

US EPA ARCHIVE DOCUMENT

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

**Richard Cooke**  
**Natasha Bell**



# Third Generation Bioreactors

Length/width dependent on contributing area

Capacity Control Structure

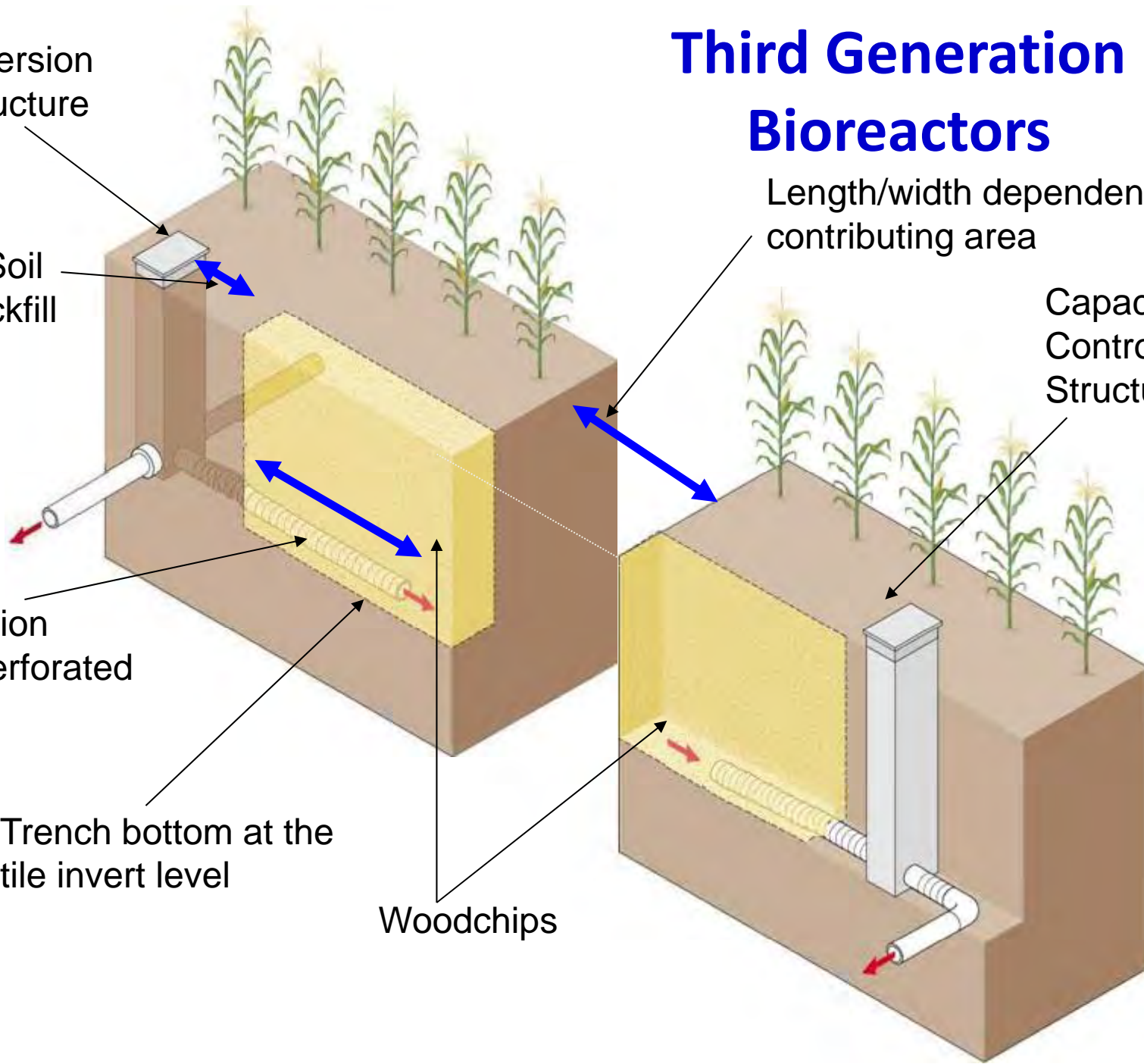
Diversion Structure

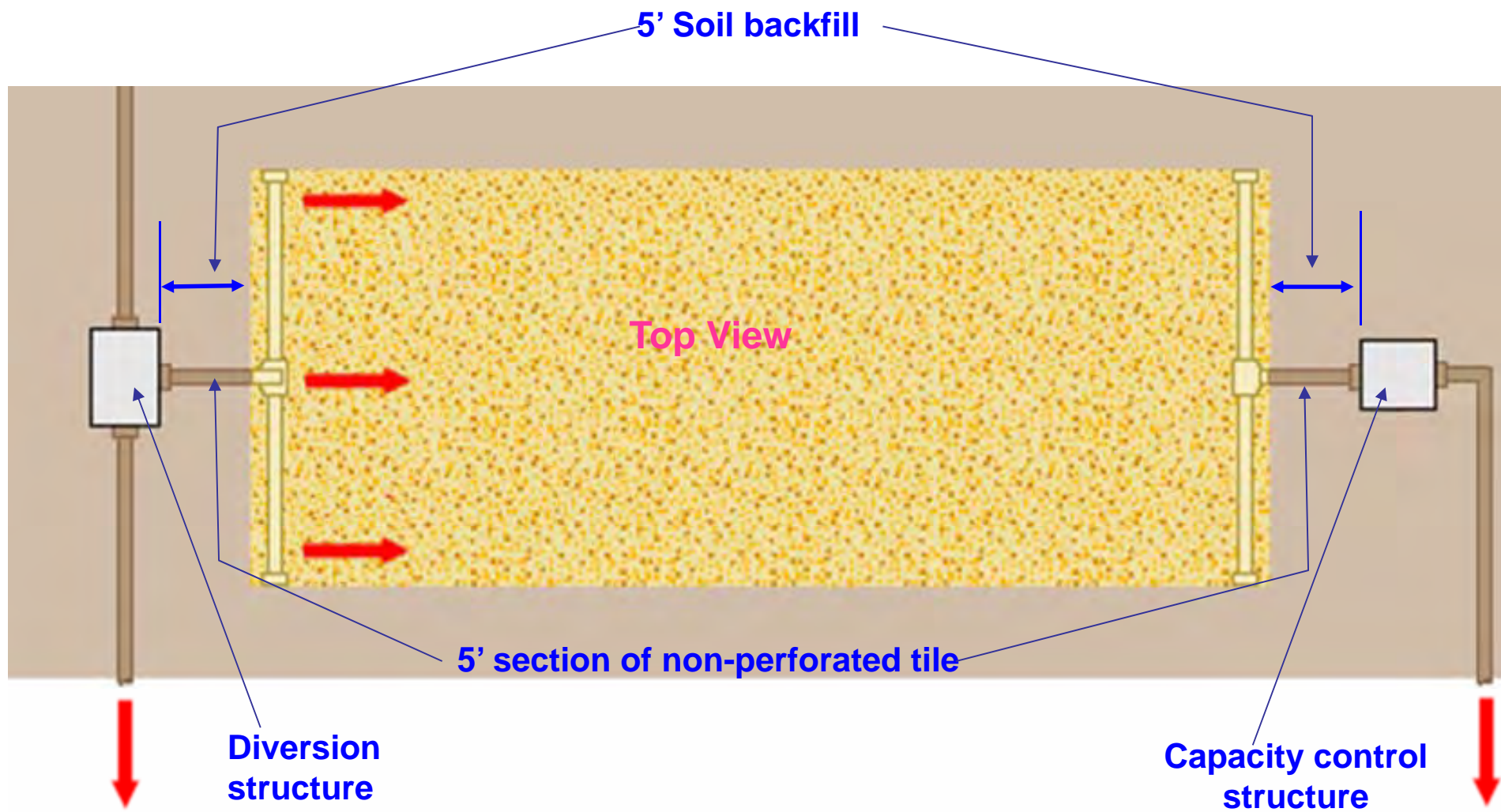
5' Soil Backfill

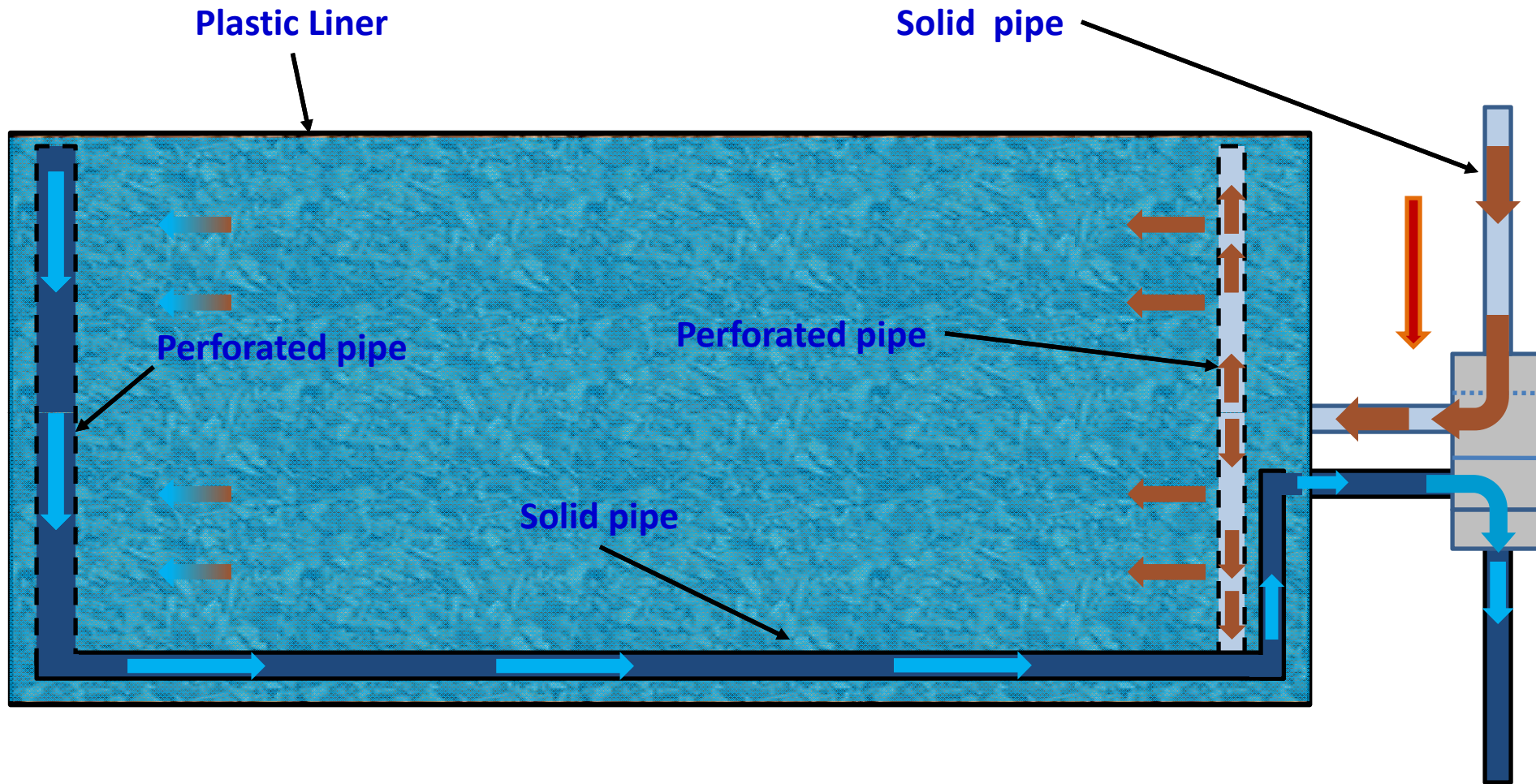
Section of perforated tile

Trench bottom at the tile invert level

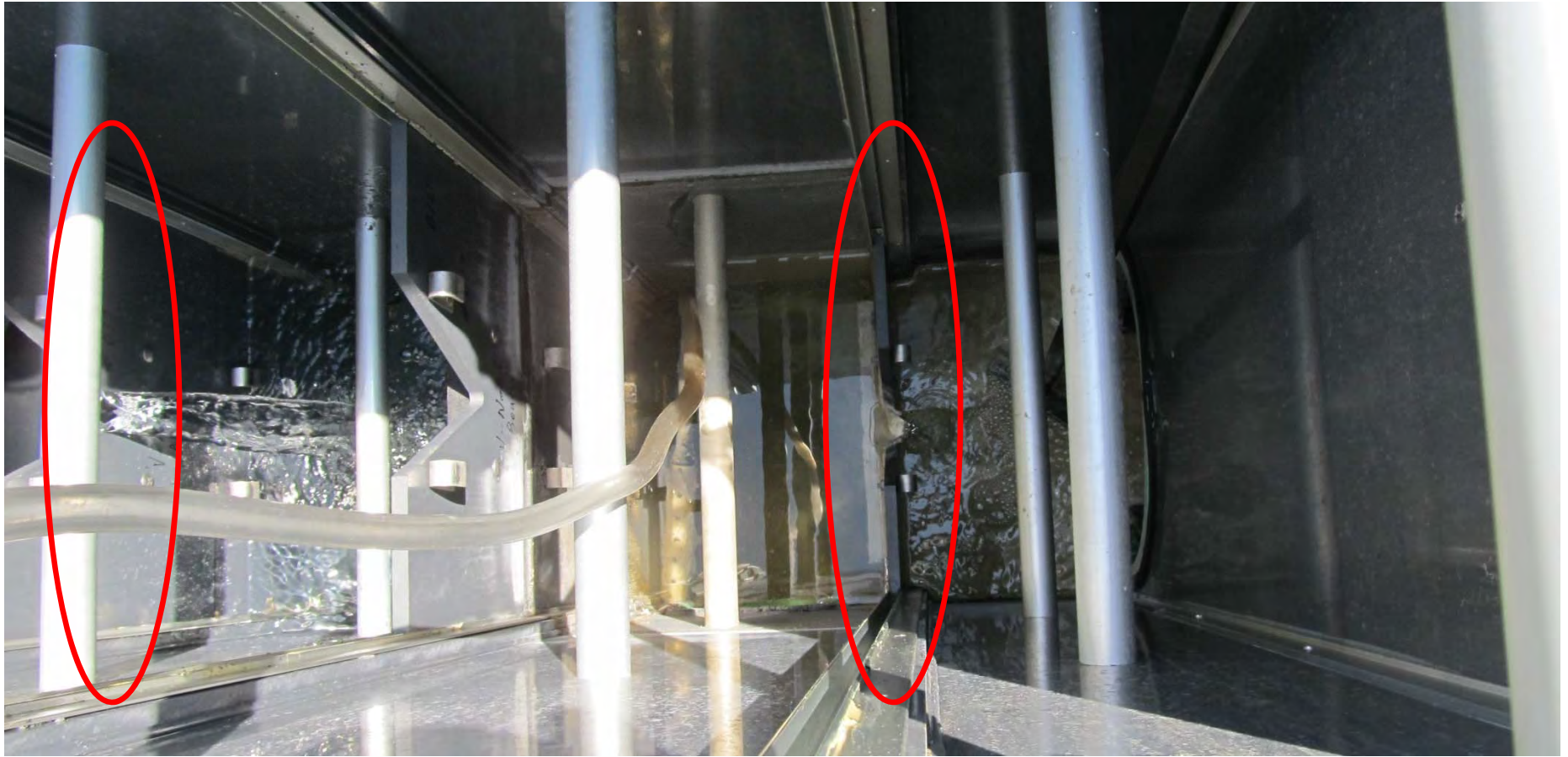
Woodchips











- **Bioreactor design is a complex balance of flow rate and residence time.**
- **Historic weather data, and soil and drainage system layout is used to evaluate bioreactor performance within specified levels of uncertainty.**
- **Operational (stop log) settings are incorporated into the design procedure.**





# Main Interface

The screenshot displays the 'Bioreactor Evaluation' software interface. The central part of the window shows a cross-sectional diagram of a bioreactor. A pop-up window titled 'Woodchip Properties' is overlaid on the diagram, showing the following values:

Woodchip Conductivity (ft/s)	0.15
Woodchip porosity	0.7

The interface is divided into several sections:

- Input Parameters (Left Side):**
  - 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 Dimensions (Right Side):**
  - 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
- Design Parameters (Bottom Left):**
  - Volumetric Design Flow Rate (cfs): 0.063
  - Anticipated Annual Load Removal (%): 50
- Results (Bottom Center):**
  - Actual Flow Capacity (cfs): .061
  - Actual Flow/Design Flow (%): 96.2
  - Hydraulic Residence Time (hours): 1.9
- Buttons (Bottom Right):** Update, Cost Analysis, Performance Analysis, Create Report, Exit
- Buttons (Bottom Center):** Save Session, Restore Session, Acknowledgements

The image is a screenshot of a web browser window. At the top, the address bar shows several tabs: 'aboutblank', 'Suggested Sites', 'Cooke, Richard A C - Outl...', 'abouttabs', and 'Yahoo! (2)'. The main content area has a blue background. On the left, there is a vertical navigation menu with several links: 'Drainage Guidelines', 'Outlets for Drainage Systems', 'Surface Drainage', 'Subsurface Drainage', 'Conservation Drainage', 'Bioreactor Design', and 'Webinar Files'. The 'Bioreactor Design' link is highlighted with a grey background. In the center of the page, there is a security warning in blue text: 'recommended that a control only be installed if a program indicates that it is missing.' Below this warning, there is a list of file names in purple text: 'comdlg32', 'mschrt20', 'mscomctl', 'msflxgrd', and 'tabctl32'. A large orange arrow points from this list towards the right. To the right of the arrow, the text 'MS Controls' is written in large red font. Below the navigation menu, another orange arrow points from the 'Bioreactor Design' link towards the right. To the right of this arrow, the text 'Sample Files' is written in large red font. In the background, the word 'Princi' is visible in large blue font, and a paragraph of text is partially visible: 'The passage of the 1850 Federal S the most fertile cropland in the wo drainage systems have a significant strong correlation between improv'.

MS Controls

Sample Files

Browser window showing a Dropbox share link: <https://www.dropbox.com/sh/a5d3bfcwvxonm1t/Fg84XqqQD>




Dropbox - Webinar\_Files - S...

File Edit View Favorites Tools Help

aboutblank Suggested Sites Cooke, Richard A C - Outl... abouttabs Yahoo! (2)

Dropbox [Download](#) [Sign up for Dropbox](#) [Sign in](#)

### Webinar\_Files

Name	Size	Modified
 Bioreactor.exe	9.81 MB	6 days ago
 Champaign_Drummer.PLT	706.28 KB	6 days ago
 WS_long_sim.PLT	2.09 MB	6 days ago

**Bioreactor Evaluation**

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

Design Parameters

Volumetric Discharge Rate

Anticipated Annual Load Removal (%): 50

Hydraulic Residence Time (hours)

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

Update

Cost Analysis

Performance Analysis

Create Report

Exit

Save Session

Restore Session

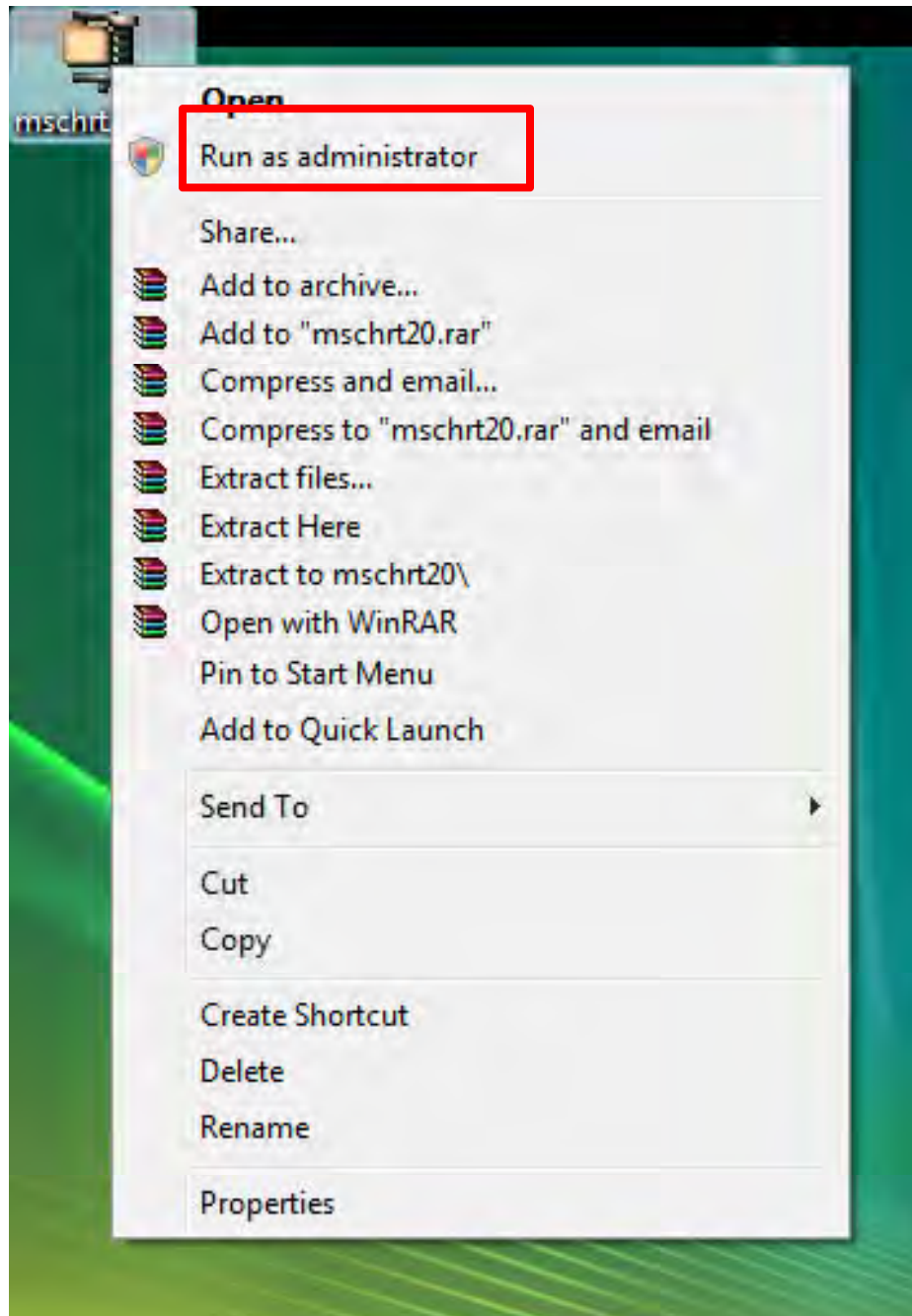
Acknowledgements

**Bioreactor**

Run-time error '339':

Component 'mschrt20.ocx' or one of its dependencies not correctly registered: a file is missing or invalid

OK



**Open**

Run as administrator

Share...



Add to archive...



Add to "mschrt20.rar"



Compress and email...



Compress to "mschrt20.rar" and email



Extract files...



Extract Here



Extract to mschrt20\'



Open with WinRAR

Pin to Start Menu

Add to Quick Launch

Send To

Cut

Copy

Create Shortcut

Delete

Rename

Properties

# Popup Help Screens

The screenshot displays the 'Bioreactor Evaluation' software interface. The main window shows a cross-section of a bioreactor with a woodchip layer. The interface includes several input fields and output displays:

- 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

A popup window titled 'Bioreactor Thickness (feet)' is overlaid on the main interface. It contains the following 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.

OK

The main interface also displays the following data and controls:

- Volumetric Design Flow Rate (cfs):** 0.063
- Anticipated Annual Load Removal (%):** 50
- Actual Flow/Design Flow (%):** 96.2
- Hydraulic Residence Time (hours):** 1.9
- Buttons:** 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)

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

(Add ends)

(Subtract overlap)

# Woodchip Properties



# Sizing Criteria

Flow rate

Residence time

Performance



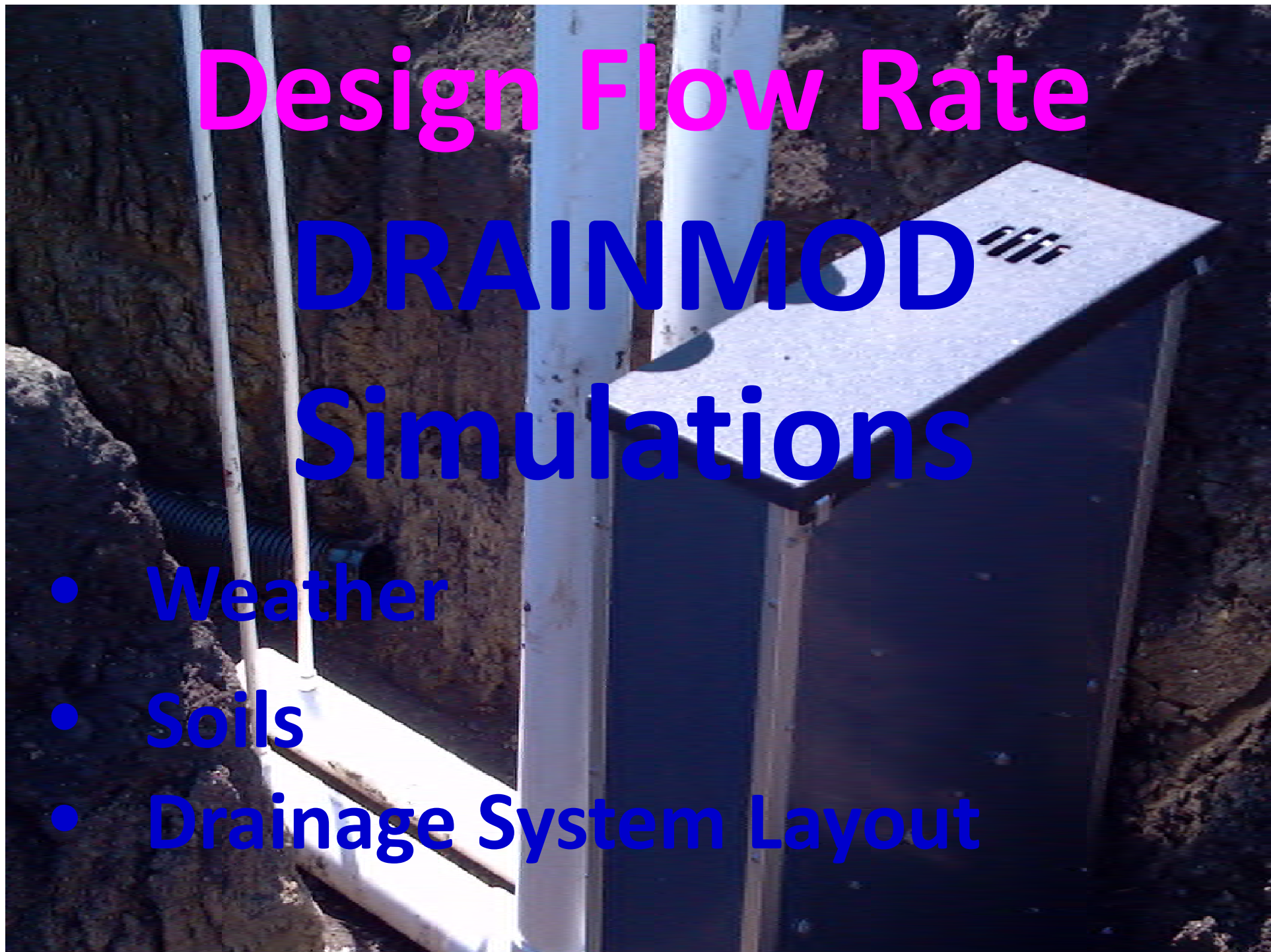
# Design Flow Rate 10-year, 24 hour drain outflow event

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



# Design Flow Rate DRAINMOD Simulations

- Weather
- Soils
- Drainage System Layout

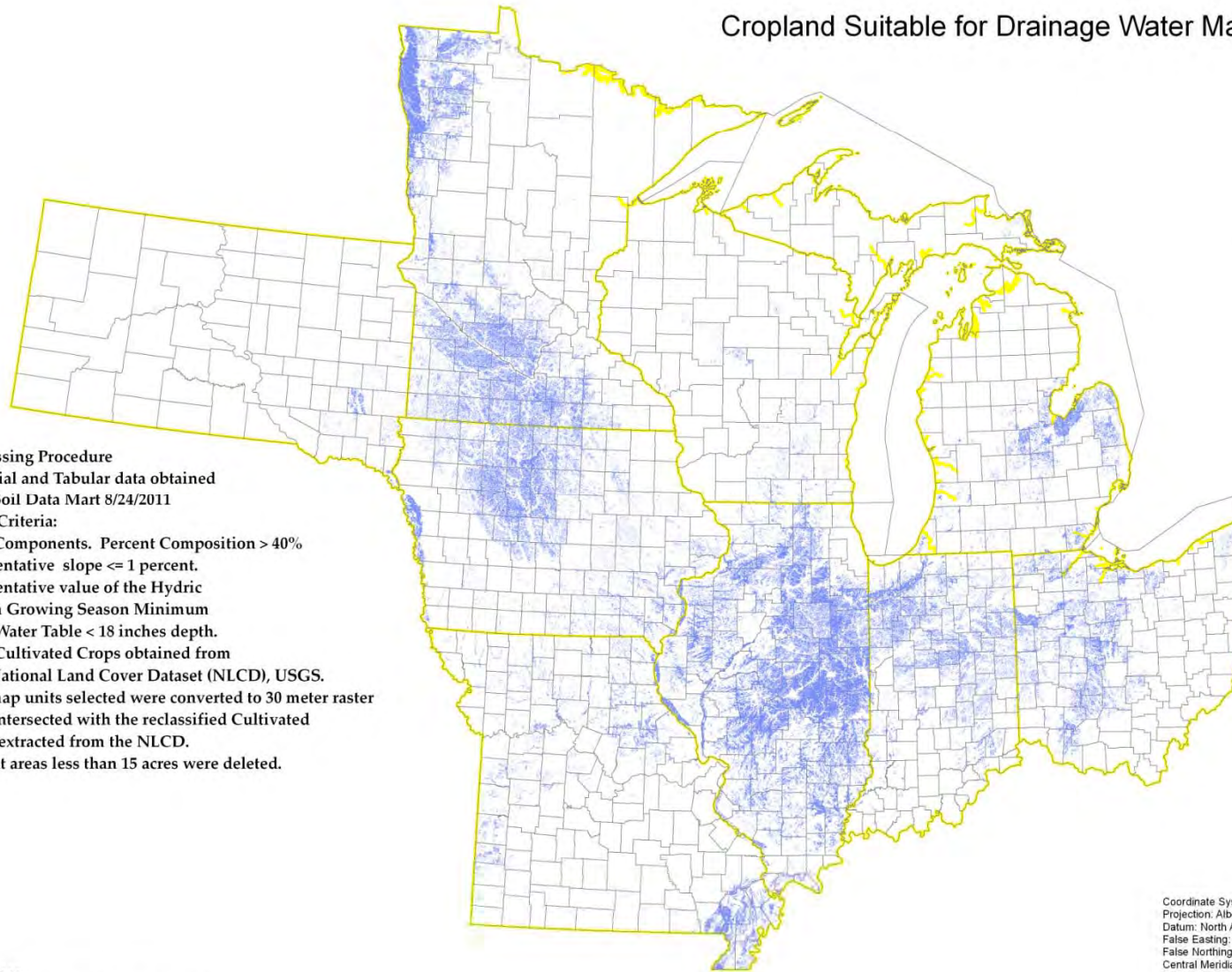


# Midwest Database



# 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.

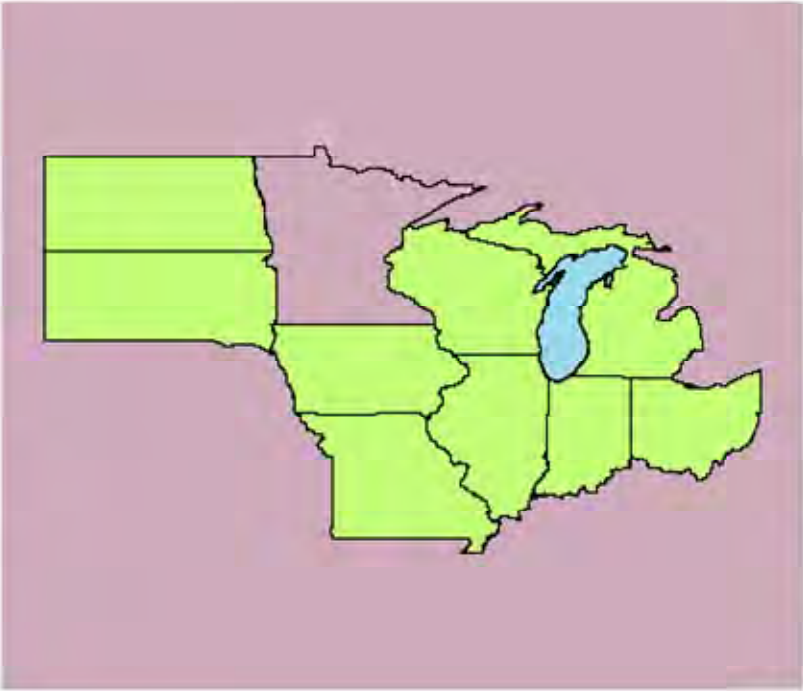
The soil map units selected were converted to 30 meter raster data and intersected with the reclassified Cultivated Cropland extracted from the NLCD.

Coincident areas less than 15 acres were deleted.

Coordinate System: USA Contiguous Albers Equal Area Conic USGS version  
 Projection: Albers  
 Datum: North American 1983  
 False Easting: 0.0000  
 False Northing: 0.0000  
 Central Meridian: -96.0000  
 Standard Parallel 1: 29.5000  
 Standard Parallel 2: 45.5000  
 Latitude Of Origin: 23.0000  
 Units: Meter

1:6,000,000

Select a state then click Continue



- Illinois
- Indiana
- Iowa
- Michigan
- Minnesota
- Missouri
- North Dakota
- Ohio
- South Dakota
- Wisconsin
- Other Location**

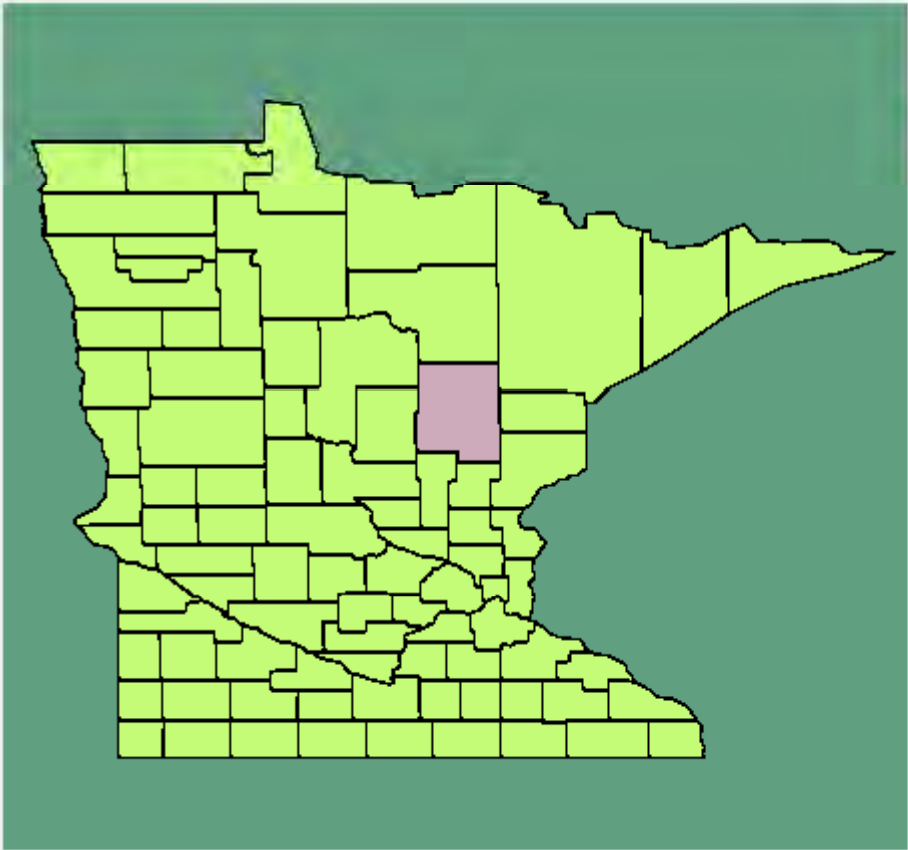
Continue



Select County-specific Weather and Soil Data

Selecting County      Selecting Soil

### Minnesota



- Aitkin
- Anoka
- Becker
- Beltrami
- Benton
- Big Stone
- Blue Earth
- Brown
- Carlton
- Carver
- Cass
- Chippewa
- Chisago
- Clay
- Clearwater
- Cook
- Cottonwood
- Crow Wing
- Dakota
- Dodge
- Douglas
- Faribault
- Fillmore
- Freeborn
- Goodhue
- Grant
- Hennepin
- Houston
- Hubbard
- Isanti

Aitkin      Leafriver ( 1984 )      Change State      Specify Drainage Depth and Spacing      Close Window

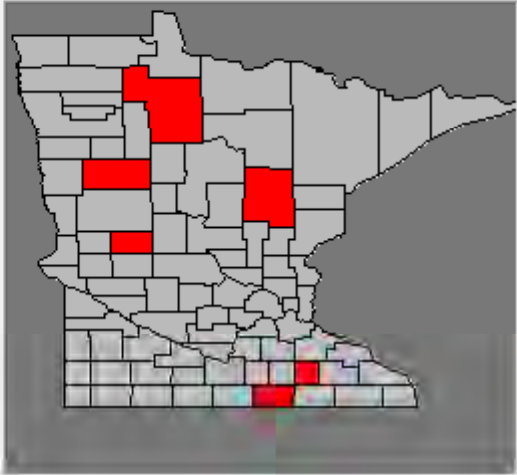
Select County-specific Weather and Soil Data

**Selecting County**

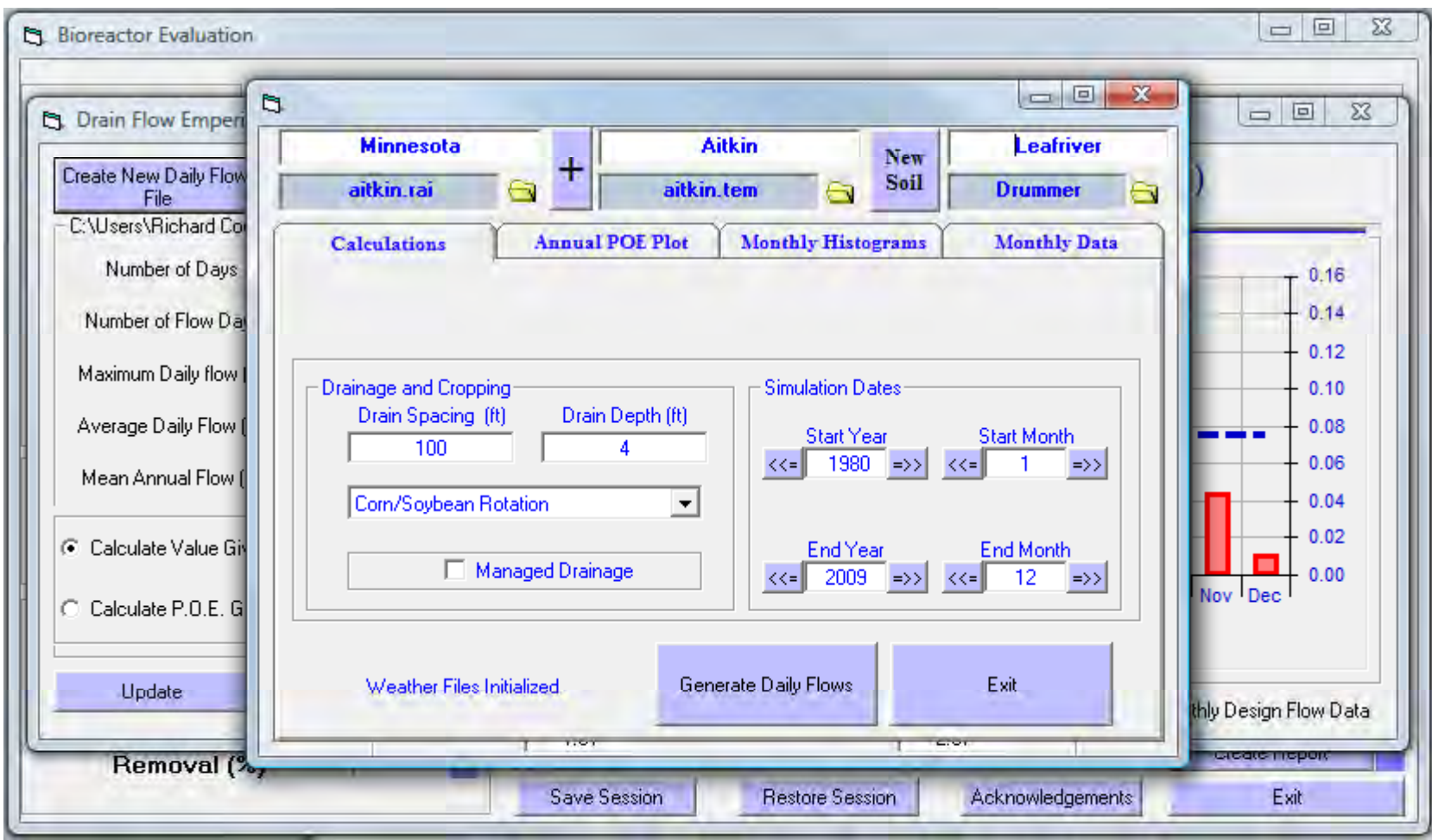
Minnesota Soils Normally Drained (Alphabetic)  
 Aitkin County Soils Normally Drained

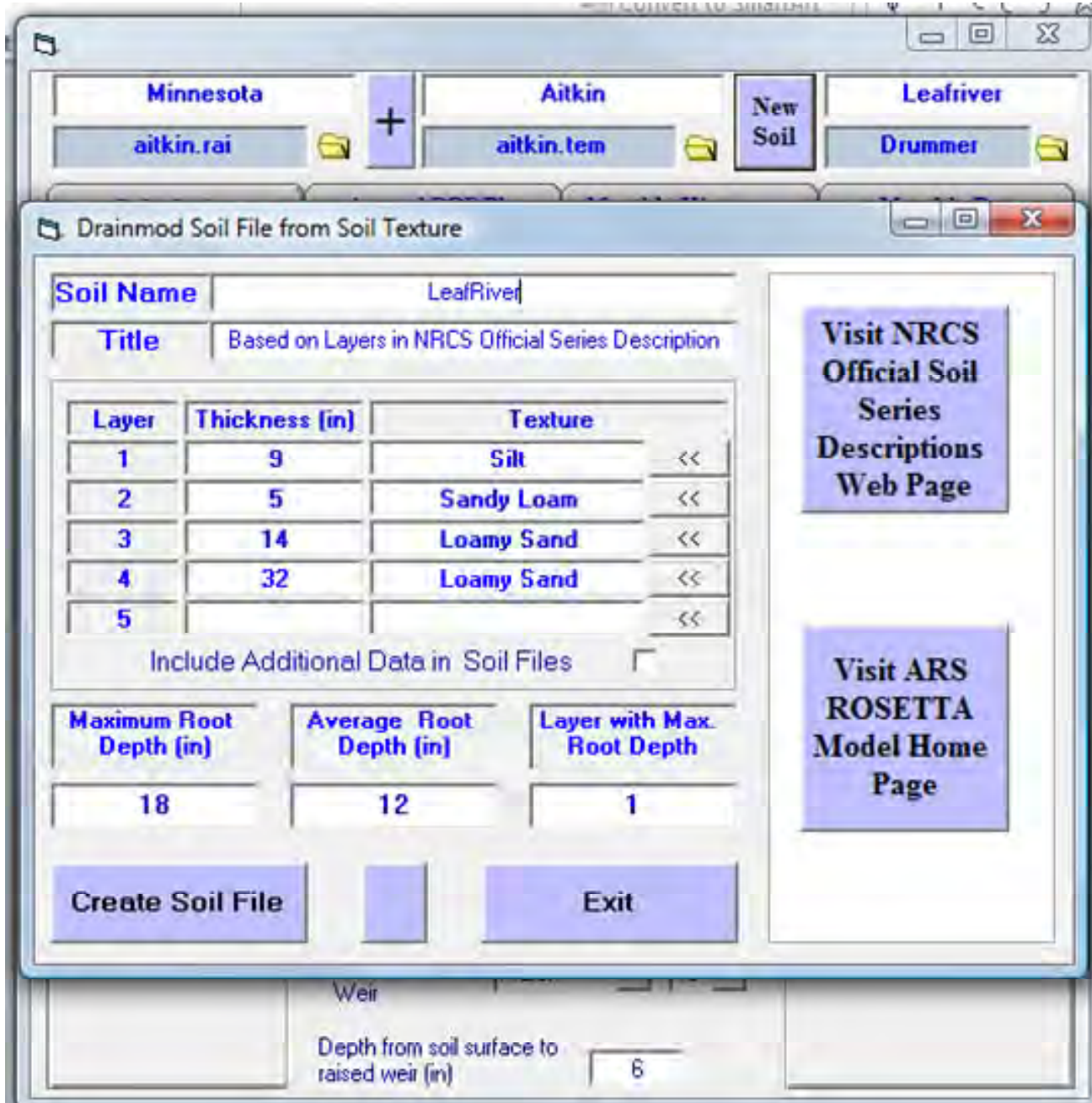
**Selecting Soil**

- B
- C
- G
- H
- J
- L
  - Leafriver**
  - Lobo
  - Loxley
  - Lupton
- M
- N
- P
- R
- S
- T
- W
  - Waskish
  - Watab
  - Waukenabo
  - Wealthwood
  - Willosippi

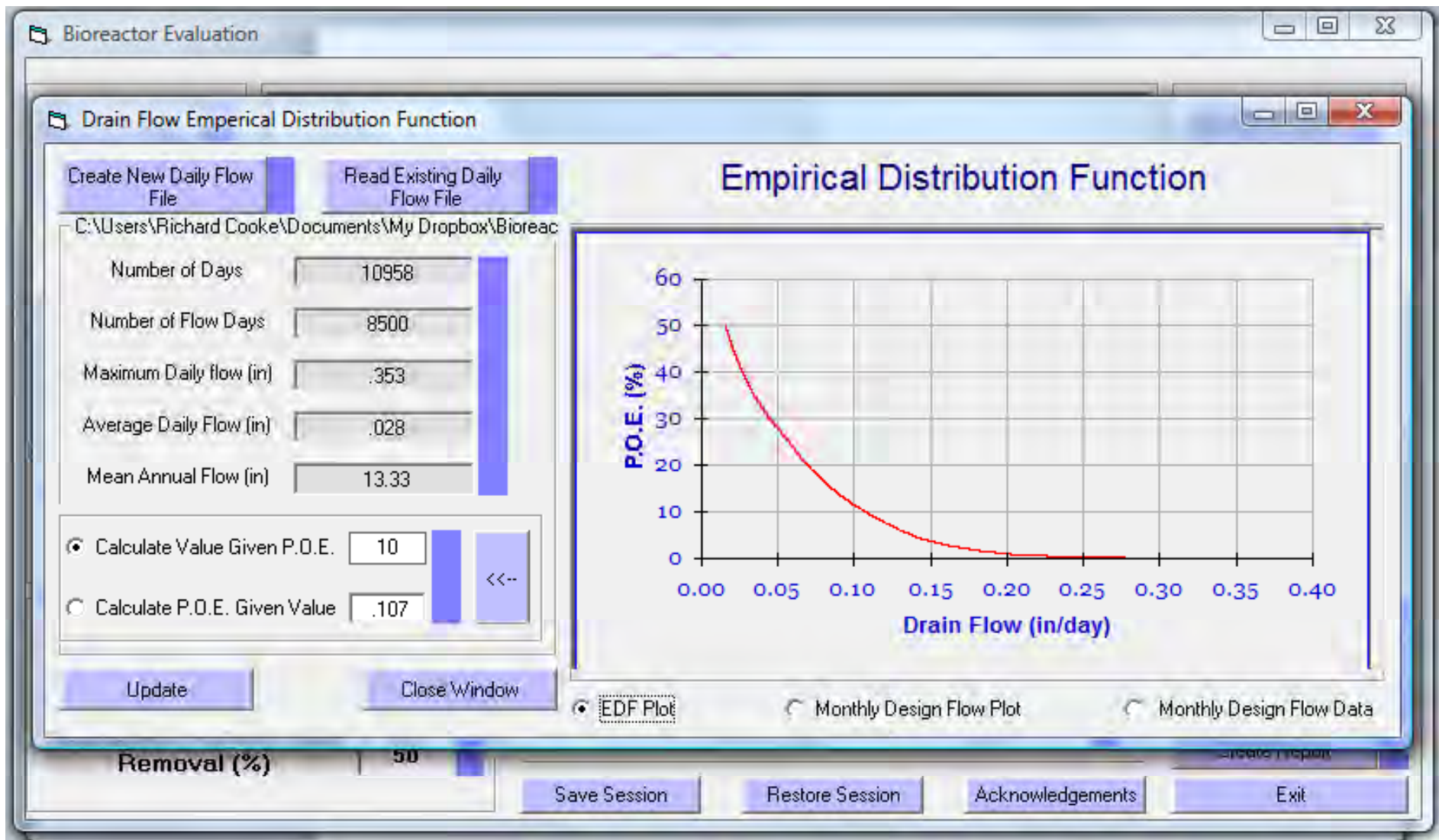


**Aitkin**      **Leafriver ( 1984 )**      Change State      Specify Drainage Depth and Spacing      Close Window

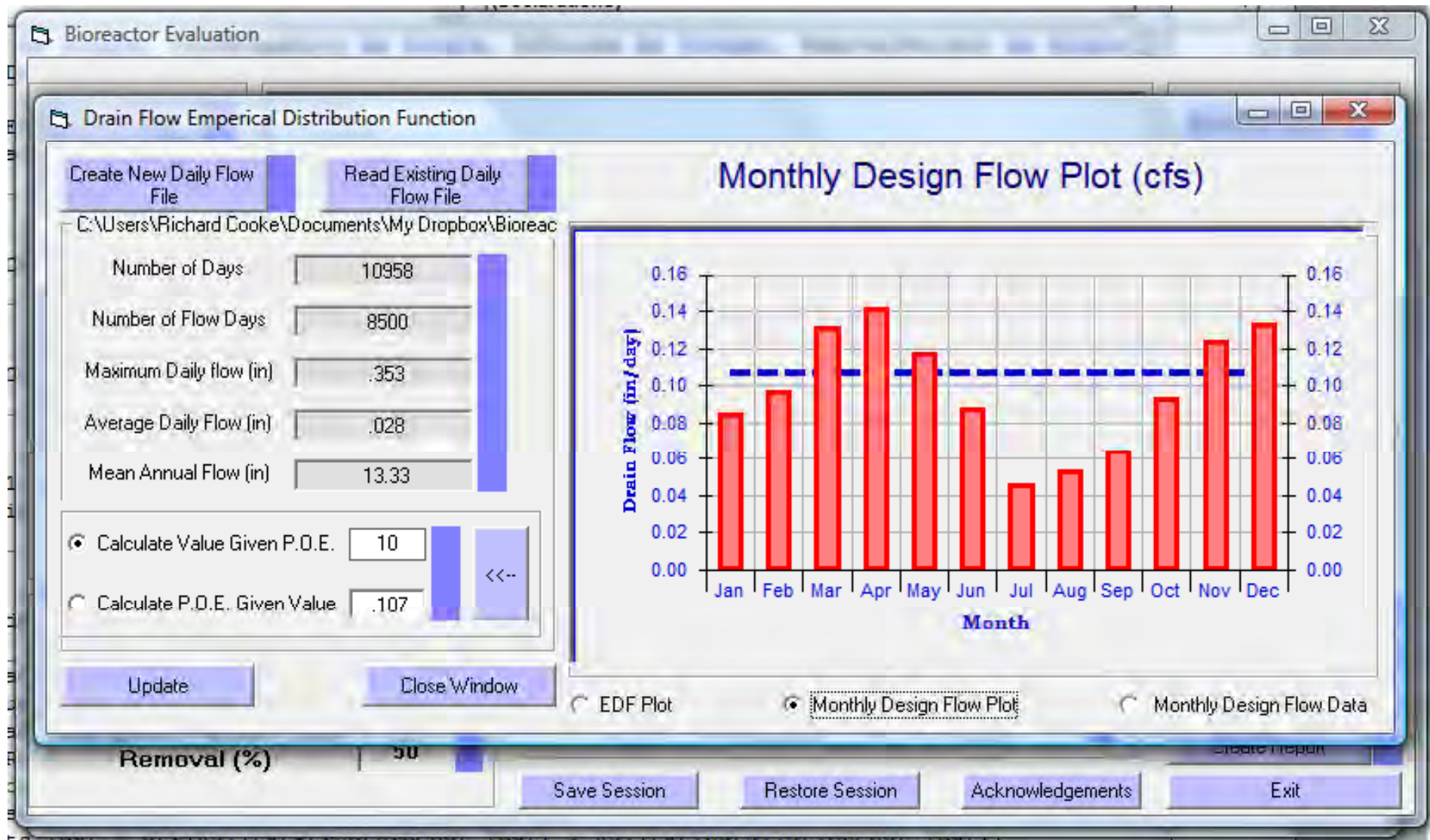




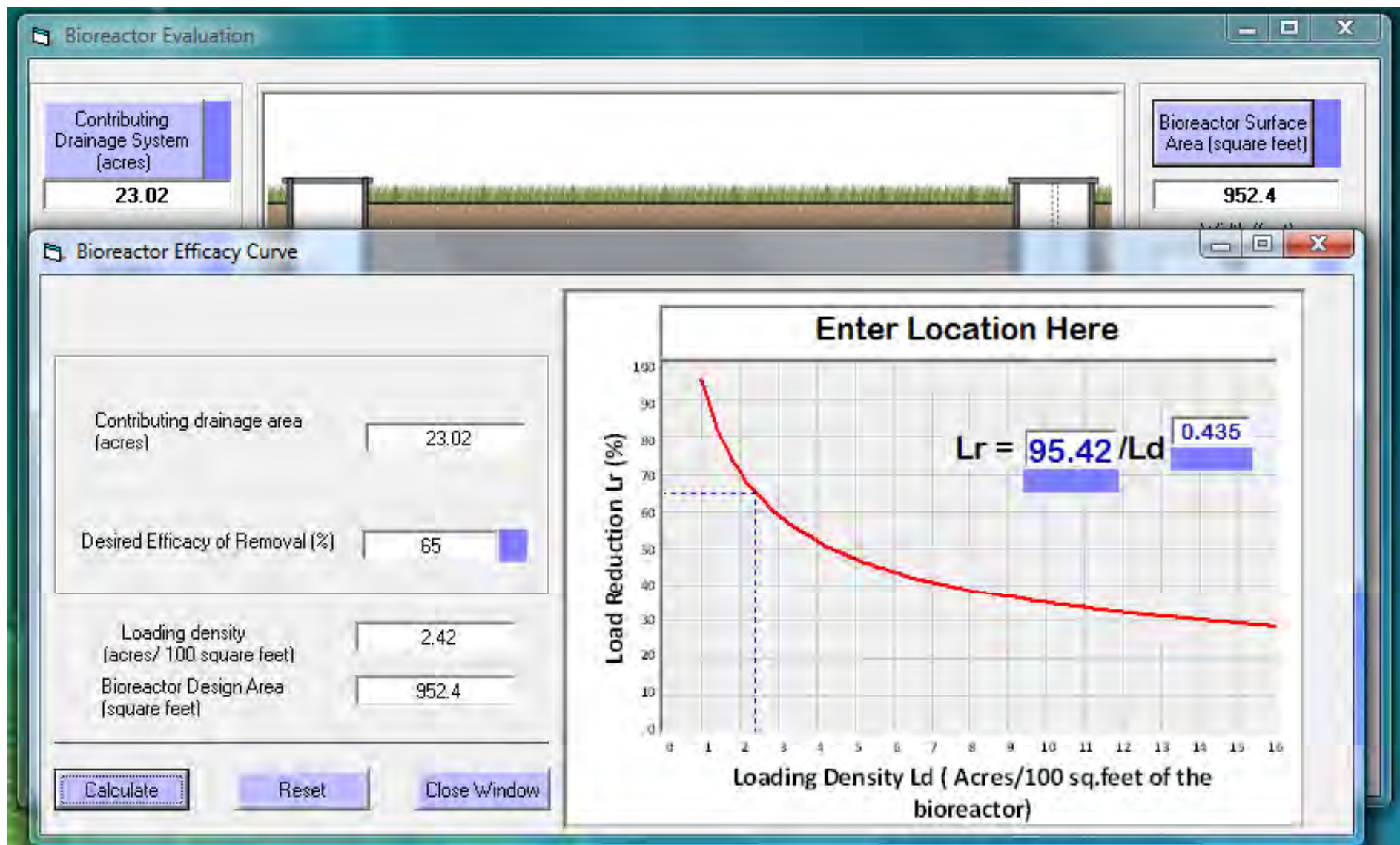
# EDF for Daily Flow



# Monthly Design Flows



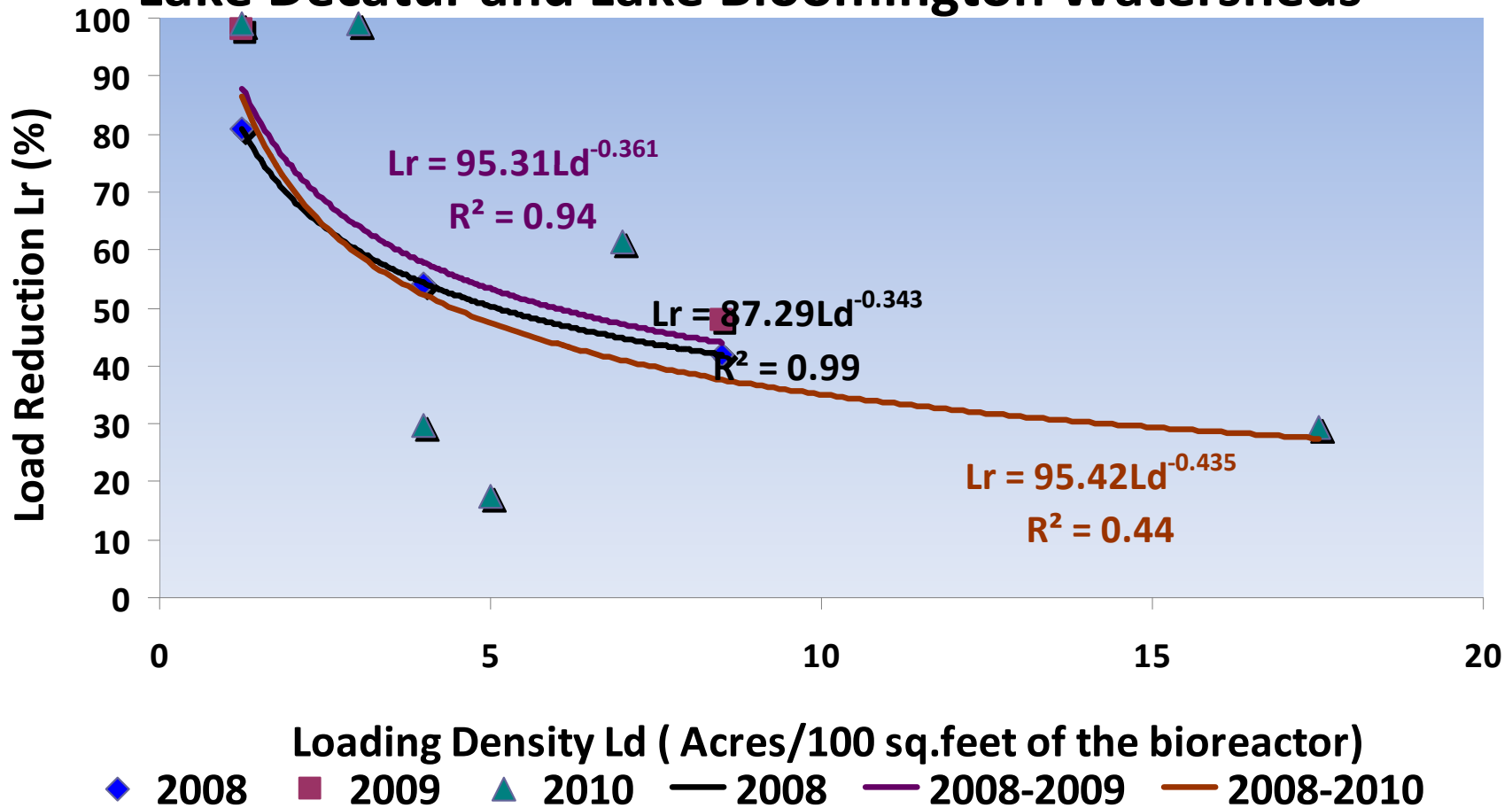
# Performance Curve



# Illinois Performance Curve

## BIOREACTOR EFFICACY CURVE

Lake Decatur and Lake Bloomington Watersheds





# Cost Analysis

Bioreactor Evaluation

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

# 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 Conductivity (ft/s)	0.15
Woodchip porosity	0.7

Woodchip Properties

**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

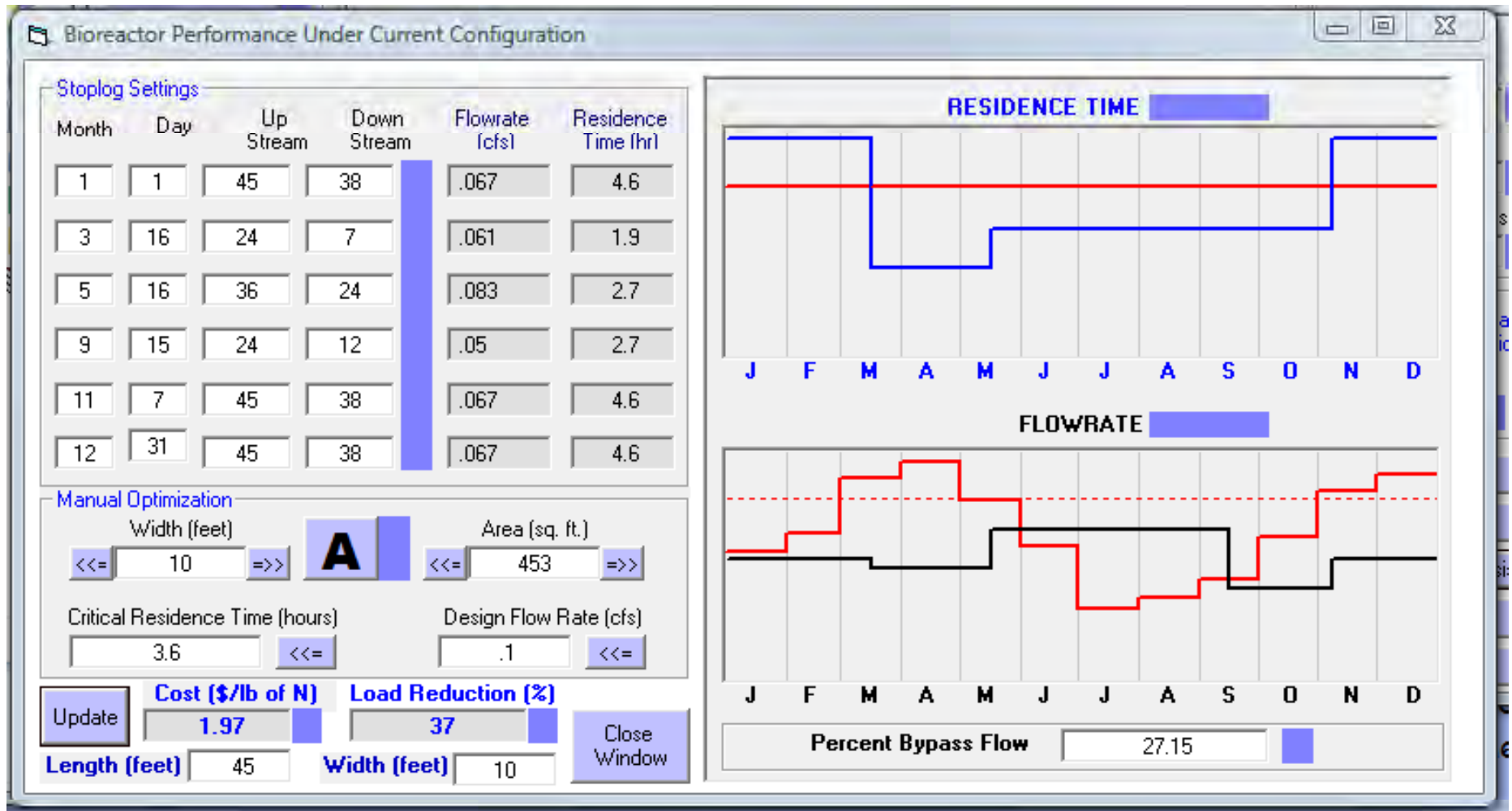
**Woodchip Properties**

Woodchip Conductivity (ft/s) 0.15  
Woodchip porosity 0.7

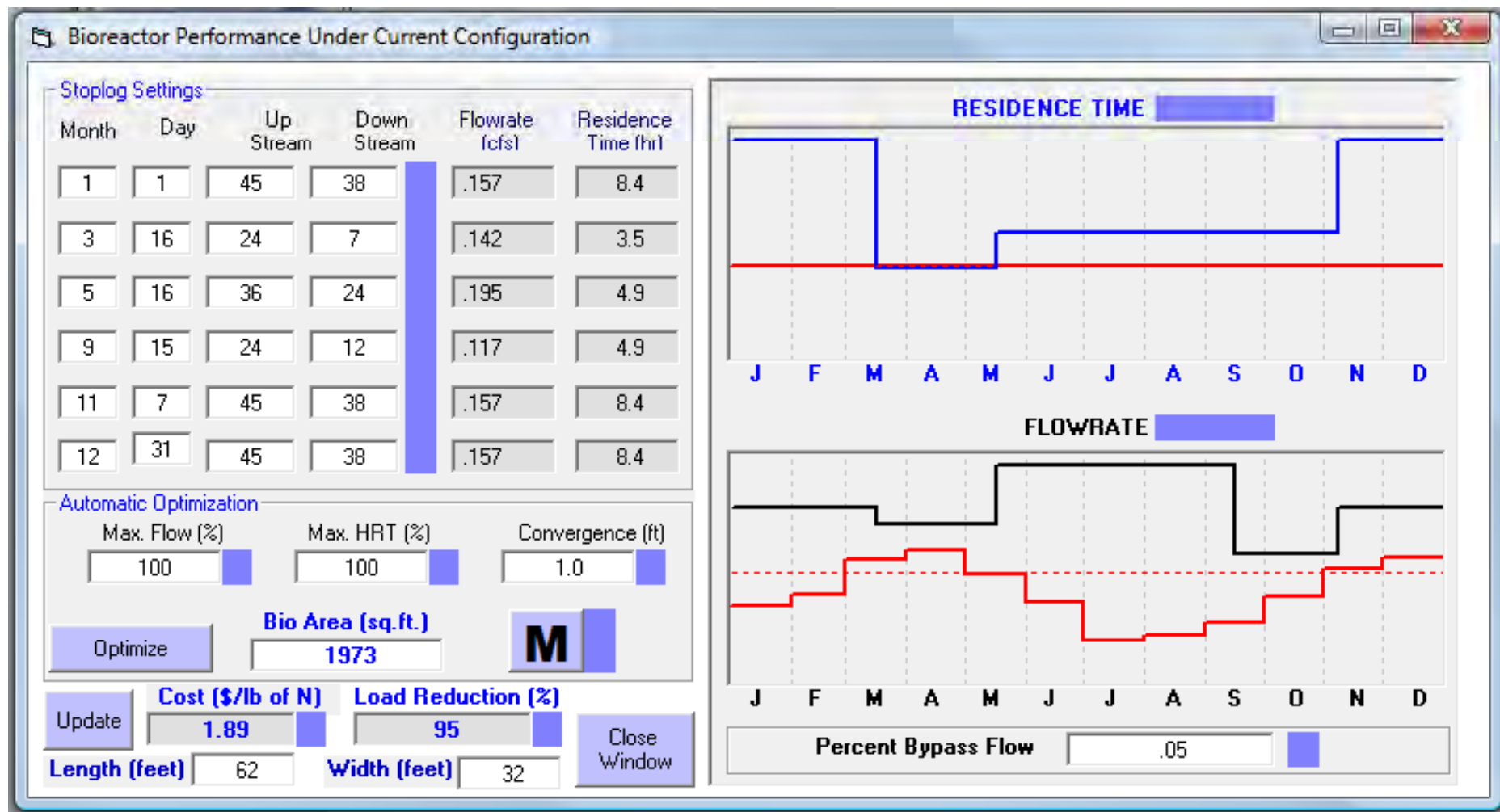
Update  
Cost Analysis  
Performance Analysis  
Create Report  
Exit

Save Session Restore Session Acknowledgements

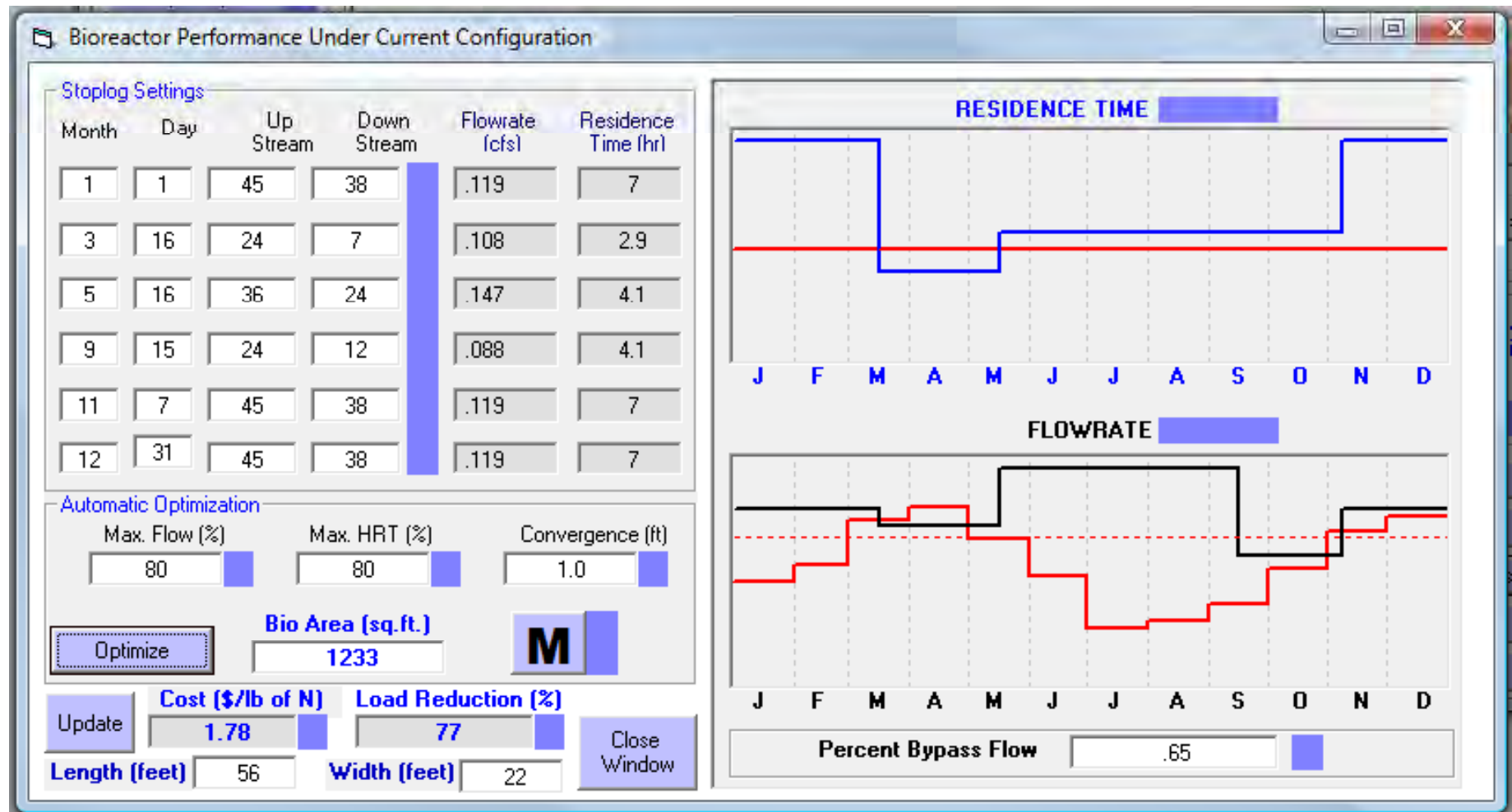
# Manual Optimization



# 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 accessed 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

**Buttons:** 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 Ruler Formula Bar Zoom 100% Zoom to Selection New Window Arrange All Freeze Panes Split Hide View Side by Side Synchronous Scrolling Reset Window Position Save Workspace Switch Windows Macros

A1 Bioreactor Design Report

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)	95
Area of Influence (acres)	23.02

**Drain Flaw Empirical Distribution Function**

Number of Days	10950
Number of Flaw Days	9500
Maximum Daily Flaw (in)	0.353
Average Daily Flaw (in)	0.028
Mean Annual Flaw (in)	13.23
Probability of Exceedance	10
Design Drainage Coefficient (in/Day)	0.107


**Bioreactor Efficacy Curve and Dimensions**

Contributing drainage area (acres)	23.02
Design Efficacy of Removal (%)	65
Loading Density (pcf/100sq ft)	2.42
Bioreactor Design Area (sq ft)	952.4
Width (feet)	28
Length (feet)	54.75
Thickness (inches)	48

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

**Design Parameters**

Height of Upstream Stepless During Critical Period (inch)	24
Height of Downstream Stepless During Critical Period (in)	7
Woodchip Conductivity (pcf)	0.15
Woodchip porosity	0.7
Volumetric Design Flaw Rate (cfz)	0.104
Anticipated Annual Load Removal (%)	80
Actual Flaw Capacity (cfz)	0.084
Actual Flaw/Design Flaw (%)	91.8
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)	13.23
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 (cfz)	Residence Time (hr)
1	1	45	38	0.155	6.7
3	16	24	7	0.14	2.7
5	16	26	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
Design Flaw Rate (cfz)	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

Bioreactor Performance Under Current Configuration

**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.)

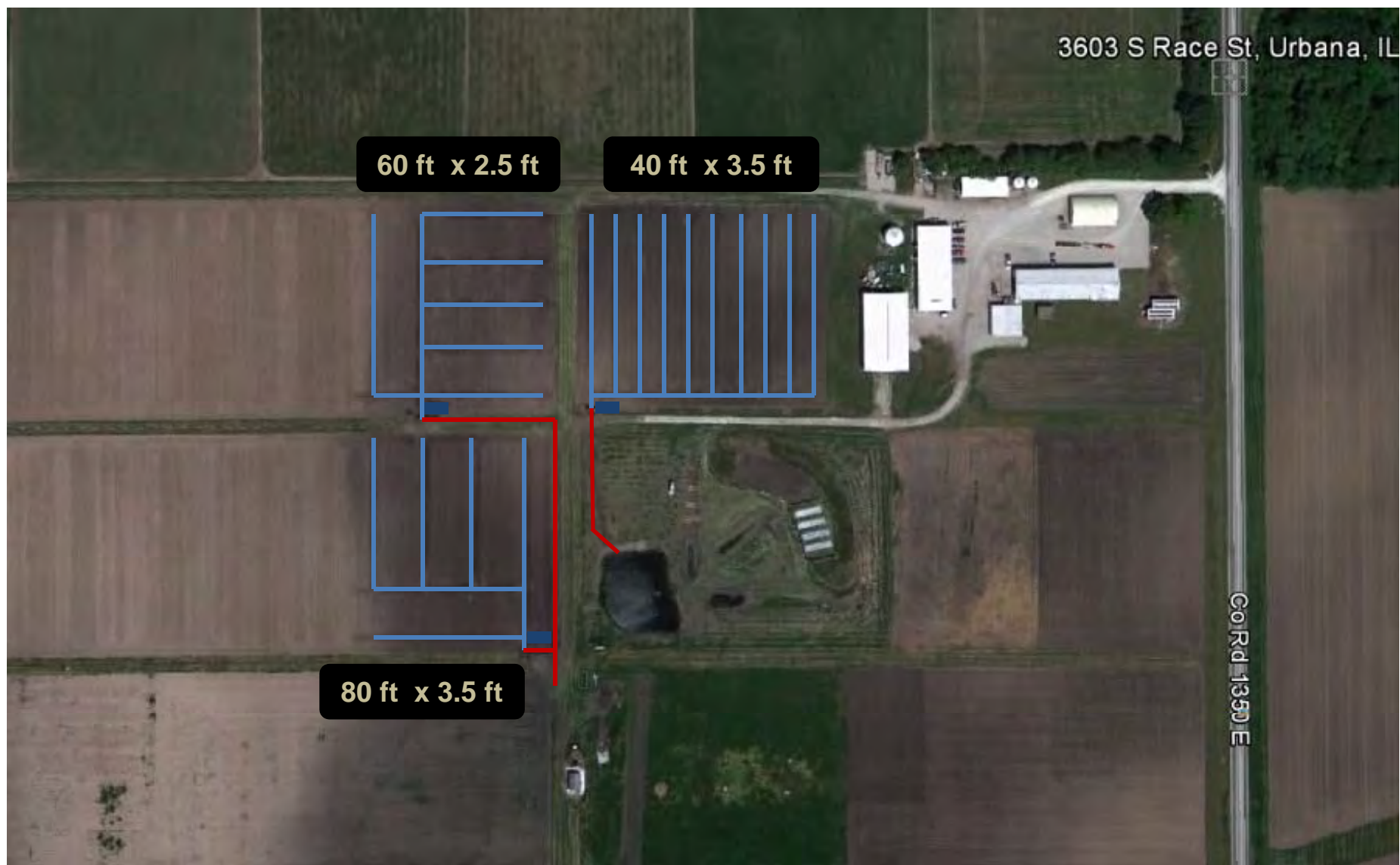
Critical Residence Time (hours)  Design Flow Rate (cfs)

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

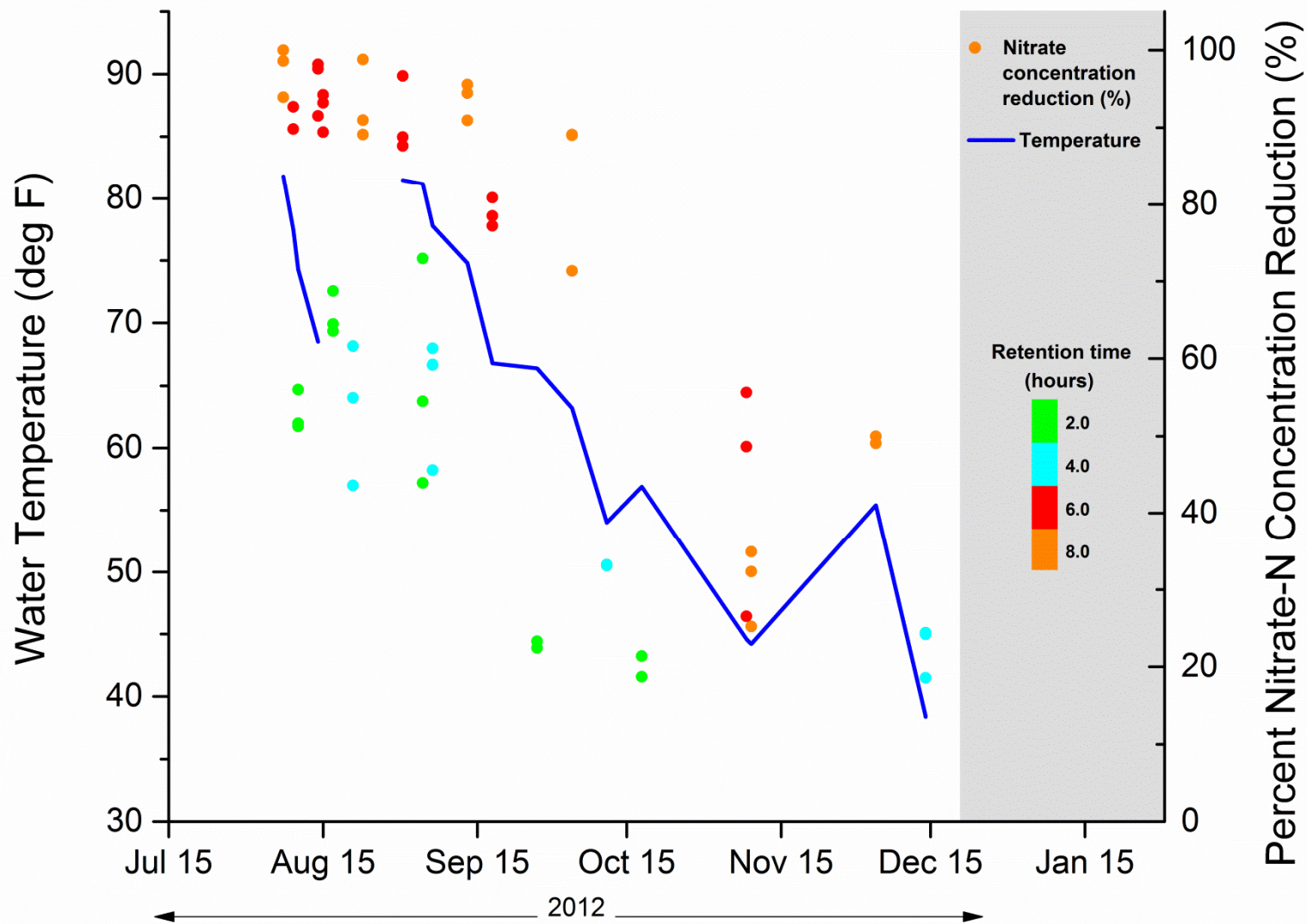
Removal (%)

Save Session Restore Session Acknowledgements Create Report Exit

January  July   
 February  August   
 March  September   
 April  October   
 May  November   
 June  December



# Preliminary Results



# Future Work: Nitrate Loads

Bioreactor Evaluation

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

# Acknowledgements



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