

Protocol and Interactive Routine for the Design of Subsurface Bioreactors in the Midwest

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The layman finds such a law as

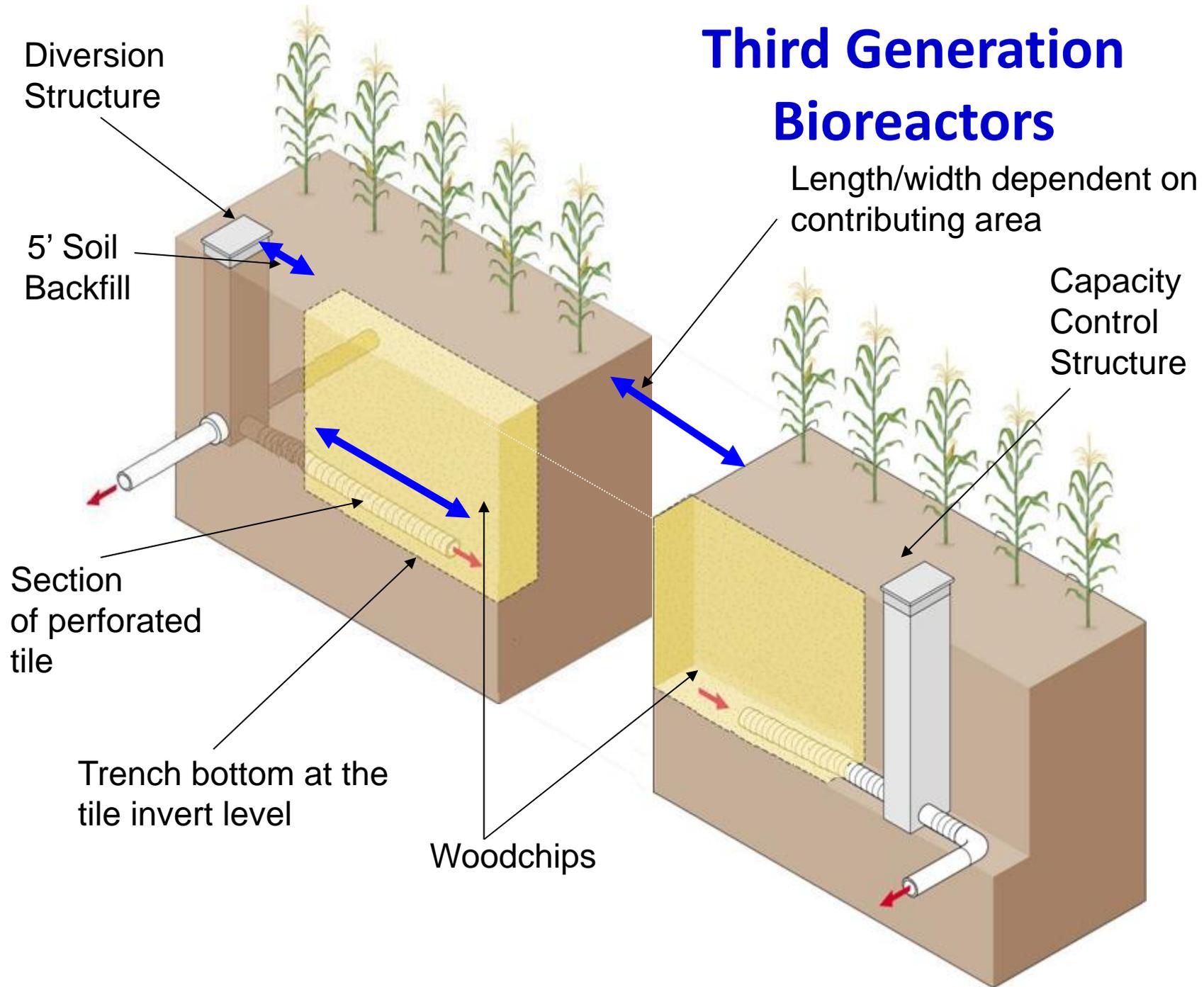
$$\frac{\partial \theta}{\partial t} = D \frac{\partial^2 \theta}{\partial x^2}$$

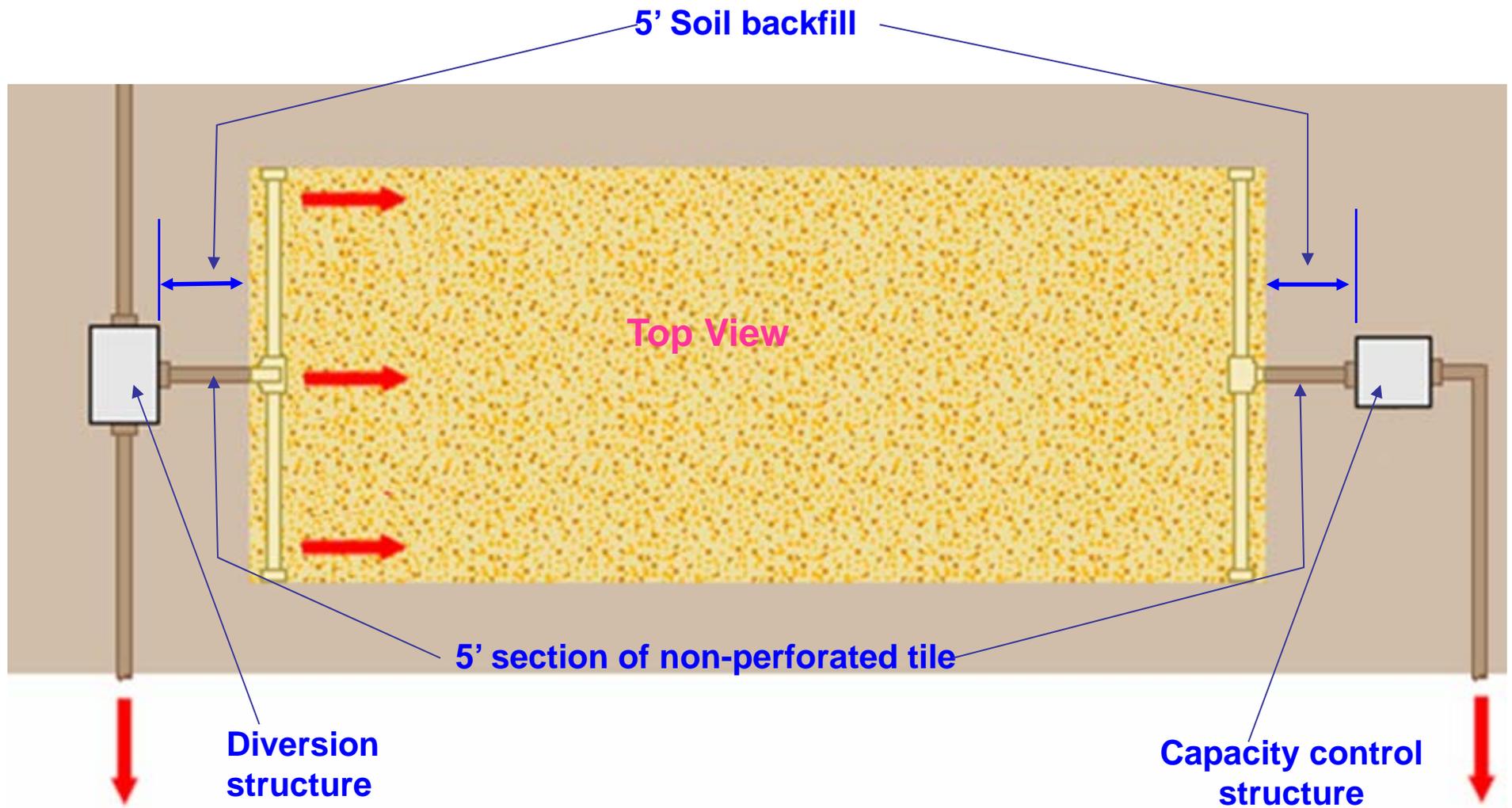
much less simple than "it oozes," of which it is the mathematical statement. The physicist reverses this judgment, and his statement is certainly the more fruitful of the two, so far as prediction is concerned. It is, however, a statement about something very unfamiliar to the plainman (*sic*).

J. B. S. Haldane

Possible Worlds and Other Papers (1927)

Third Generation Bioreactors





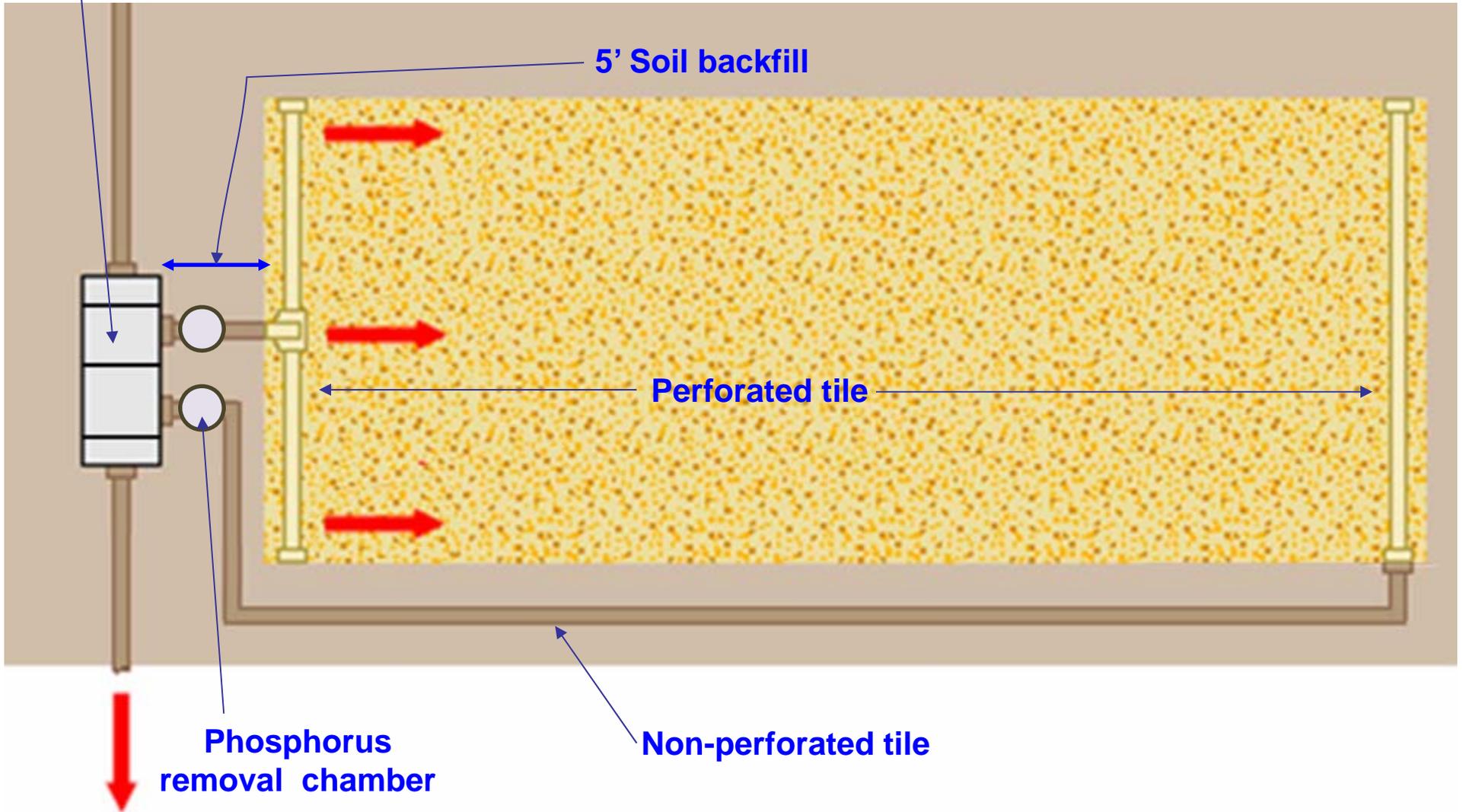
Combination structure

5' Soil backfill

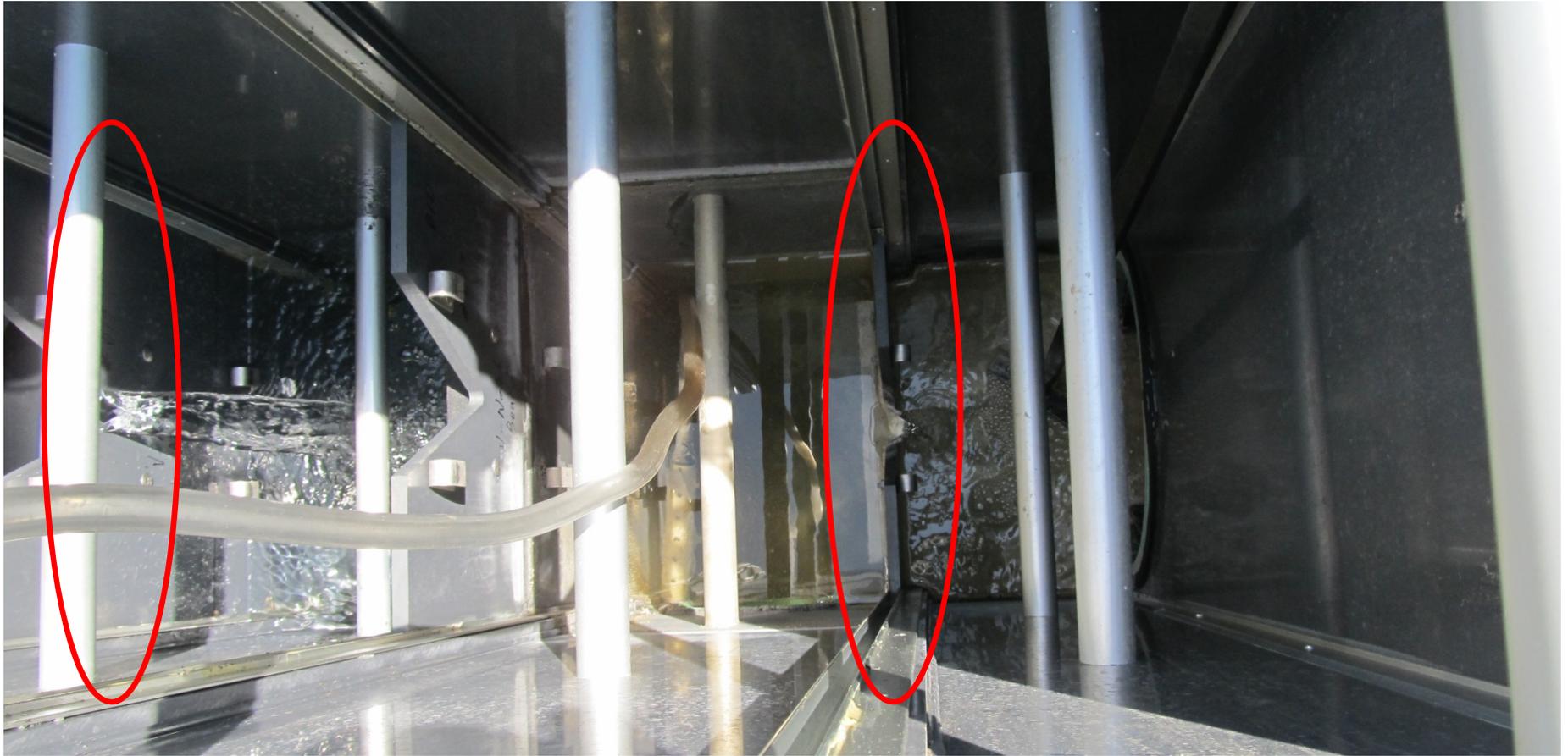
Perforated tile

Phosphorus removal chamber

Non-perforated tile

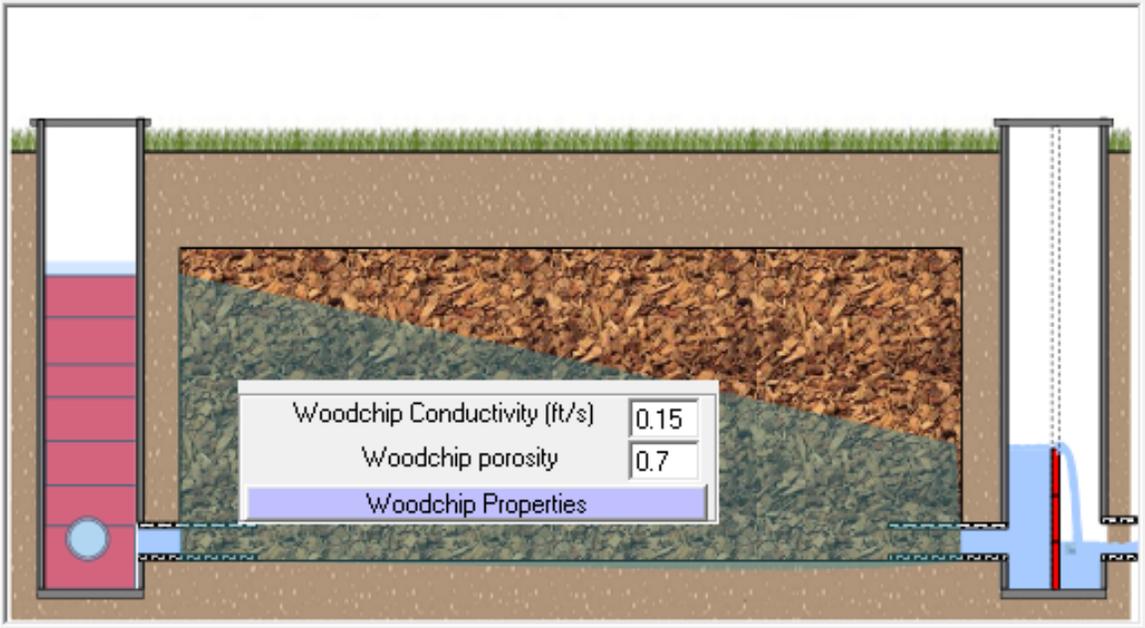






Main Interface

Bioreactor Evaluation



Parameter	Value
Contributing Drainage System (acres)	20
Design Flow Rate (in/day)	0.075
Exceedance Probability for Design Flow (%)	10
Height of Upstream Stoplogs During Critical Period (inches)	24
Bioreactor Surface Area (square feet)	453
Width (feet)	10
Length (feet)	45.3
Thickness (inches)	48
Height of Downstream Stoplogs During Critical Period (inches)	7
Woodchip Conductivity (ft/s)	0.15
Woodchip porosity	0.7

Design Parameters

Volumetric Design Flow Rate (cfs)	0.063
Anticipated Annual Load Removal (%)	50
Actual Flow Capacity (cfs)	.061
Actual Flow/Design Flow (%)	96.2
Hydraulic Residence Time (hours)	1.9

Update
Cost Analysis
Performance Analysis
Create Report
Exit

Save Session Restore Session Acknowledgements

Popup Help Screens

The image shows a software application window titled "Bioreactor Evaluation" with a central diagram of a bioreactor cross-section. A popup window titled "Bioreactor Thickness (feet)" is overlaid on the main window, providing detailed information about the woodchip layer. The main window displays various input and output parameters for the bioreactor.

Bioreactor Evaluation Parameters:

Parameter	Value
Contributing Drainage System (acres)	20
Design Flow Rate (in/day)	0.075
Bioreactor Surface Area (square feet)	453
Width (feet)	10
Length (feet)	45.3
Volumetric Design Flow Rate (cfs)	0.063
Anticipated Annual Load Removal (%)	50
Actual Flow/Design Flow (%)	96.2
Hydraulic Residence Time (hours)	1.9

Bioreactor Thickness (feet) Help Text:

i This is the thickness of the woodchip layer. Where possible, such as when a bioreactor is located in a filter strip or an uncultivated area, this layer should extend to the soil surface. Woodchips under a soil layer will be compressed, resulting in reduced porosity and hydraulic conductivity. These properties should be determined under the conditions that will prevail at the site. The woodchips should be separated from an overlying soil layer by a plastic or geotextile liner.

Buttons: OK, Save Session, Restore Session, Acknowledgements, Cost Analysis, Performance Analysis, Create Report, Exit

Contributing Area

Based on size and slope of outlet pipe

$$A_c = 0.311 \frac{d^{2.67} s^{0.5}}{Dc \cdot n}$$

Contributing Area

Based on tile lengths and intersection angles

$$A_c = SL + \left(\frac{\pi E}{8} - \frac{I}{\cos(\alpha)} \right) S^2$$

Contributing Area

Bioreactor Evaluation

Contributing Drainage System (acres) **23.02**

Bioreactor Surface Area (square feet) **453**

Contributing Area of Drainage System

Unknown Intersection Angles Known Intersection Angle Laterals Perpendicular to Main

Cumulative tile length (feet)

Spacing (feet)

of tile ends (outlet excluded)

of tile intersections

Tile intersection angle (degrees)

Area of Influence (acres)

Update **Reset** **Close Window**

Area = $S(L1 + L2) + 2(\pi S^2/8) - [S^2/2\text{Cos}(\alpha)]$

The diagram illustrates the calculation of the contributing area for a drainage system. It shows a main tile of length $L1$ and a lateral tile of length $L2$ intersecting at an angle α . The diagram includes labels for "Add ends" and "Subtract overlap", and a diagram of a triangular overlap area.

Woodchip Properties



Sizing Criteria

Flow rate

Residence time

Performance



Design Flow Rate

10-year, 24 hour drain
outflow event

- Grassed waterways
(NRCS-412)
- Constructed wetlands
(NRCS-656)





Design Flow Rate

DRAINMOD

Simulations

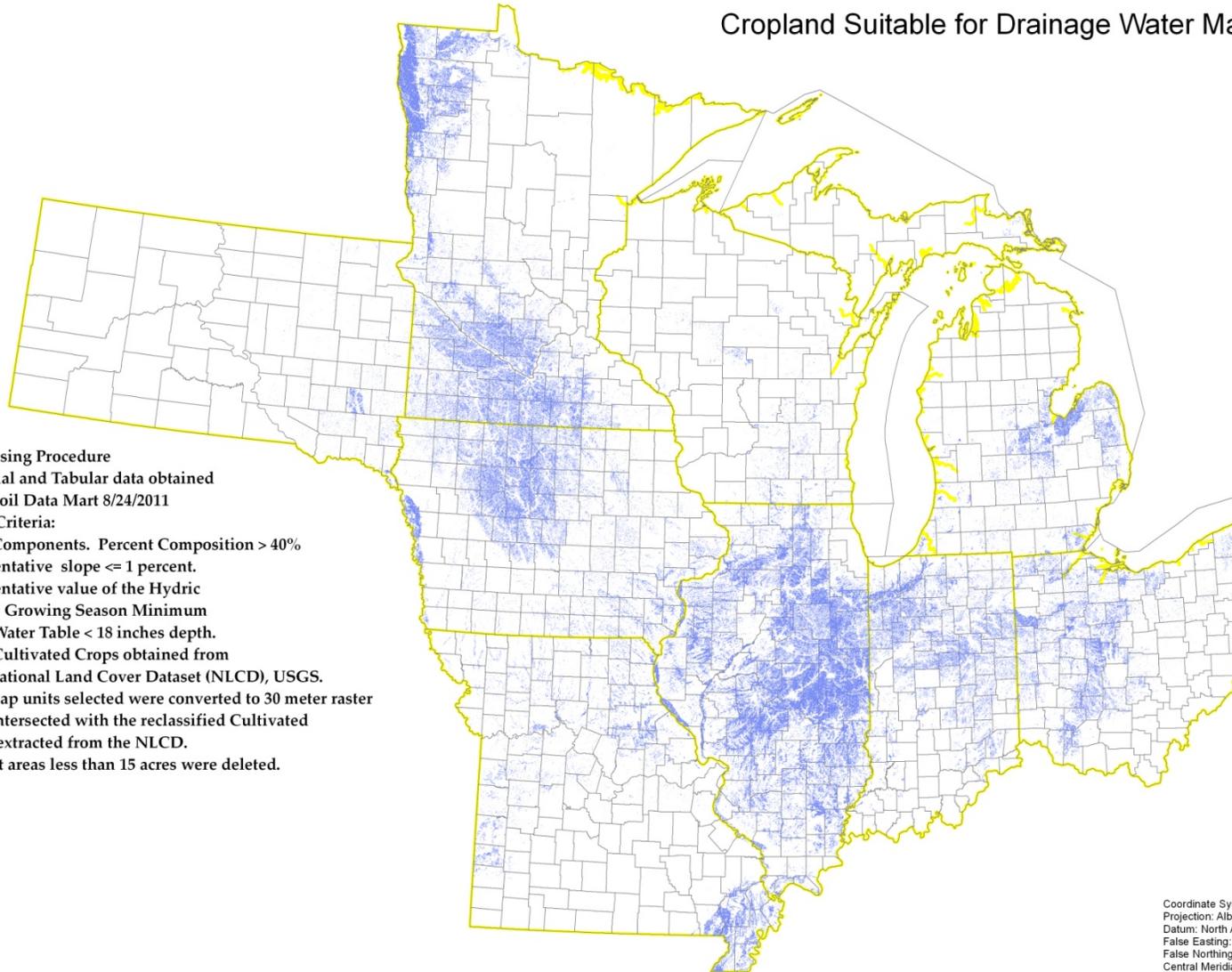
- **Weather**
- **Soils**
- **Drainage System Layout**

Midwest Database



NRCS Midwest DWM States

Cropland Suitable for Drainage Water Management



Illinois	10,289,165 Ac
Indiana	2,752,251 Ac
Iowa	4,076,072 Ac
Missouri	1,844,238 Ac
Michigan	1,259,731 Ac
Minnesota	6,308,982 Ac
Ohio	2,146,231 Ac
South Dakota	228,842 Ac
Wisconsin	309,427 Ac

Geoprocessing Procedure

Soils Spatial and Tabular data obtained from the Soil Data Mart 8/24/2011

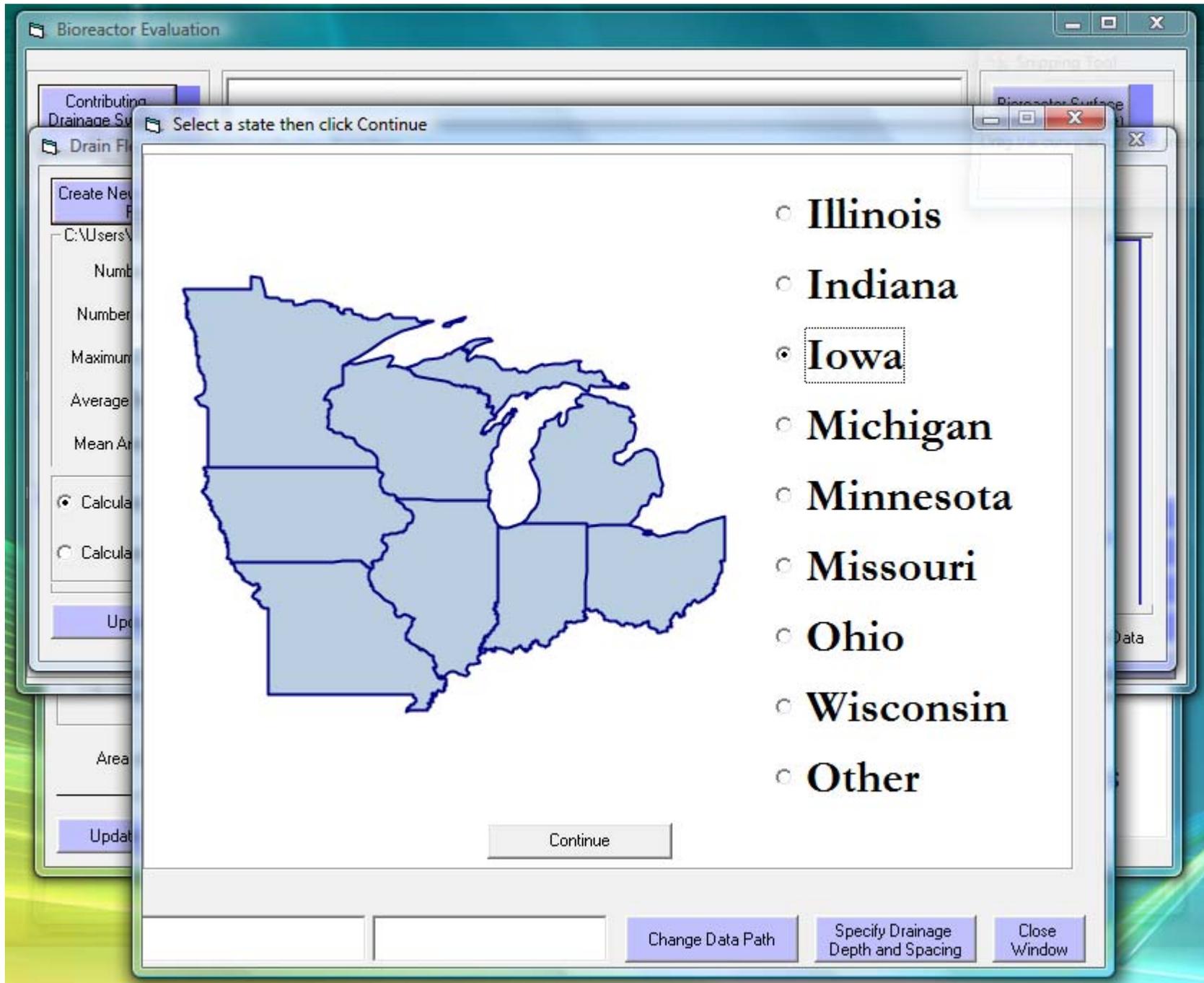
Selection Criteria:

1. Major Components. Percent Composition > 40%
2. Representative slope <= 1 percent.
3. Representative value of the Hydric Definition Growing Season Minimum Depth of Water Table < 18 inches depth.

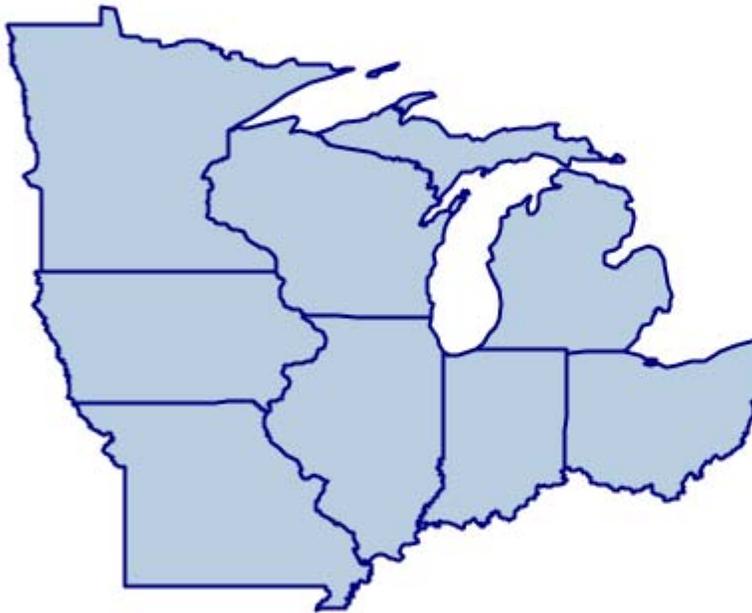
Extent of Cultivated Crops obtained from the 2006 National Land Cover Dataset (NLCD), USGS.

The soil map units selected were converted to 30 meter raster data and intersected with the reclassified Cultivated Cropland extracted from the NLCD.

Coincident areas less than 15 acres were deleted.



Select a state then click Continue



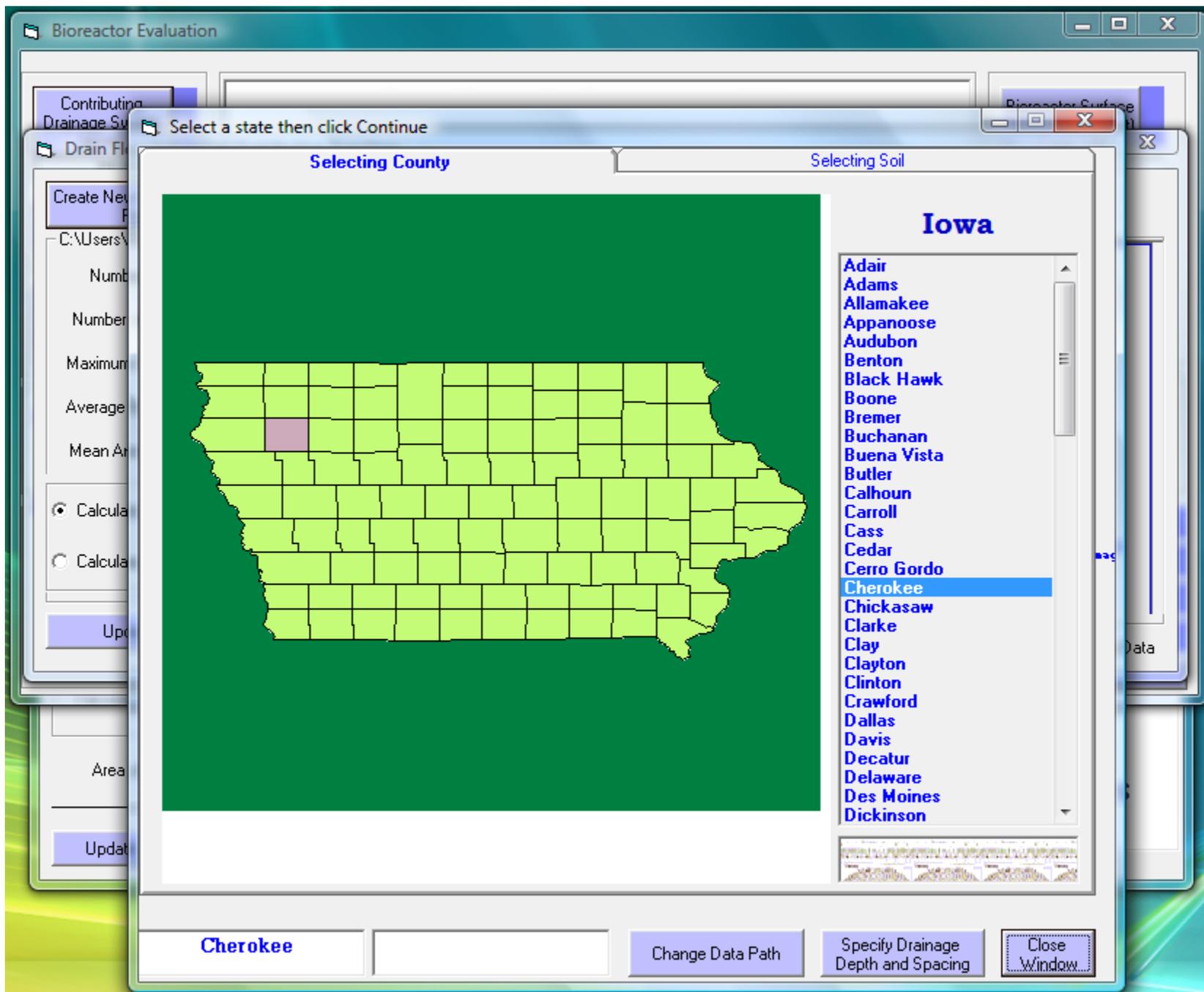
- Illinois
- Indiana
- Iowa
- Michigan
- Minnesota
- Missouri
- Ohio
- Wisconsin
- Other

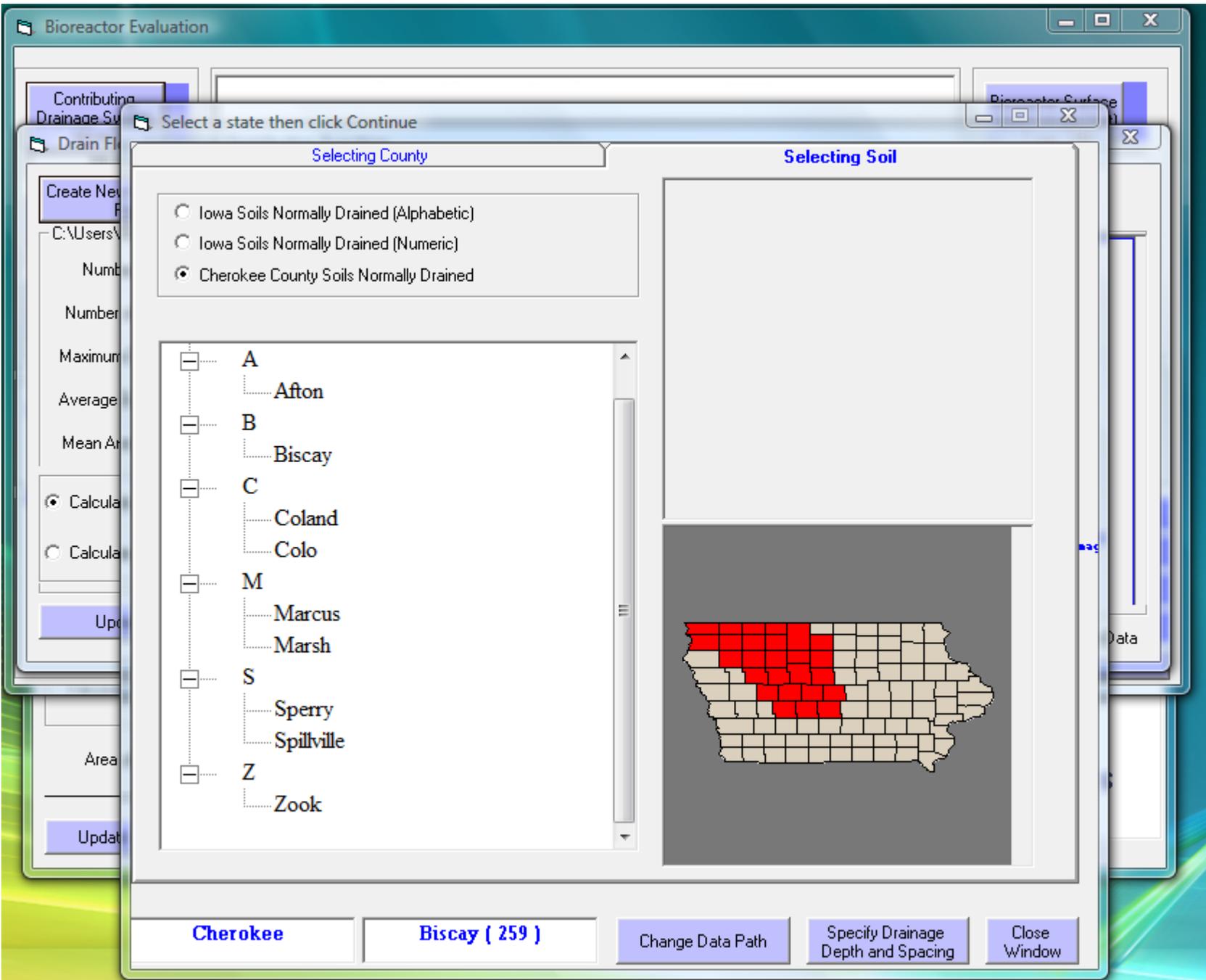
Continue

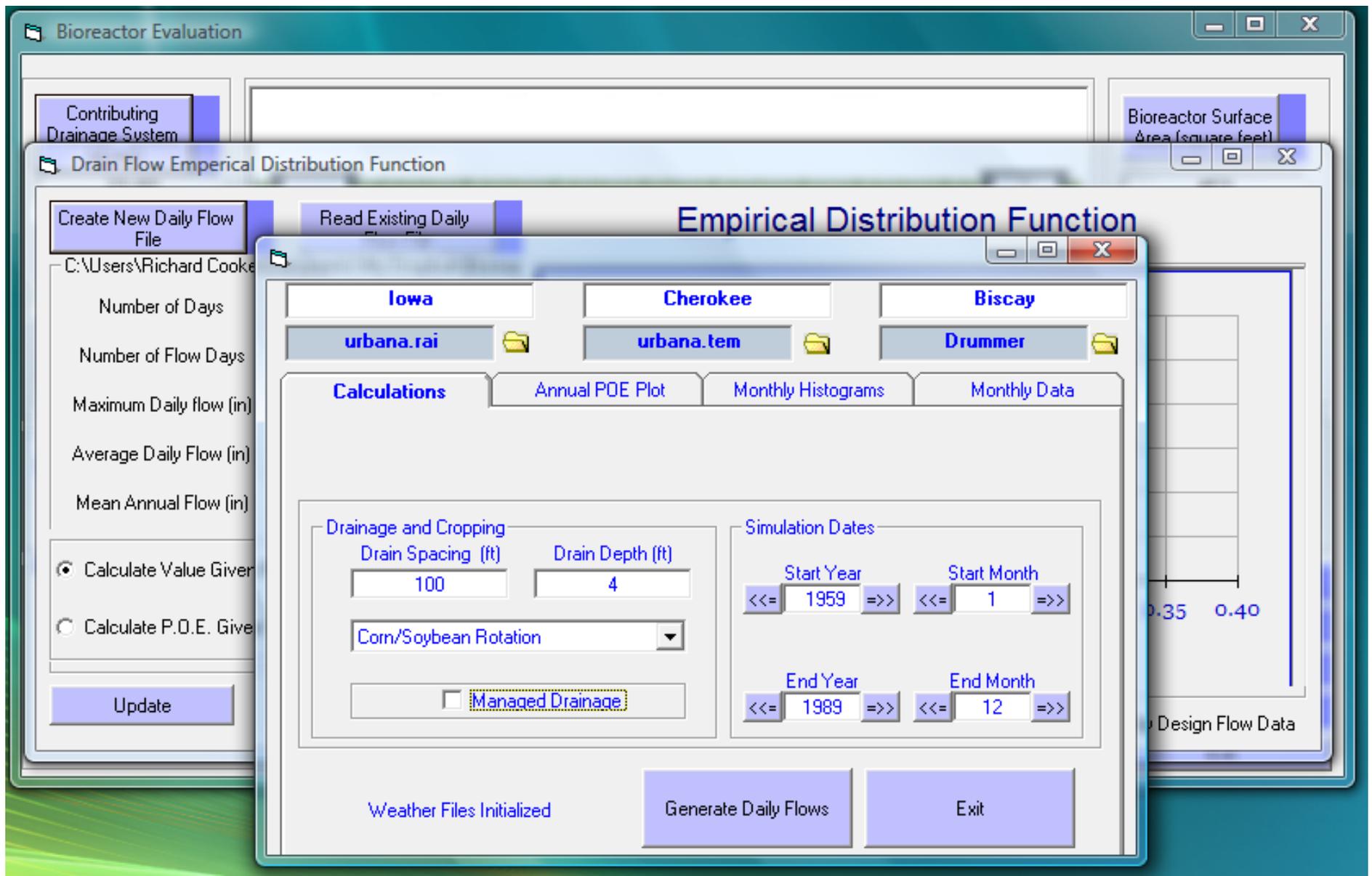
Change Data Path

Specify Drainage
Depth and Spacing

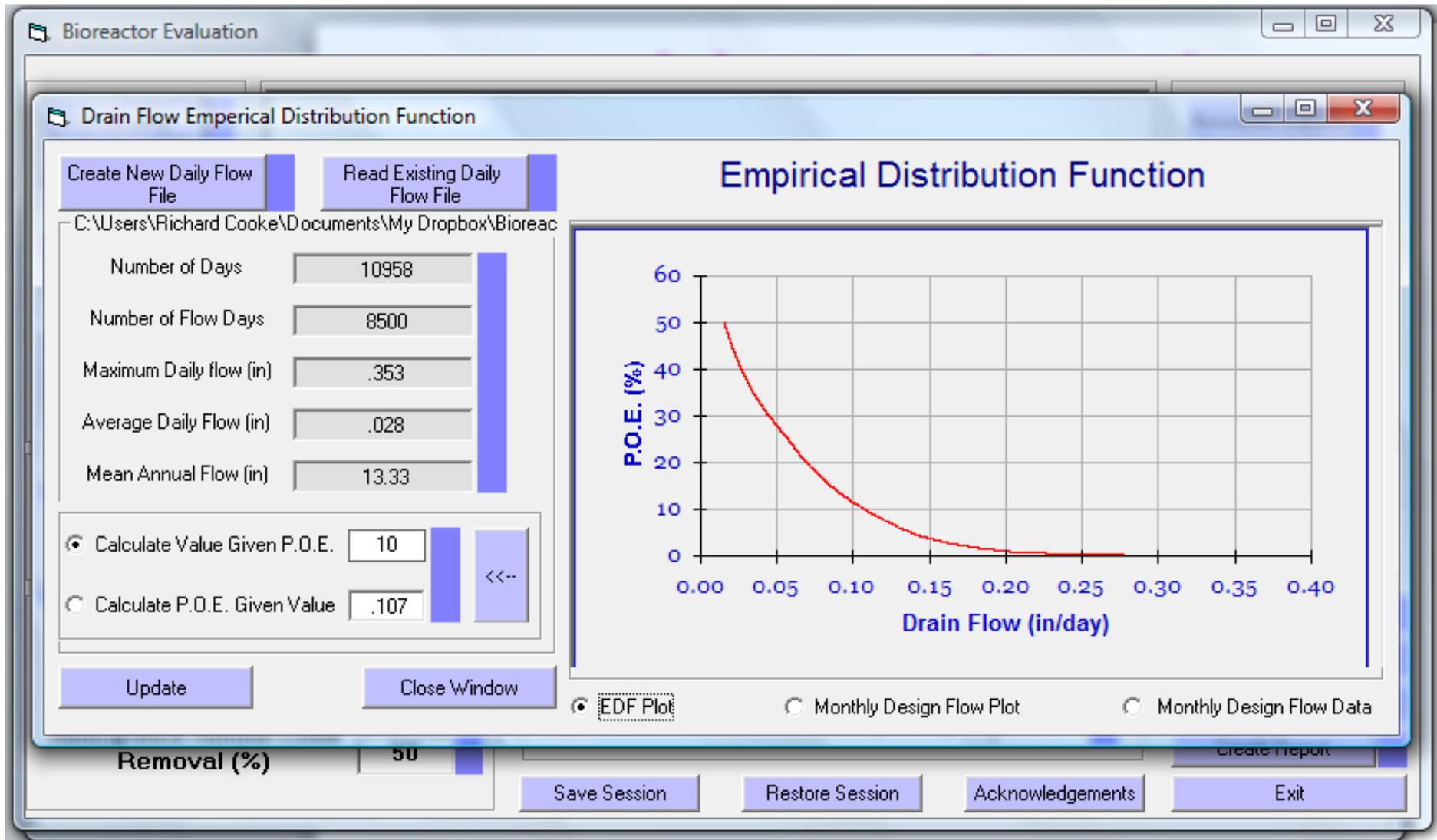
Close
Window



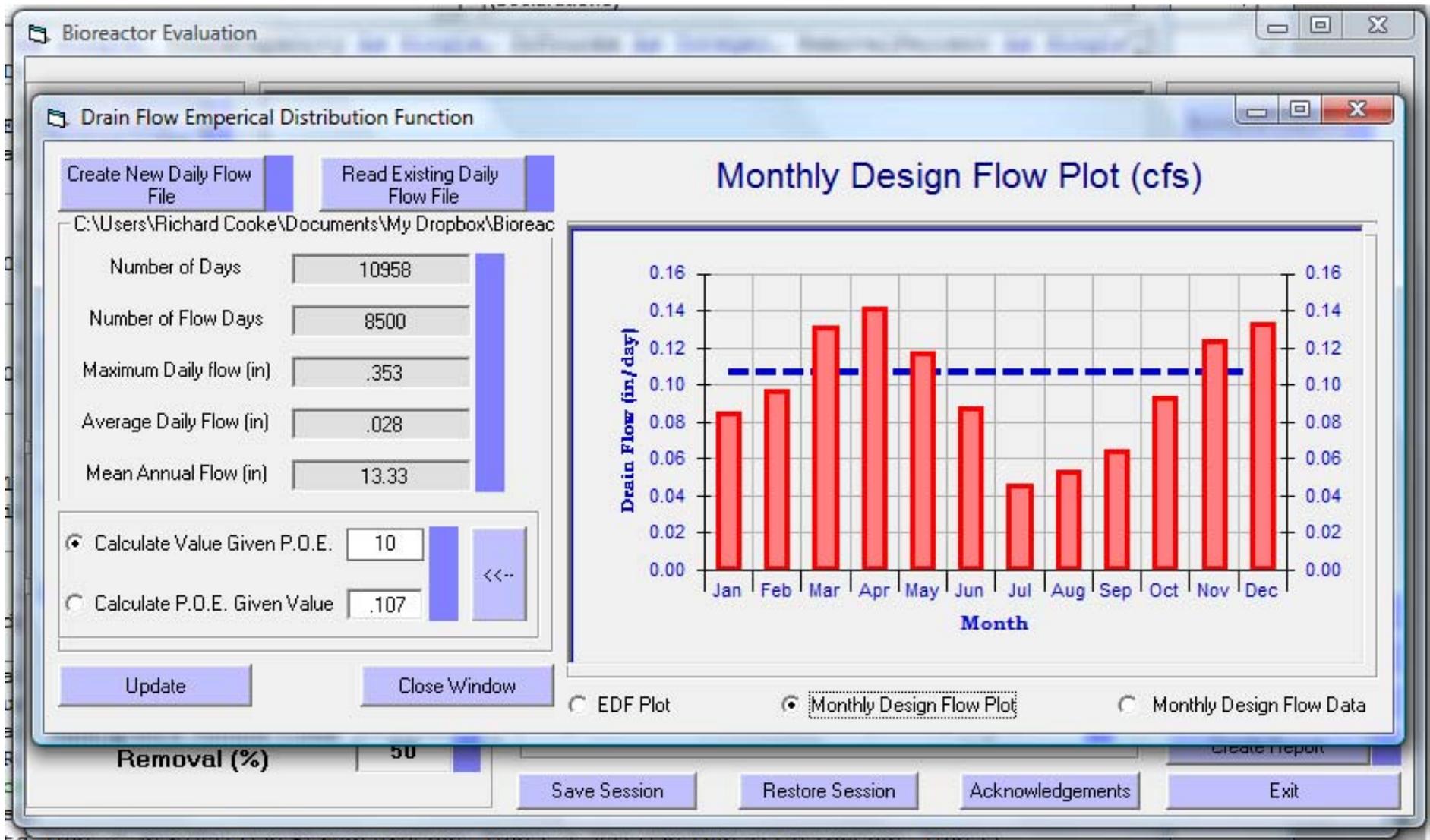




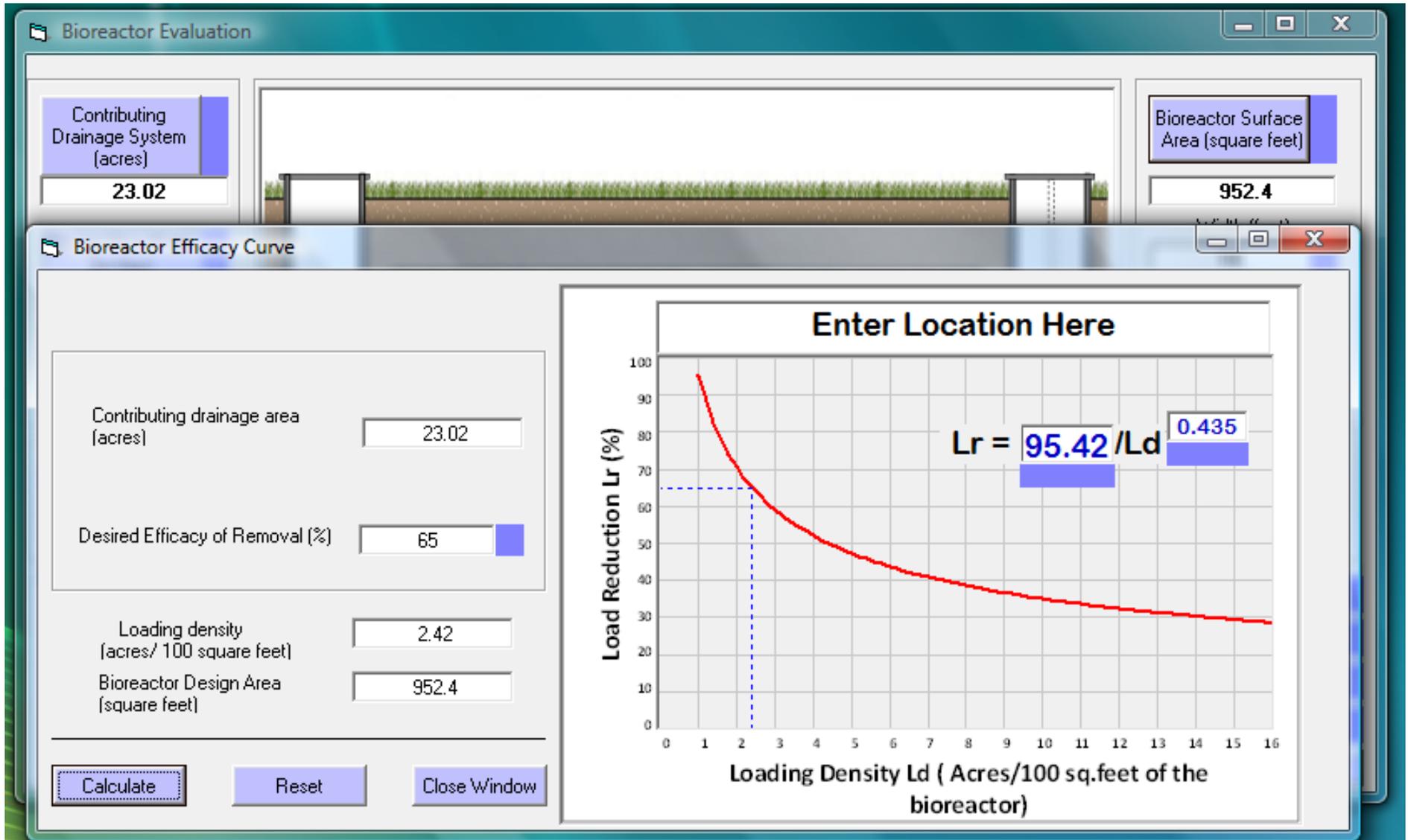
EDF for Daily Flow



Monthly Design Flows



Performance Curve

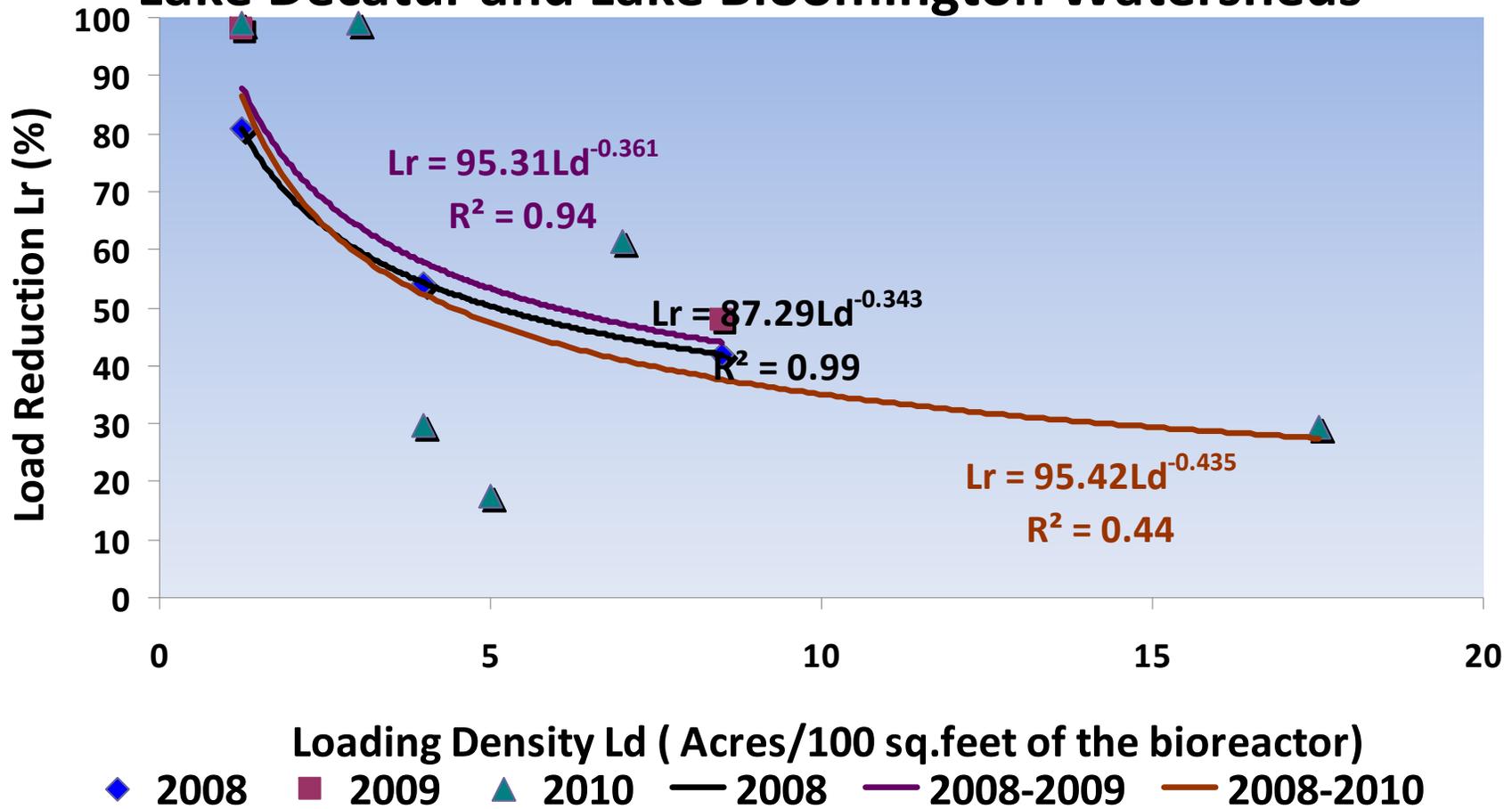


Site	Drainage Area (acres)	Bioreactor Area (square feet)	Loading Density (acres/100 sq. feet)
Decatur West	5	400	1.25
De Land West	28	930	3.00
Amenia	15	400	3.75
Decatur East	16	400	4.00
Bloomington North	20	400	5.00
De Land North	39	560	7.00
De Land East	34	400	8.50
Mount Zion	70	400	17.5

Illinois Performance Curve

BIOREACTOR EFFICACY CURVE

Lake Decatur and Lake Bloomington Watersheds



Cost Analysis

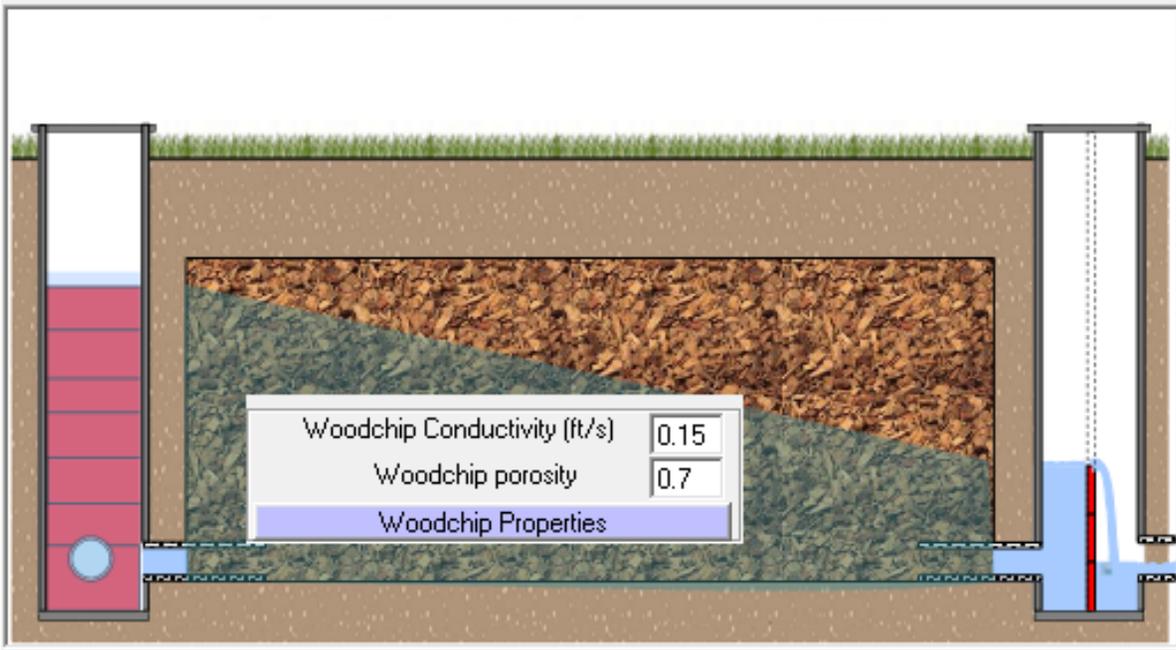
Bioreactor Evaluation

Contributing Drainage System (acres) 23.02	Woodchip Costs Expected Life (years): 10 Truck Capacity (cubic yards): 40 Cost per Truckload (\$): 2000 Cost (\$): 8000	Structures/Installation Cost of Control Structure(s) (\$): 2000 Installation Cost (\$): 800 Cost of Structures and Installation (\$): 2800	Nitrate/Flow Average Annual Drain Flow (inches): 13.33 Average Nitrate Concentration (ppm): 12 Nitrate Removal (lbs/acre/year): 23.6	Bioreactor Surface Area (square feet): 952.4 Width (feet): 16 Length (feet): 59.53 Thickness (inches): 48
Design Flow Rate (in/day): .107	Optimize Transport =>>	Total Cost (\$): 10800	Cost of N Removal (\$/lb): 1.99	Height of Downstream Stoplogs During Critical Period (inches): 7
Exceedance Probability for Design Flow (%): 10	Design Parameters Volumetric Design Flow Rate (cfs): .103 Anticipated Annual Load Removal (%): 65	Actual Flow Capacity (cfs): .074	Actual Flow/Design Flow (%): 71.6	Update
Height of Upstream Stoplogs During Critical Period (inches): 24		Hydraulic Residence Time (hours): 3.2		Cost Analysis
		Save Session	Restore Session	Performance Analysis
			Acknowledgements	Create Report
				Exit

Buttons: Update Cost, Close Cost Form

Length/Width Effects

Bioreactor Evaluation



Contributing Drainage System (acres): 23.02

Design Flow Rate (in/day): .107

Exceedance Probability for Design Flow (%): 10

Height of Upstream Stoplogs During Critical Period (inches): 24

Bioreactor Surface Area (square feet): 952.4

Width (feet): 10

Length (feet): 95.24

Thickness (inches): 48

Height of Downstream Stoplogs During Critical Period (inches): 7

Woodchip Properties

- Woodchip Conductivity (ft/s): 0.15
- Woodchip porosity: 0.7

Design Parameters

Volumetric Design Flow Rate (cfs): .103

Anticipated Annual Load Removal (%): 65

Actual Flow Capacity (cfs): .029

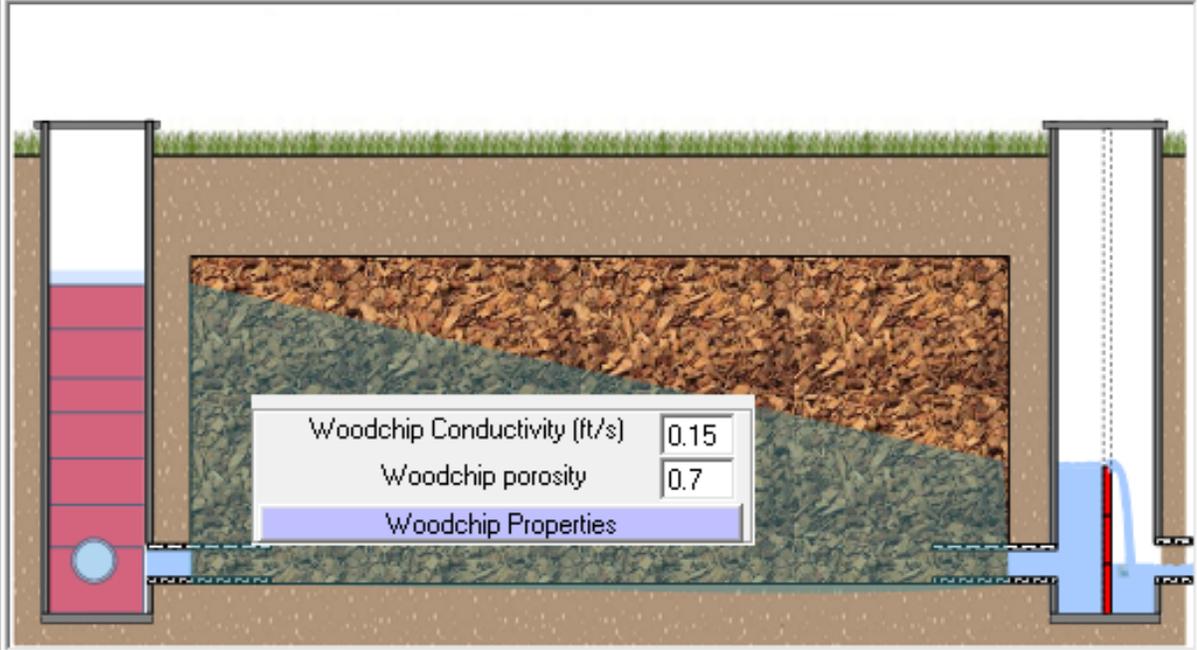
Actual Flow/Design Flow (%): 28

Hydraulic Residence Time (hours): 8.3

Buttons: Update, Cost Analysis, Performance Analysis, Create Report, Exit, Save Session, Restore Session, Acknowledgements

Length/Width Effects

Bioreactor Evaluation



Contributing Drainage System (acres) **23.02**

Design Flow Rate (in/day) **.107**

Exceedance Probability for Design Flow (%) **10**

Height of Upstream Stoplogs During Critical Period (inches) **24**

Bioreactor Surface Area (square feet) **952.4**

Width (feet) **20**

Length (feet) **47.62**

Thickness (inches) **48**

Height of Downstream Stoplogs During Critical Period (inches) **7**

Design Parameters

Volumetric Design Flow Rate (cfs) **.103**

Anticipated Annual Load Removal (%) **65**

Actual Flow Capacity (cfs) **.115**

Actual Flow/Design Flow (%) **111.9**

Hydraulic Residence Time (hours) **2.1**

Woodchip Conductivity (ft/s) **0.15**

Woodchip porosity **0.7**

Woodchip Properties

Update

Cost Analysis

Performance Analysis

Create Report

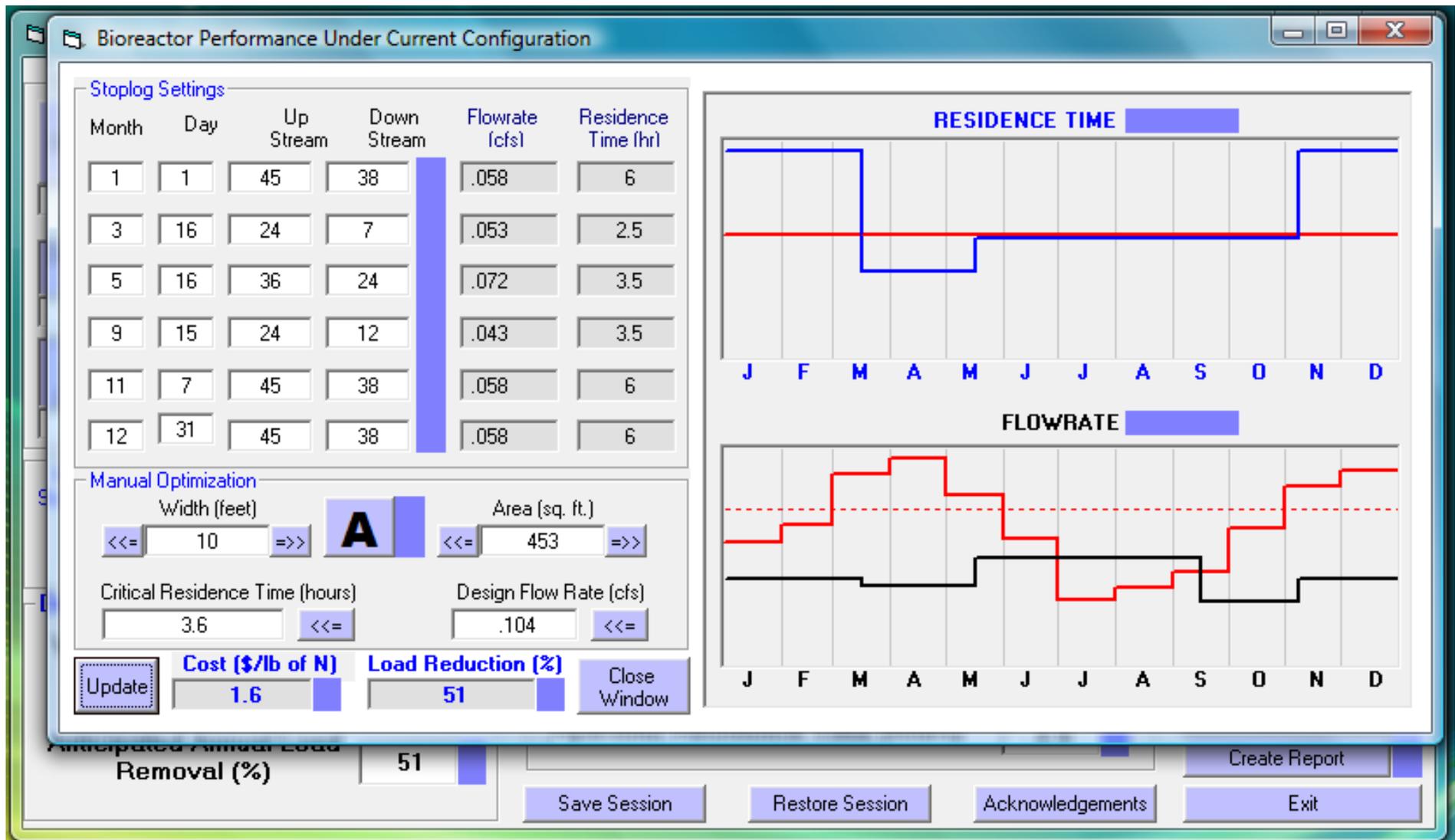
Exit

Save Session

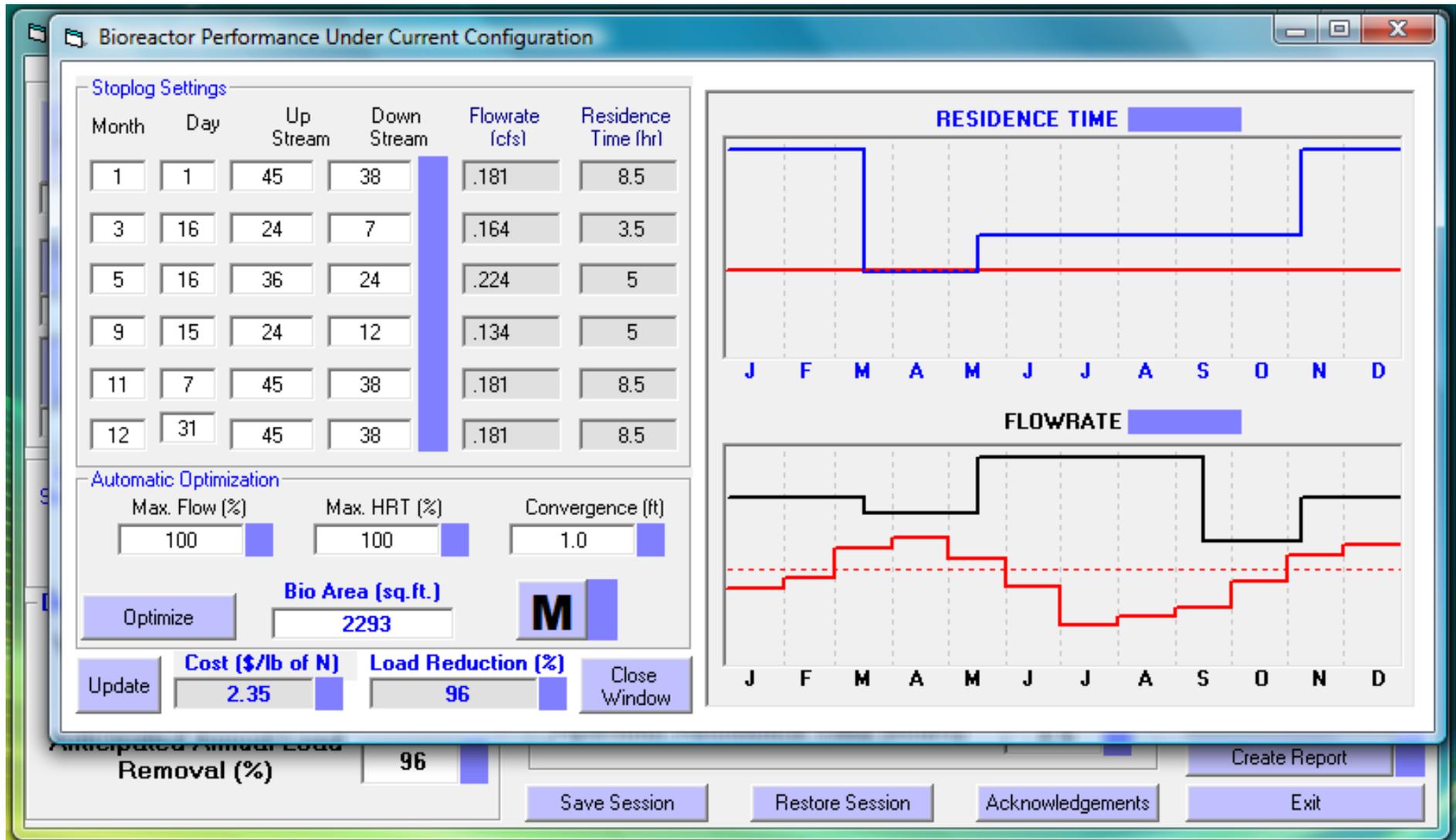
Restore Session

Acknowledgements

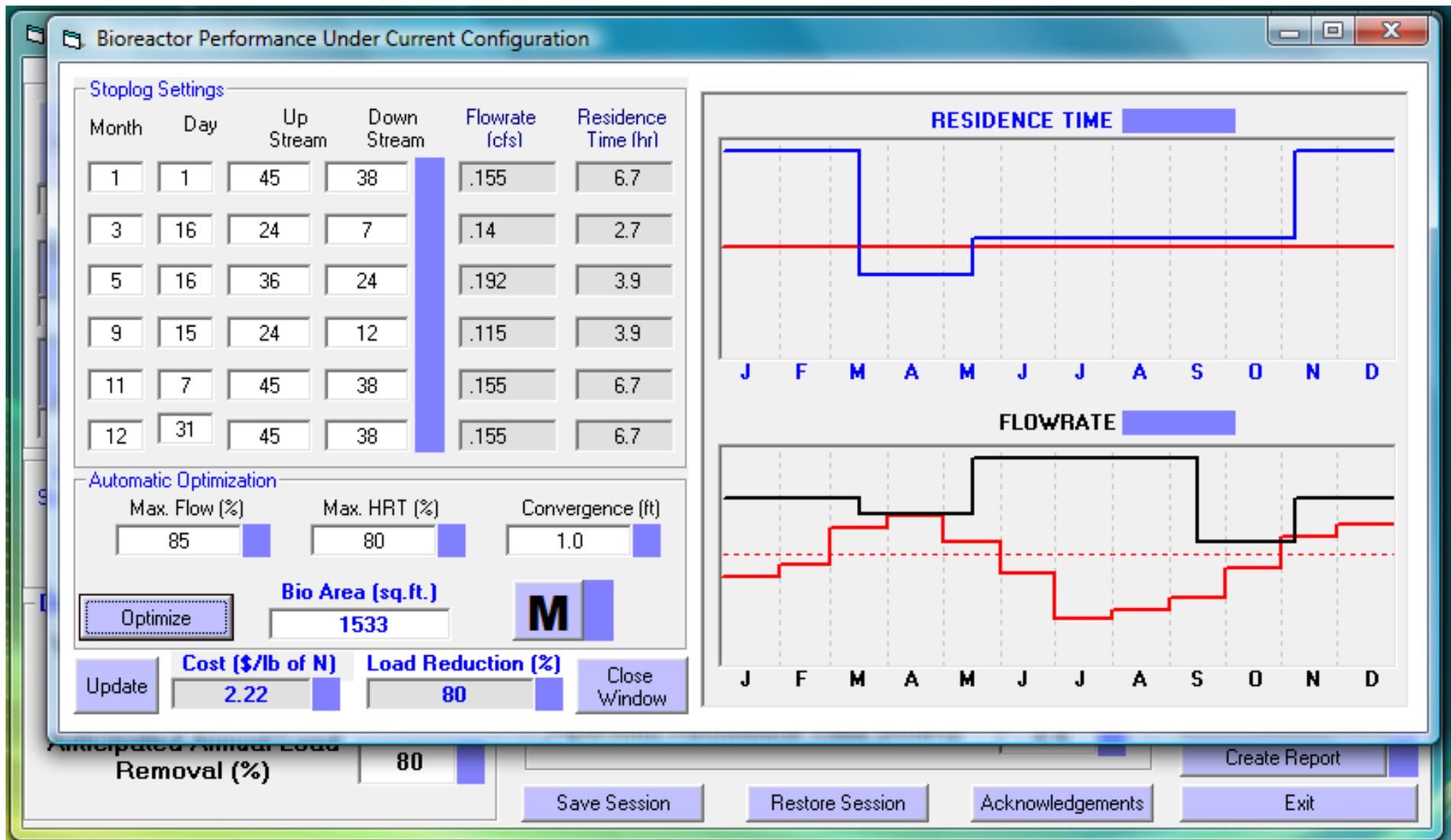
Manual Optimization



Automatic Optimization



Incorporating Performance



Report Generation

Bioreactor Evaluation

Bioreactor Design Report

Information from this routine is stored in an Excel file that can be viewed or printed as required. This file can only be access on computers with Microsoft Excel.

Contributing Drainage System (acres): 23.02

Design Flow Rate (in/day): .107

Exceedance Probability for Design Flow (%): 10

Height of Upstream Stoplogs During Critical Period (inches): 24

Bioreactor Surface Area (square feet): 1533

Width (feet): 28

Length (feet): 54.75

Thickness (inches): 48

Height of Downstream Stoplogs During Critical Period (inches): 7

Design Parameters

Volumetric Design Flow Rate (cfs): .104

Anticipated Annual Load Removal (%): 80

Actual Flow Capacity (cfs): .084

Actual Flow/Design Flow (%): 81.8

Hydraulic Residence Time (hours): 2.5

View Report Save Report Close Window

Update

Cost Analysis

Performance Analysis

Create Report

Save Session Restore Session Acknowledgements Exit

Report Generation

Book1 - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View

Normal Page Layout Page Break Preview Custom Views Full Screen

Workbook Views Show Ruler Formula Bar Gridlines Headings Zoom 100% Zoom to Selection New Window Arrange All Freeze Panes Unhide

View Side by Side Synchronous Scrolling Reset Window Position Save Switch Workspace Windows Macros

A1 Σ Bioreactor Design Report

J K L M N O P Q R S T U V W X Y Z AA

Date and Time: 5/23/2012 00:20

Bioreactor Design Report

Contributing Area of Drainage System

Cumulative tile length (feet)	10000
Spacing (feet)	100
# of tile ends (outlet excluded)	2
# of tile intersections	1
Tile intersection angle (degrees)	55
Area of Influence (acres)	23.02

Drain Flaw Empirical Distribution Function

Number of Days	10958
Number of Flaw Days	3500
Maximum Daily Flaw (in)	0.353
Average Daily Flaw (in)	0.028
Mean Annual Flaw (in)	13.33
Probability of Exceedance	10
Drainage Coefficient (in/Day)	0.107

Monthly Drain Flaw (in/Day)

Jan	.095	Jul	.046
Feb	.097	Avg	.054
Mar	.122	Sep	.065
Apr	.142	Oct	.094
May	.118	Nov	.124
Jun	.088	Dec	.134

Bioreactor Efficacy Curve and Dimensions

Contributing drainage area (acres)	23.02
Drainage Efficacy of Removal (%)	65
Loading Density (pcf/100 sq ft)	2.42
Bioreactor Drainage Area (sq ft)	452.4
Width (feet)	28
Length (feet)	54.75
Thickness (inches)	48

Date and Time: 5/23/2012 00:20

Drain Parameters

Height of Upstream Step (in)	24
Height of Downstream Step (in)	7
Woodchip Conductivity (ft/yr)	0.15
Woodchip porosity	0.7
Volumetric Drain Flaw Rate (cfr)	0.104
Anticipated Annual Load Removal (%)	80
Actual Flaw Capacity (cfr)	0.084
Actual Flaw/Drain Flaw (%)	31.8
Hydraulic Residence Time (hours)	2.5

Cart Analysis

Woodchips	
Expected Life (years)	10
Truck Capacity (cubic yards)	40
Cost per Truckload (\$)	2000
COST OF WOODCHIPS (\$)	12000
Structure/Installation	
Cost of Central Structure (\$) (\$)	2000
Installation Cost (\$)	800
COST OF STRUCTURES AND INSTALLATION (\$)	2800
Nitrate/Flaw	
Average Annual Drain Flaw (inches)	13.33
Average Nitrate Concentration (ppm)	12
NITRATE REMOVAL (lb/acre/year)	29
OVERALL COST (\$)	14800
COST of N REMOVAL (\$/lb)	2.22

Date and Time: 5/23/2012 00:20

Performance Analysis

Month	Day	Upstream	Downstream	Flawrate (cfr)	Residence Time (hr)
1	1	45	38	0.155	6.7
3	16	24	7	0.14	2.7
5	16	36	24	0.192	3.9
9	15	24	12	0.115	3.9
11	7	45	38	0.155	6.7
12	31	45	38	0.155	6.7

If Manual Optimization:

Critical Residence Time (hr)	3.6
Drain Flaw Rate (cfr)	0.104

If Automated Optimization:

Max. Flaw (%)	85
Max. HRT (%)	80
Convergence (ft)	1

Page: 1 of 3 Page: 2 of 3 Page: 3 of 3

Future Work: Residence Time

Stoplog Settings

Month	Day	Up Stream	Down Stream	Flowrate (cfs)	Residence Time (hr)
1	1	45	38	.155	6.7
3	16	24	7	.14	2.7
5	16	36	24	.192	3.9
9	15	24	12	.115	3.9
11	7	45	38	.155	6.7
12	31	45	38	.155	6.7

Manual Optimization

Width (feet) Area (sq. ft.)

Critical Residence Time (hours) Design Flow Rate (cfs)

Cost (\$/lb of N) **Load Reduction (%)**

Anticipated Annual Load Removal (%)

Buttons: Update, Close Window, Save Session, Restore Session, Acknowledgements, Create Report, Exit

Month	Residence Time (hr)
January	3.6
February	3.6
March	3.6
April	3.6
May	3.6
June	3.6
July	3.6
August	3.6
September	3.6
October	3.6
November	3.6
December	3.6

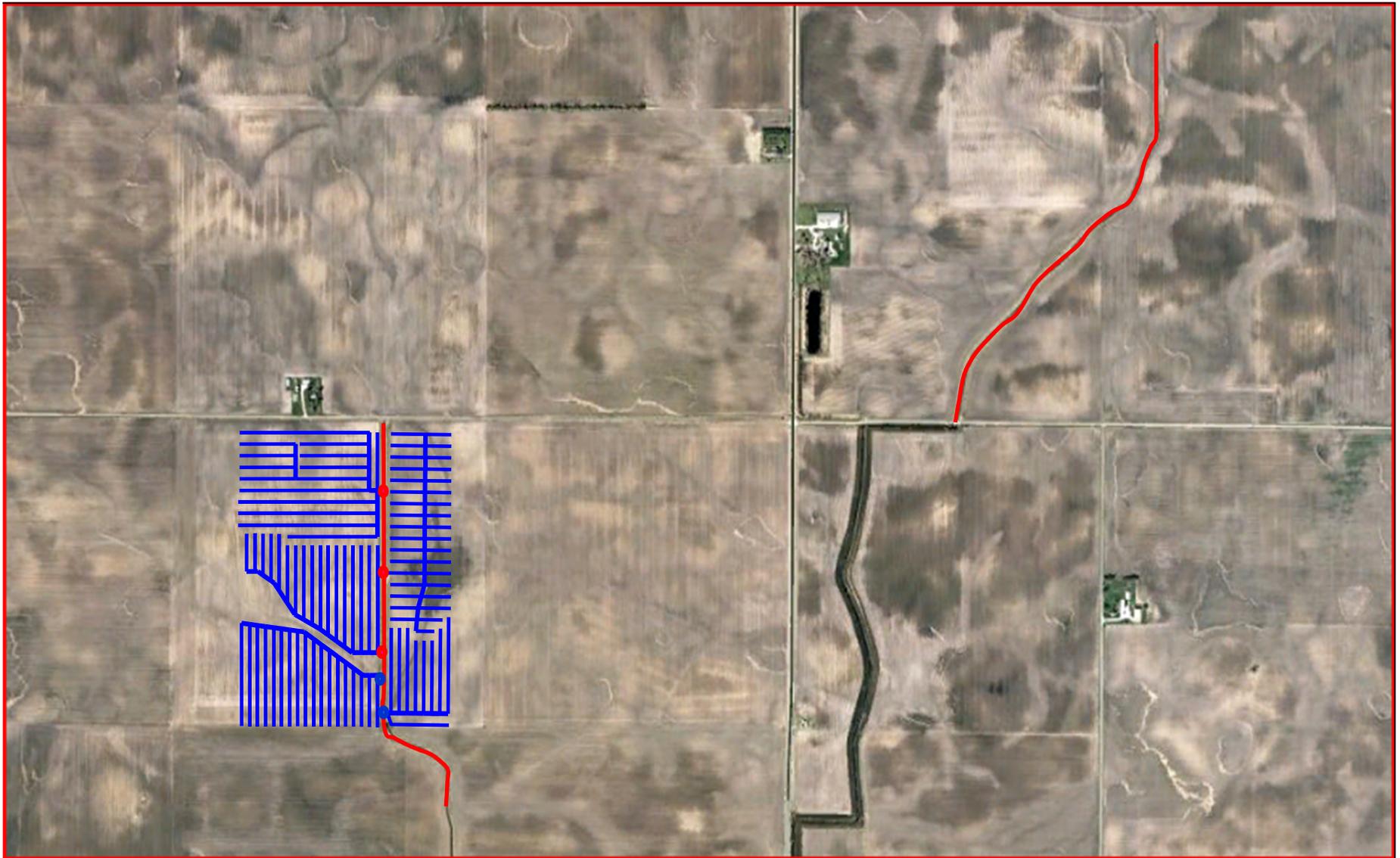
Future Work: Nitrate Loads

Bioreactor Evaluation

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Exceedance Probability for Design Flow (%) 10	Design Parameters	Actual Flow Capacity (cfs) .074	Actual Flow/Design Flow (%) 71.6	Update
Height of Upstream Stoplogs During Critical Period (inches) 24	Volumetric Design Flow Rate (cfs) .103	Hydraulic Residence Time (hours) 3.2		Cost Analysis
Anticipated Annual Load Removal (%) 65				Performance Analysis
		Save Session	Restore Session	Create Report
			Acknowledgements	Exit

Buttons: Update Cost, Close Cost Form

Future Work: Long-term Trends



Acknowledgements



This routine was developed for the Illinois NRCS as part of a Conservation Innovation Grant titled "The Development of Performance Curves for Bioreactors in Illinois." Supplemental funding was provided by The Sand County Foundation. The bioreactors were constructed with funds provided by the Environmental Protection Agency.



Close Window



Thank You

