	0.196	1.18	30	0.35	10.00	107.7	32.3	29.06	0.060	21.58	99.8	21.5	0.17	99.19
5	DENIT-SU2	72	0.196	1.18	30	0.35	10.00	107.7	32.3	38.01	0.020	28.23	99.9	28.2	0.18	99.19
6	DENIT-SU2	72	0.196	1.18	30	0.35	10.00	107.7	32.3	17.01	0.030	12.63	99.8	12.6	0.16	99.19
1	DENIT-SU3	24	2.638	5.28	80	4.22	5.58	64.4	51.5	18.00	0.010	8.39	99.9	8.4	0.16	99.20
2	DENIT-SU3	24	2.638	5.28	80	4.22	5.58	64.4	51.5	40.00	0.039	18.64	99.9	18.6	0.17	99.19
3	DENIT-SU3	24	2.638	5.28	80	4.22	5.58	64.4	51.5	16.00	0.050	7.46	99.7	7.4	0.16	99.20
4	DENIT-SU3	24	2.638	5.28	80	4.22	5.58	64.4	51.5	29.06	0.050	13.55	99.8	13.5	0.16	99.19
5	DENIT-SU3	24	2.638	5.28	80	4.22	5.58	64.4	51.5	38.01	0.020	17.72	99.9	17.7	0.17	99.19
6	DENIT-SU3	24	2.638	5.28	80	4.22	5.58	64.4	51.5	17.01	0.110	7.93	99.4	7.9	0.16	99.20
3	DENIT-SU4	24	2.638	5.28	30	1.58	5.58	64.4	19.3	16.00	0.020	19.89	99.9	19.9	0.17	99.19
4	DENIT-SU4	24	2.638	5.28	30	1.58	5.58	64.4	19.3	29.06	0.130	36.12	99.6	36.0	0.18	99.19
5	DENIT-SU4	24	2.638	5.28	30	1.58	5.58	64.4	19.3	38.01	0.030	47.25	99.9	47.2	0.19	99.18
6	DENIT-SU4	24	2.638	5.28	30	1.58	5.58	64.4	19.3	17.01	0.120	21.14	99.3	21.0	0.17	99.19