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Bioreactor Performance In Minnesota

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Outline

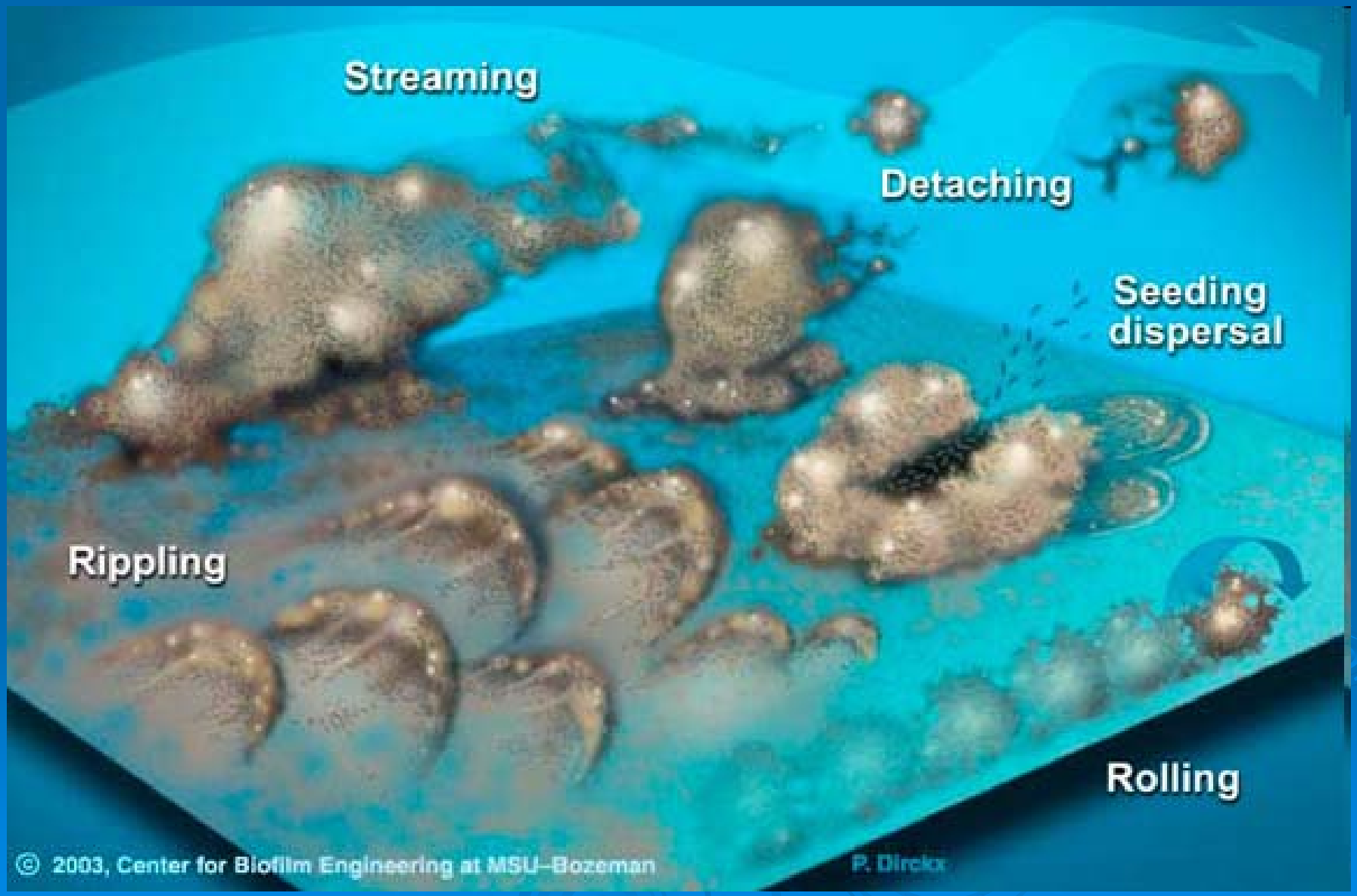
- Introduction
- Site Descriptions and Field Operations
- Setup for Sampling & Flow
- Pollutant Reduction: Nitrogen, Phosphorus, E Coli., Herbicides, Nitrous Oxide
- Summary

Trench with Woodchip

Denitrifier Community in Anaerobic Biofilter Reactor

- More than 100 species of (heterotrophic) bacteria can reduce nitrate to nitrogen gas
- Under anaerobic conditions, microorganism use nitrogen oxides as electron acceptors
- $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_20 \rightarrow N_2$
- Denitrifying bacteria also have the ability to degrade toxic organic compounds

Planktonic Bacteria vs. Biolfilm



Field Operations of Current Study

- Claremont-Bioreactor installed 2007
  - Corn-Corn-Soybean rotation

2007	2008	2009	
150	200	0	lbsN/acre

  - Anhydrous Ammonia, Fall Applied
- Dundas-Bioreactor installed 2007
  - Corn-Soybean rotation

2008	2009	
100	0	lbsN/acre

  - Anhydrous Ammonia, Fall Applied
  - Fall 2007, dairy manure applied

Monitored Parameters Bioreactor

- Physico-Chemical
  - Hydraulic Residence Time (HRT)
  - Temperature Profile
  - pH, Oxido-reduction Potential, Dissolved Oxygen
- Longevity
  - Kinetics of carbon source dissipation
  - C/N Ratio change over time
  - Cellulose, hemi-cellulose, and lignin degradation
  - Lignin/N

Site Monitoring

Sampling Scheme

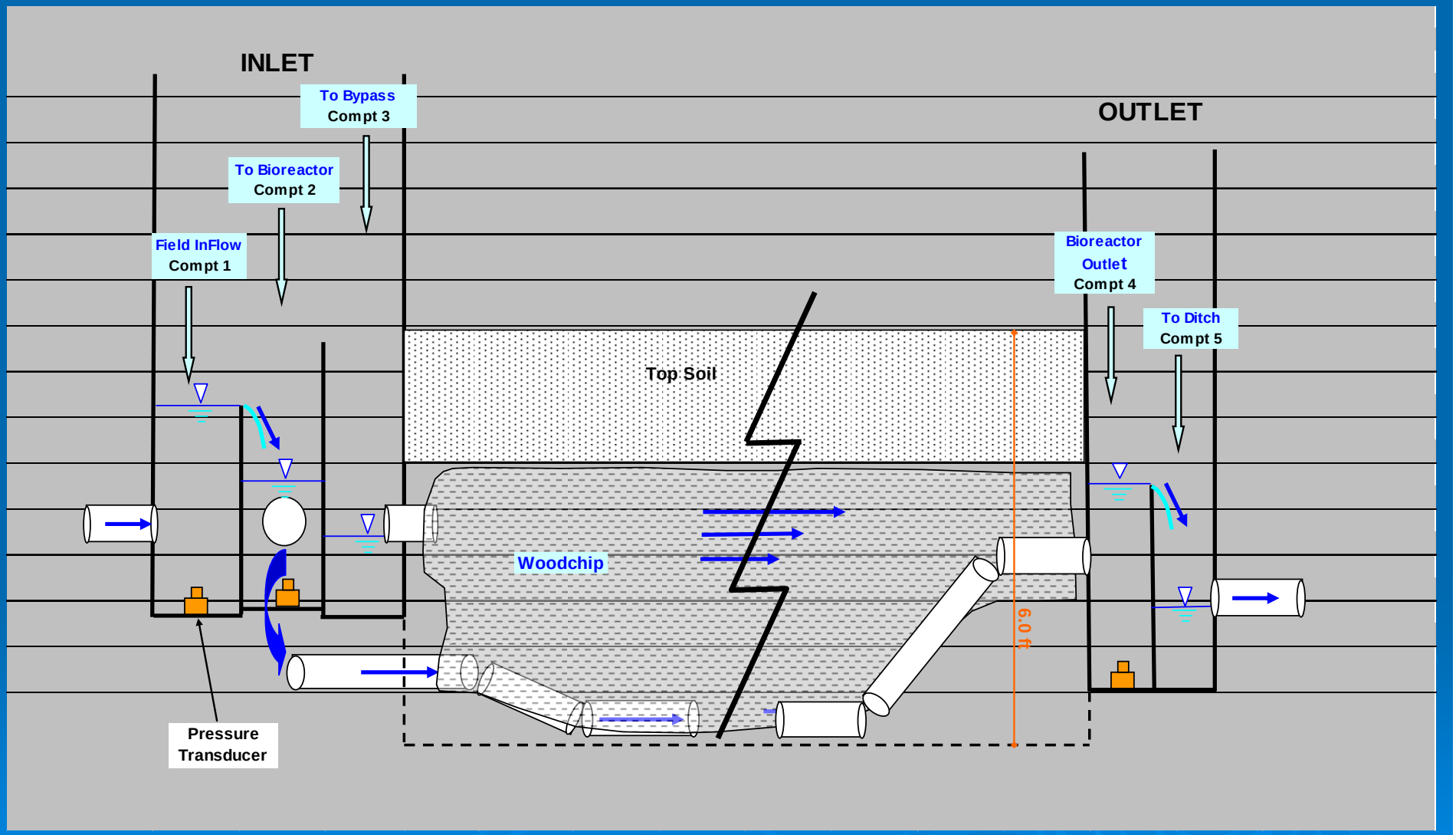
Pollutants Monitored

- Nitrate
- Total Phosphorus
- E Coli (Dundas Site)
- Nitrous Oxide
- Herbicides: Acetochlor & Atrazine

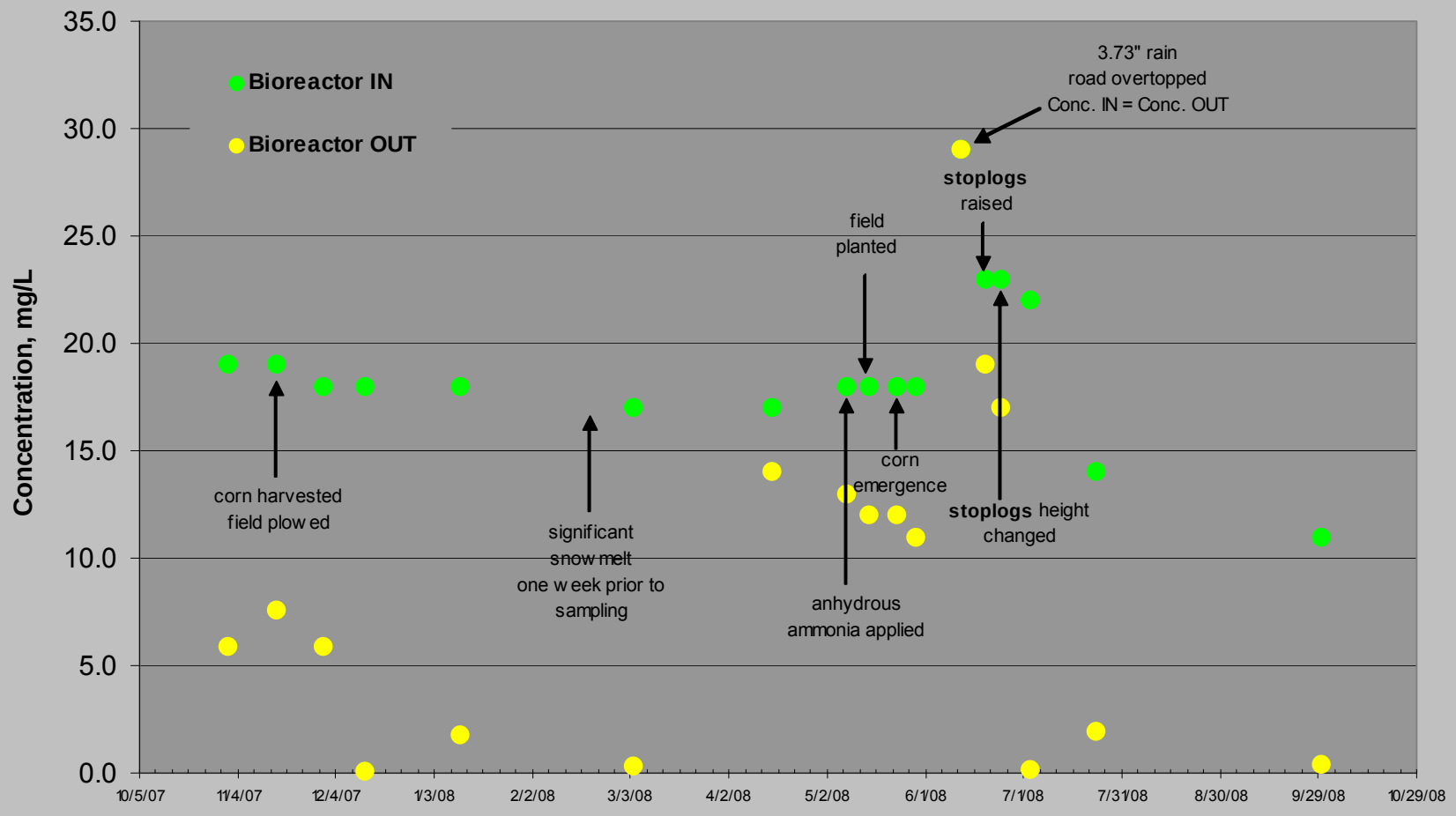
Claremont Site

Bioreactor Site

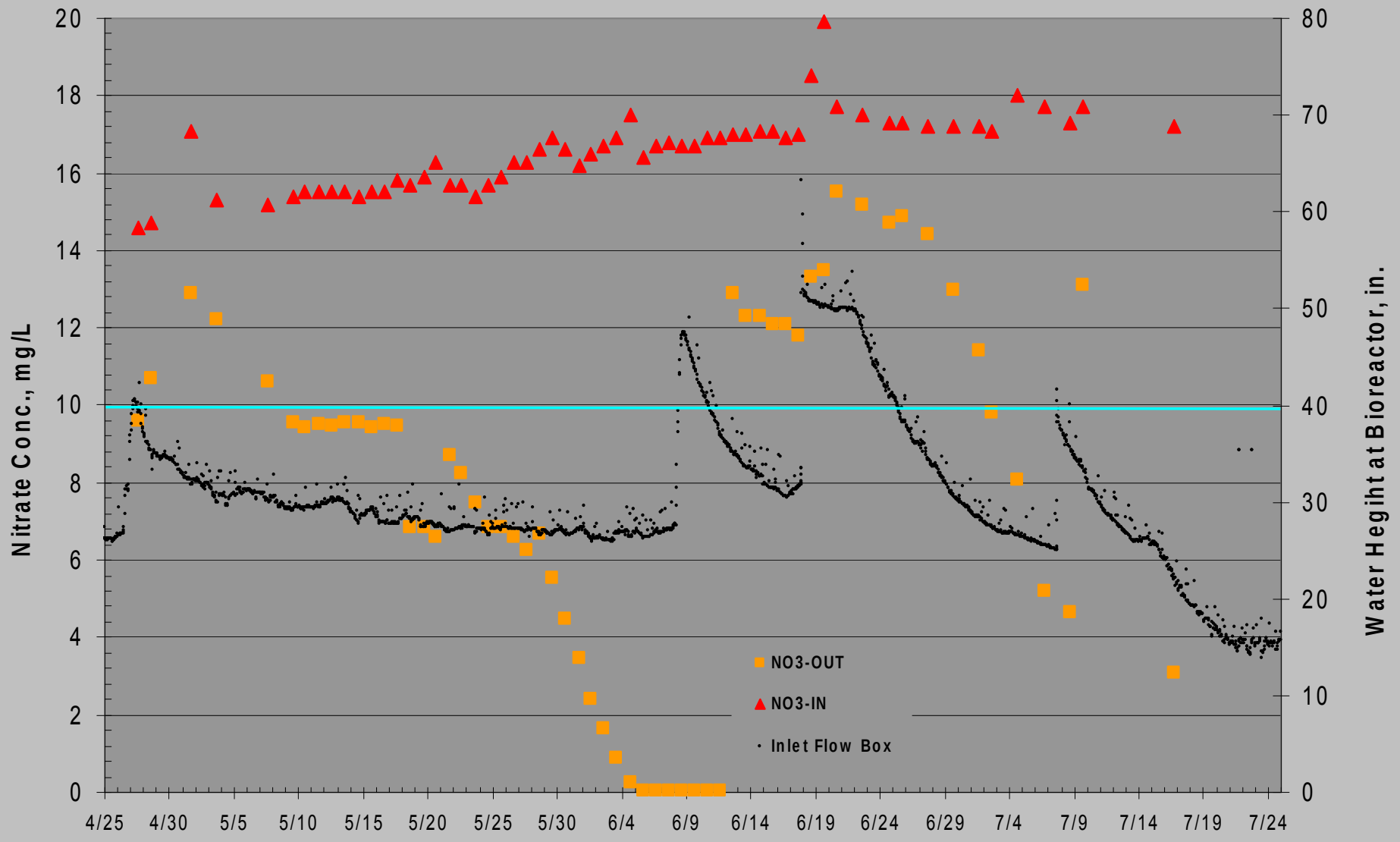
Flow Control Box Setup



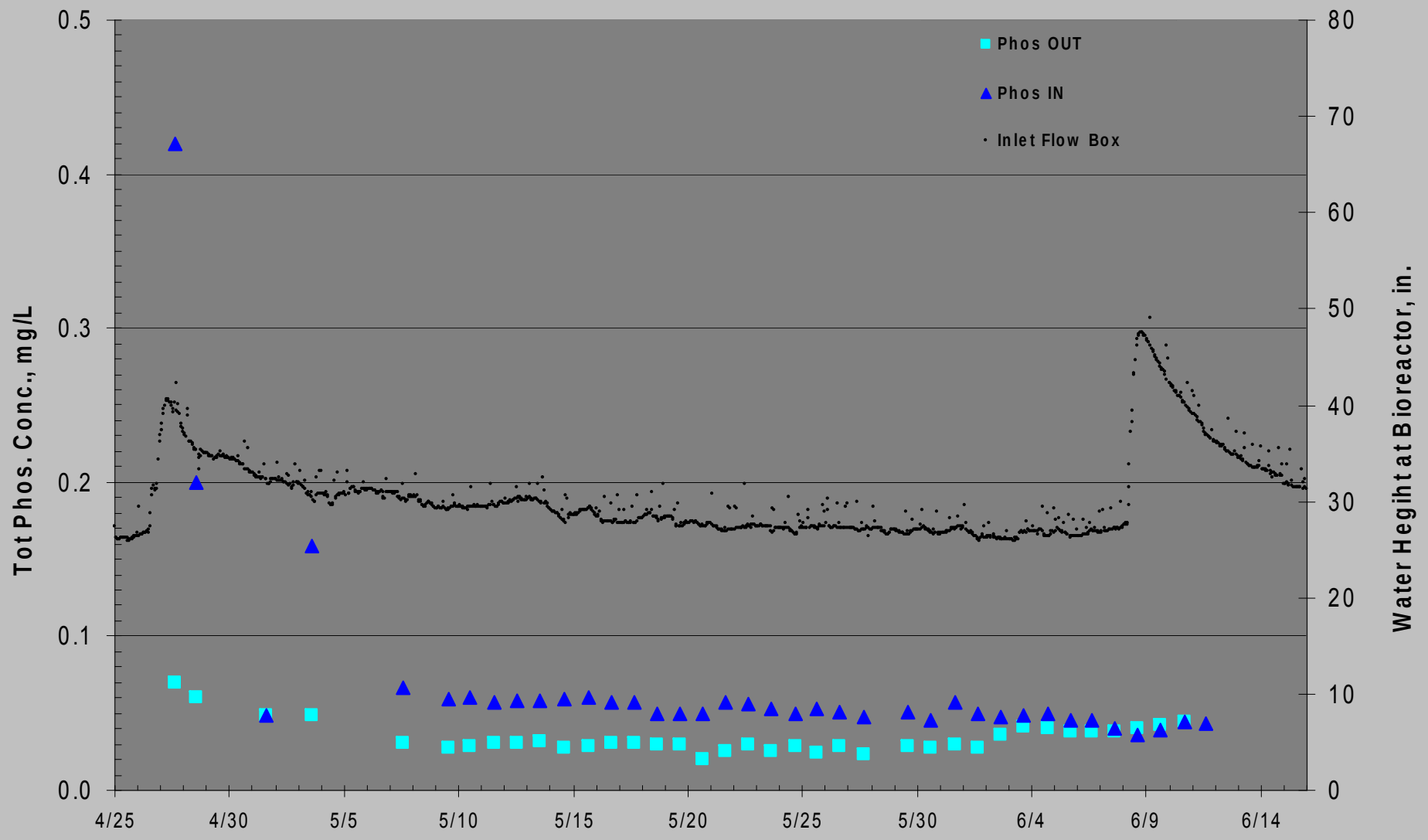
Nitrate Concentrations at Claremont in 2008



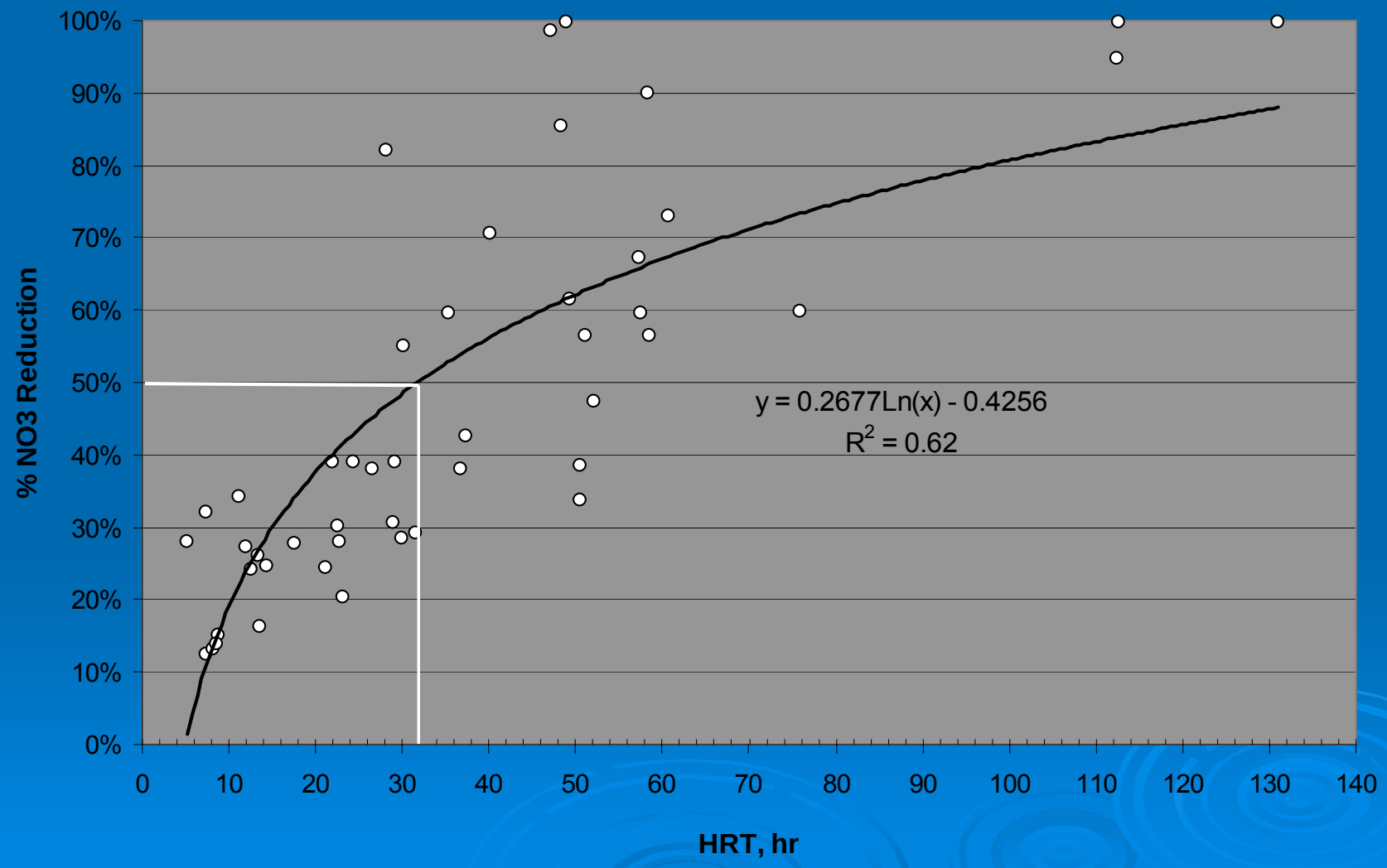
Nitrate Concentration in 2009



Claremont: Total P - 2009



Bioreactor Flow and Hydraulic Residence Time (HRT) April – July 2009



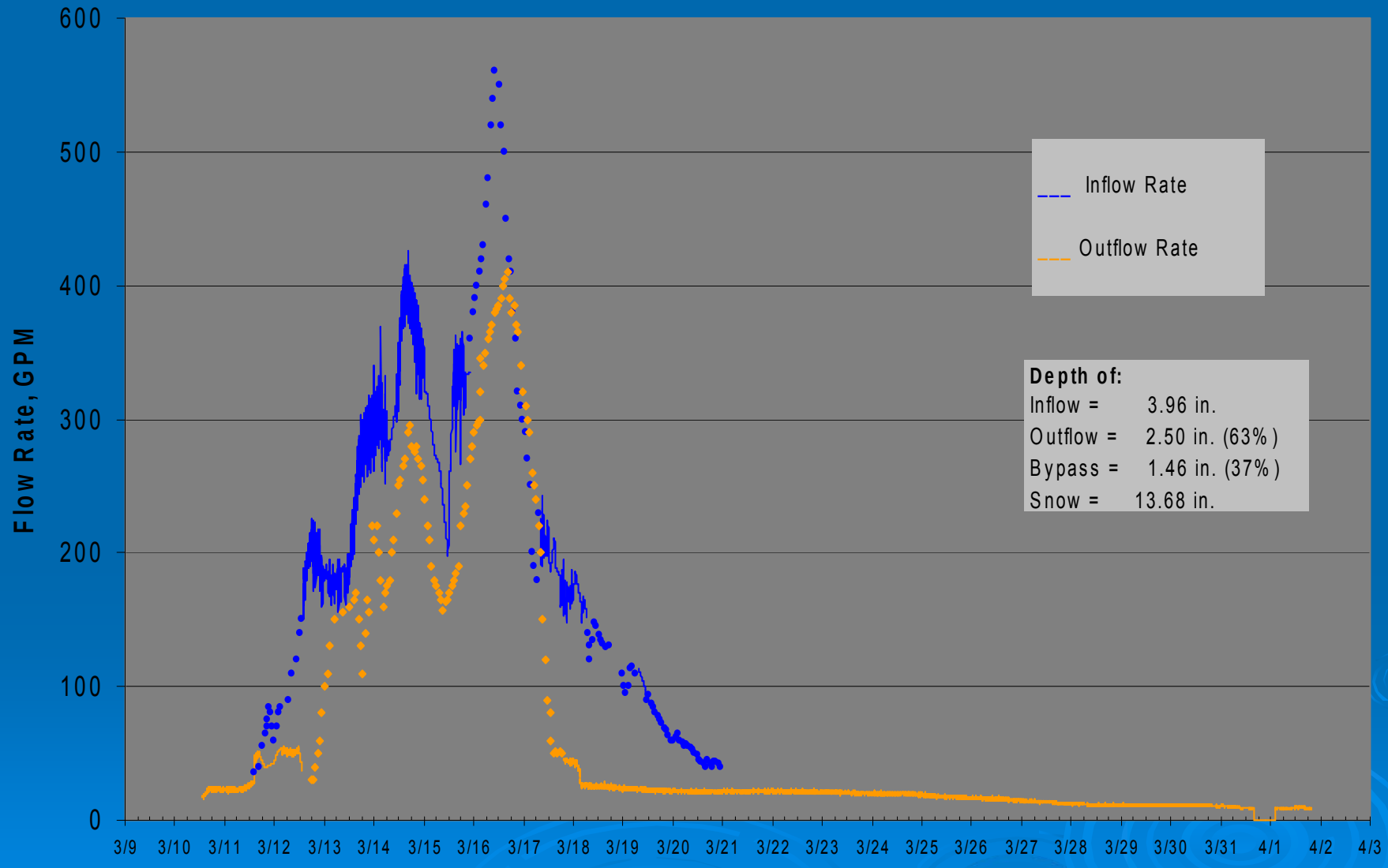
Claremont Site: Flow and Rainfall (2009)

Contributing Area	26.0 acres
Rainfall	25.2 inches
Outlet Flow	5.8 inches
Bypass Flow	4.5 inches
Total Flow	10.2 inches

Claremont: Pollutant Loading-2009

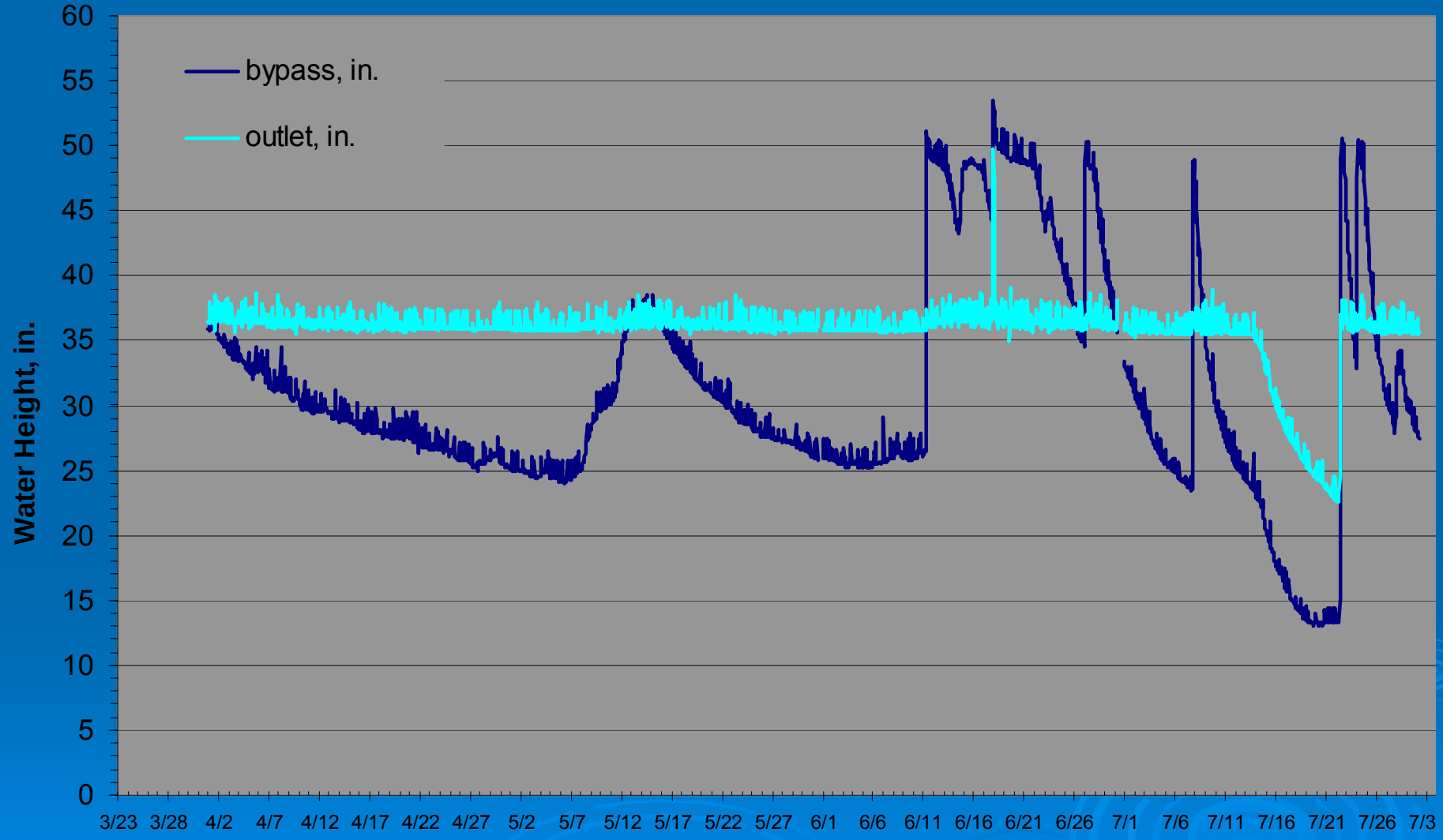
Station	Nitrate	Tot P
Inlet, lbs/ac	16.1	0.119
Outlet, lbs/ac	8.5	0.057
Reduction, lbs/ac	**7.6**	**0.063**
Reduction, %	**47.0%**	**52.4%**

Claremont Snowmelt 2010



Claremont: Snowmelt Pollutant Loading

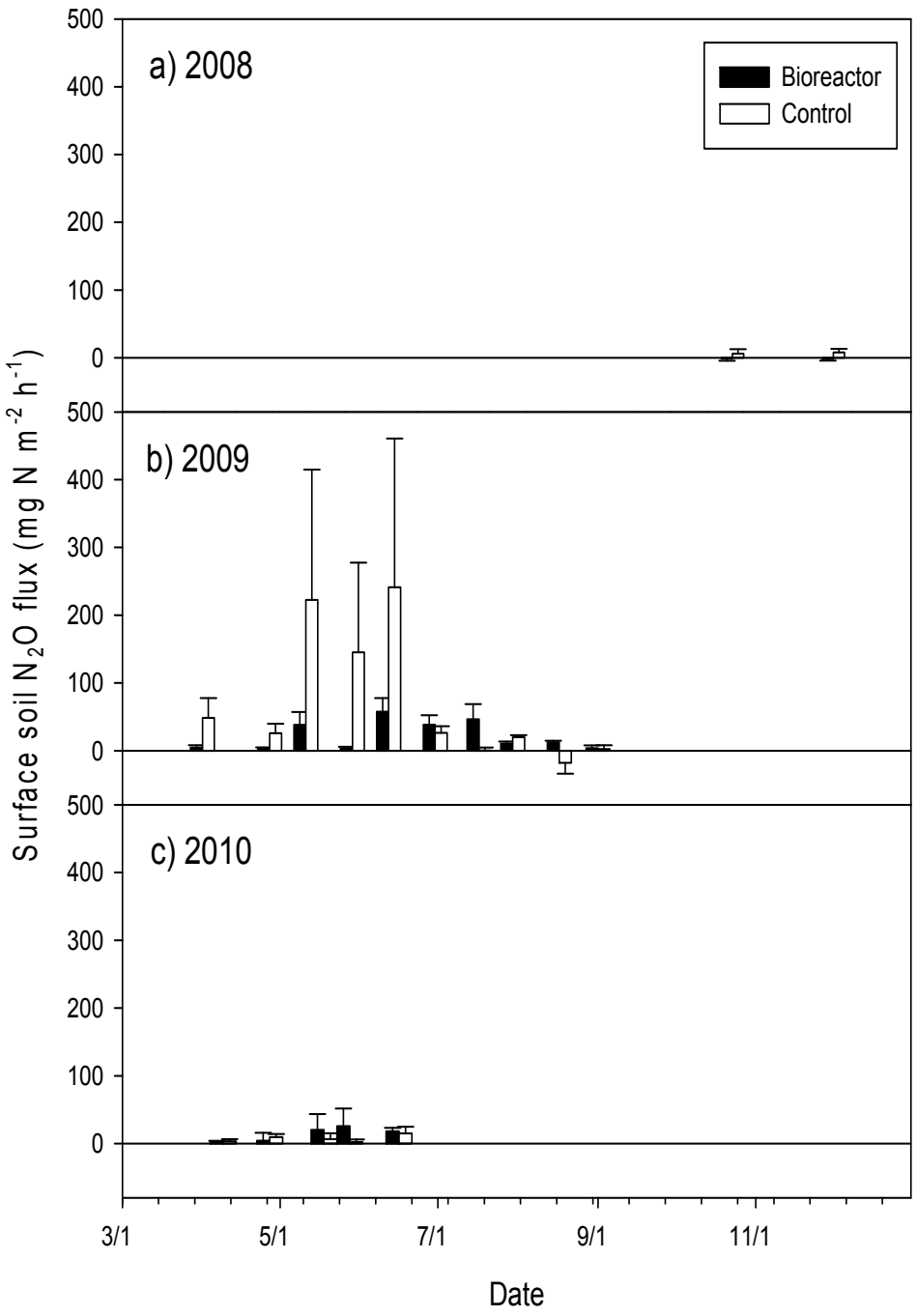
Station	Flow Depth, in.	Nitrate Loading, lbs/ac	Tot P Loading, lbs/ac
INFLOW	3.96	17.3	0.217
OUTFLOW	2.50	8.3	0.218
Reduction		52%	-0.4%


CLAREMONT
March-July 2010 Flow Event
bypass, in.
outlet, in.
Water Height, in.
60
55
50
45
40
35
30
25
20
15
10
5
0
3/23
3/28
4/2
4/7
4/12
4/17
4/22
4/27
5/2
5/7
5/12
5/17
5/22
5/27
6/1
6/6
6/11
6/16
6/21
6/26
7/1
7/6
7/11
7/16
7/21
7/26
7/3

Claremont: Pollutant Loading
April-June 2010

Station	Flow Depth, in.	Nitrate, lbs/ac	Tot P, lbs/ac
Inlet	5.07	5.59	0.0083
Outlet	2.68	4.56	0.0050
Reduction		18%	40%

Inlet = bypass + outlet

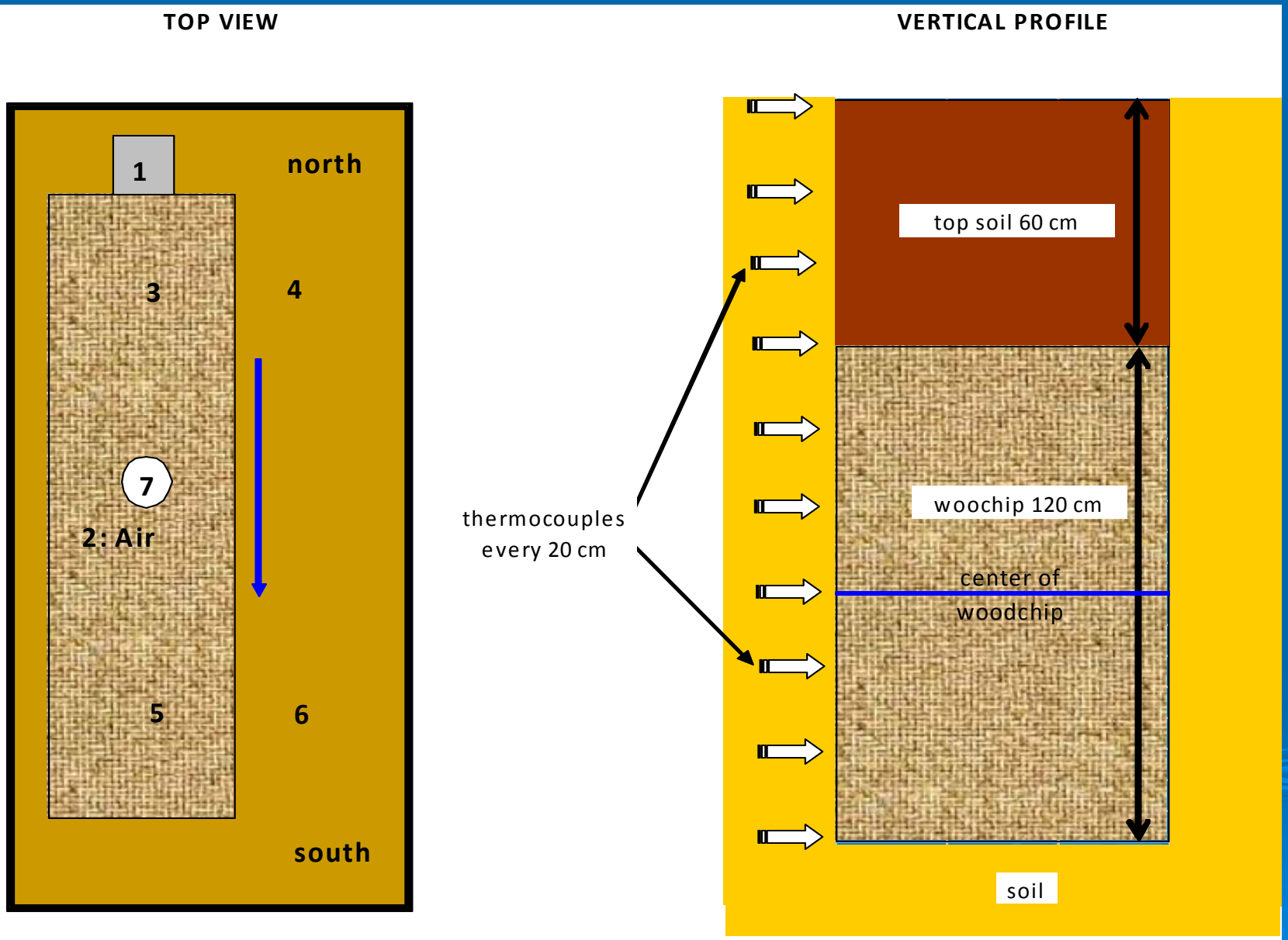


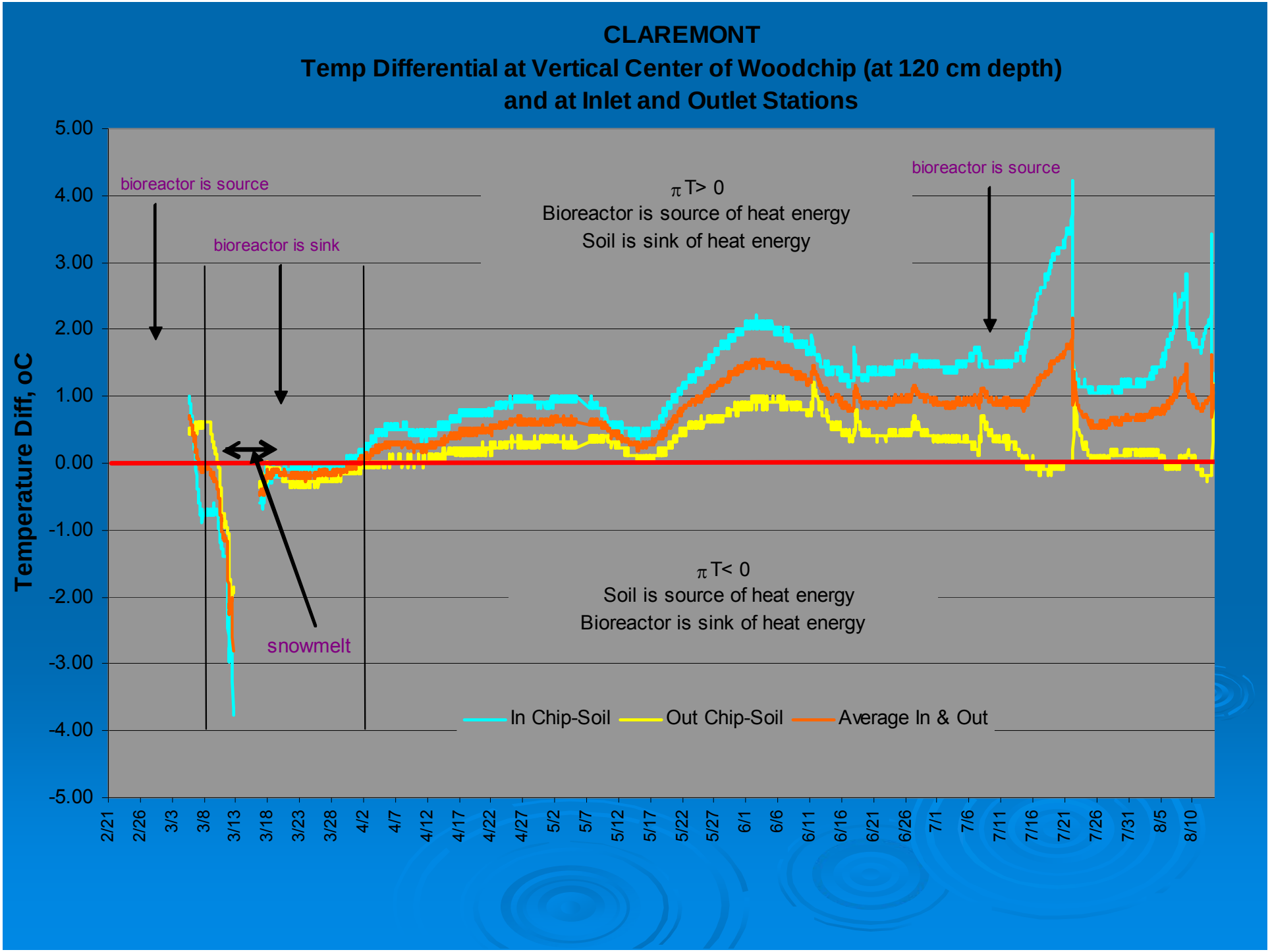
N_2O emissions at Claremont, MN

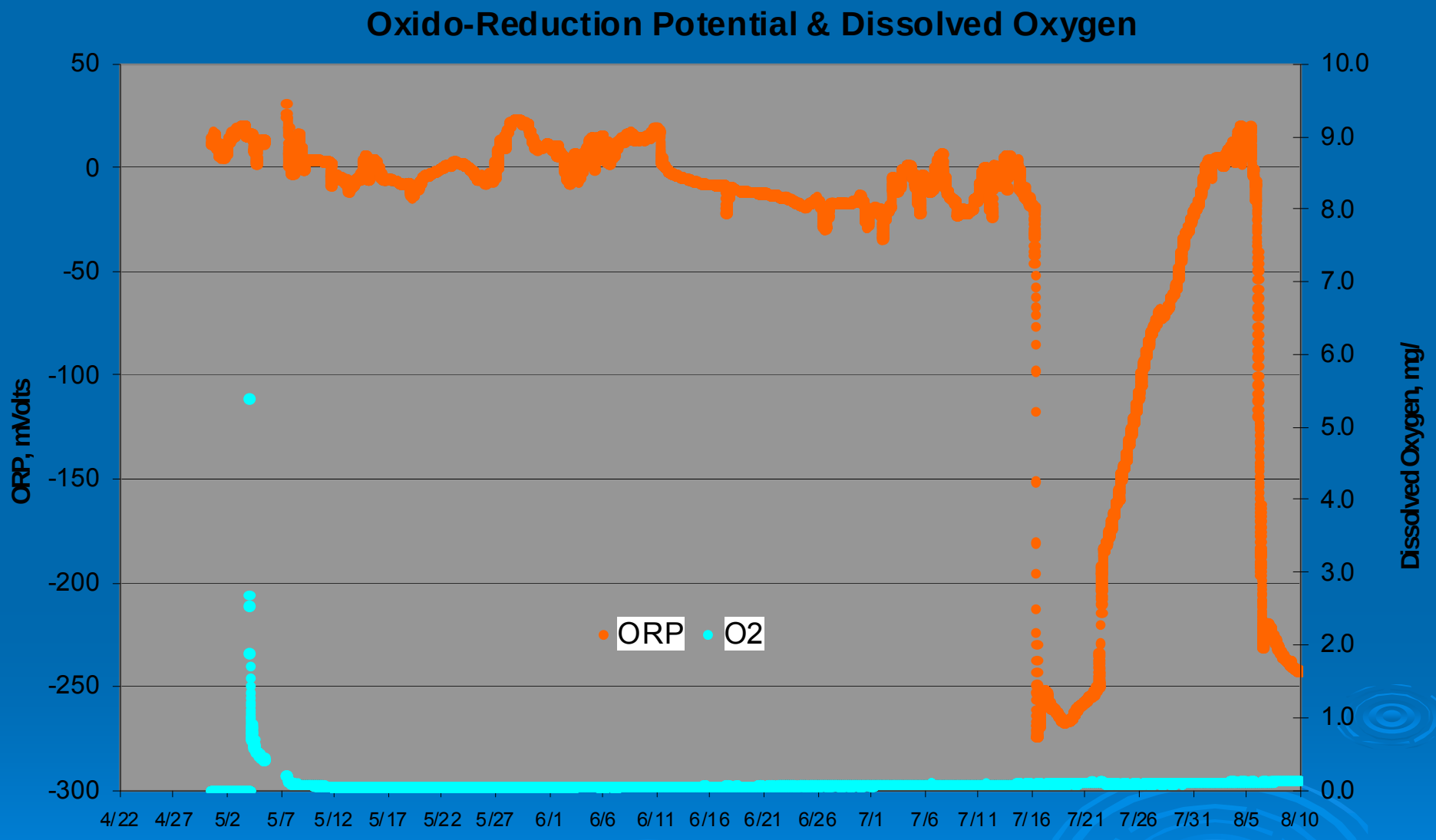
N_2O-N loading (unit: g N ha^{-1})

	Bioreactor	Control
2009	794.9 (299.2)	2634.8 (2184.3)
2010*	272.0 (145.5)	154.6 (33.3)

*from April through June


TOP VIEW
VERTICAL PROFILE
1
north
3
4
7
2: Air
5
6
south
thermocouples
every 20 cm
top soil 60 cm
woochip 120 cm
center of
woodchip
soil


CLAREMONT
Temp Differential at Vertical Center of Woodchip (at 120 cm depth)
and at Inlet and Outlet Stations
Temperature Diff, oC
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
bioreactor is source
bioreactor is sink
bioreactor is source
π T> 0
Bioreactor is source of heat energy
Soil is sink of heat energy
π T< 0
Soil is source of heat energy
Bioreactor is sink of heat energy
snowmelt
In Chip-Soil
Out Chip-Soil
Average In & Out
2/21
2/26
3/3
3/8
3/13
3/18
3/23
3/28
4/2
4/7
4/12
4/17
4/22
4/27
5/2
5/7
5/12
5/17
5/22
5/27
6/1
6/6
6/11
6/16
6/21
6/26
7/1
7/6
7/11
7/16
7/21
7/26
7/31
8/5
8/10

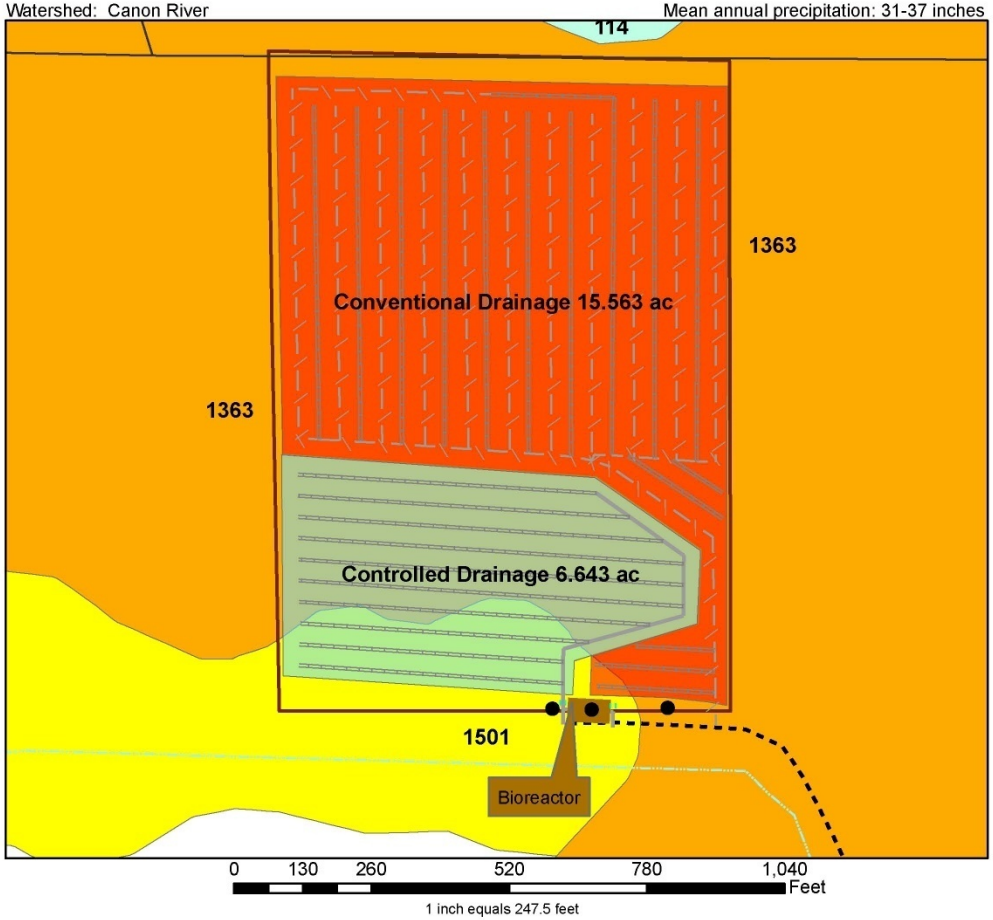

Claremont:
Oxido-Reduction Potential & Dissolved Oxygen
ORP, mVolts
Dissolved Oxygen, mg/
50
0
-50
-100
-150
-200
-250
-300
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ORP
O2
4/22
4/27
5/2
5/7
5/12
5/17
5/22
5/27
6/1
6/6
6/11
6/16
6/21
6/26
7/1
7/6
7/11
7/16
7/21
7/26
7/31
8/5
8/10

Dundas Site

Drainage Water Management Plan Map

NRCS CIG Grant
Location: Rice County, Minnesota
Watershed: Canon River

Practice: Controlled Drainage
Dominant Soil Ksat: Moderately high (0.20 to 0.60 in/hr)
Mean annual precipitation: 31-37 inches



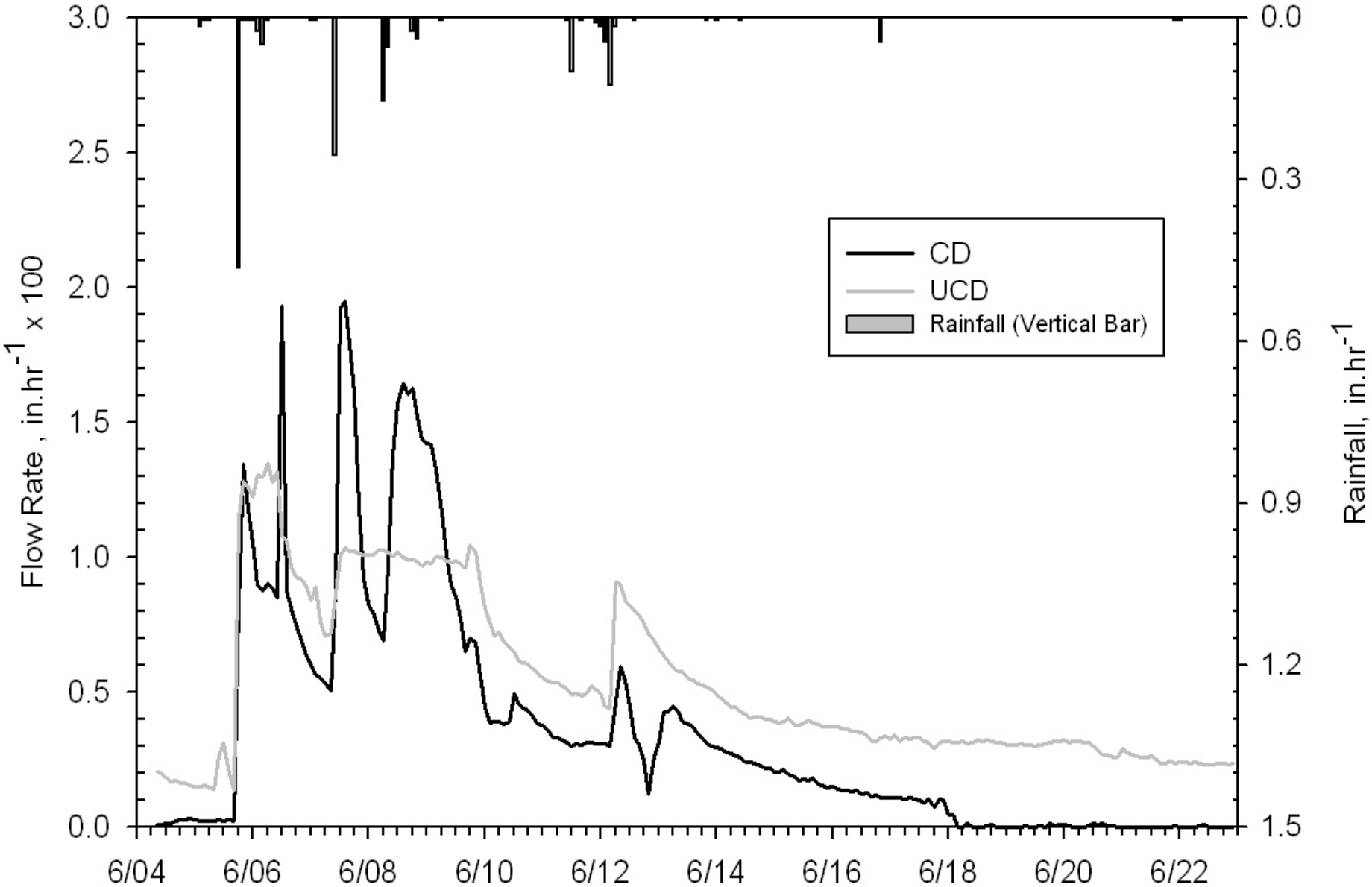
Legend

Drainage Type
- Controlled
- Conventional
- Control Structures
- ACCESS POINT
- Data Logger

Rice County Soils
Unit name (MUSYM)
- Glencoe clay loam (114)
- Dundas silt loam (1363) Dominant Soil
- Klossner mucky silty clay loam (1501)

Soil Type	Drainage Type	Acres
Klossner	Controlled	1.737
Klossner	Conventional	0.08
Dundas	Controlled	4.906
Dundas	Conventional	15.483

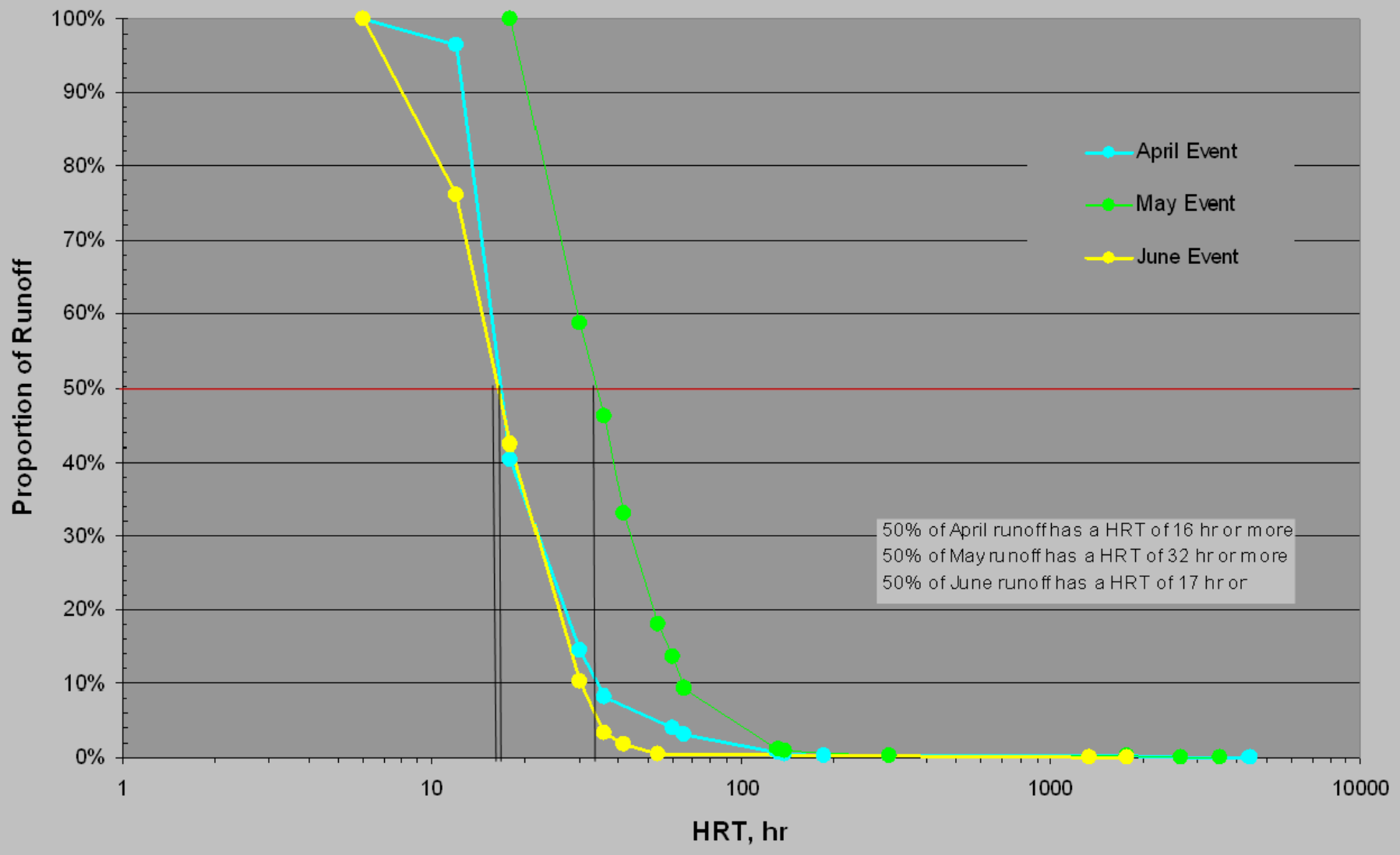
Map prepared by, MDA
January 2009


3.0
2.5
2.0
1.5
1.0
0.5
0.0
Flow Rate , in.hr-1 x 100
0.0
0.3
0.6
0.9
1.2
1.5
Rainfall, in.hr-1
CD
UCD
Rainfall (Vertical Bar)
6/04
6/06
6/08
6/10
6/12
6/14
6/16
6/18
6/20
6/22

Dundas Site: Flow and Rainfall for 2008

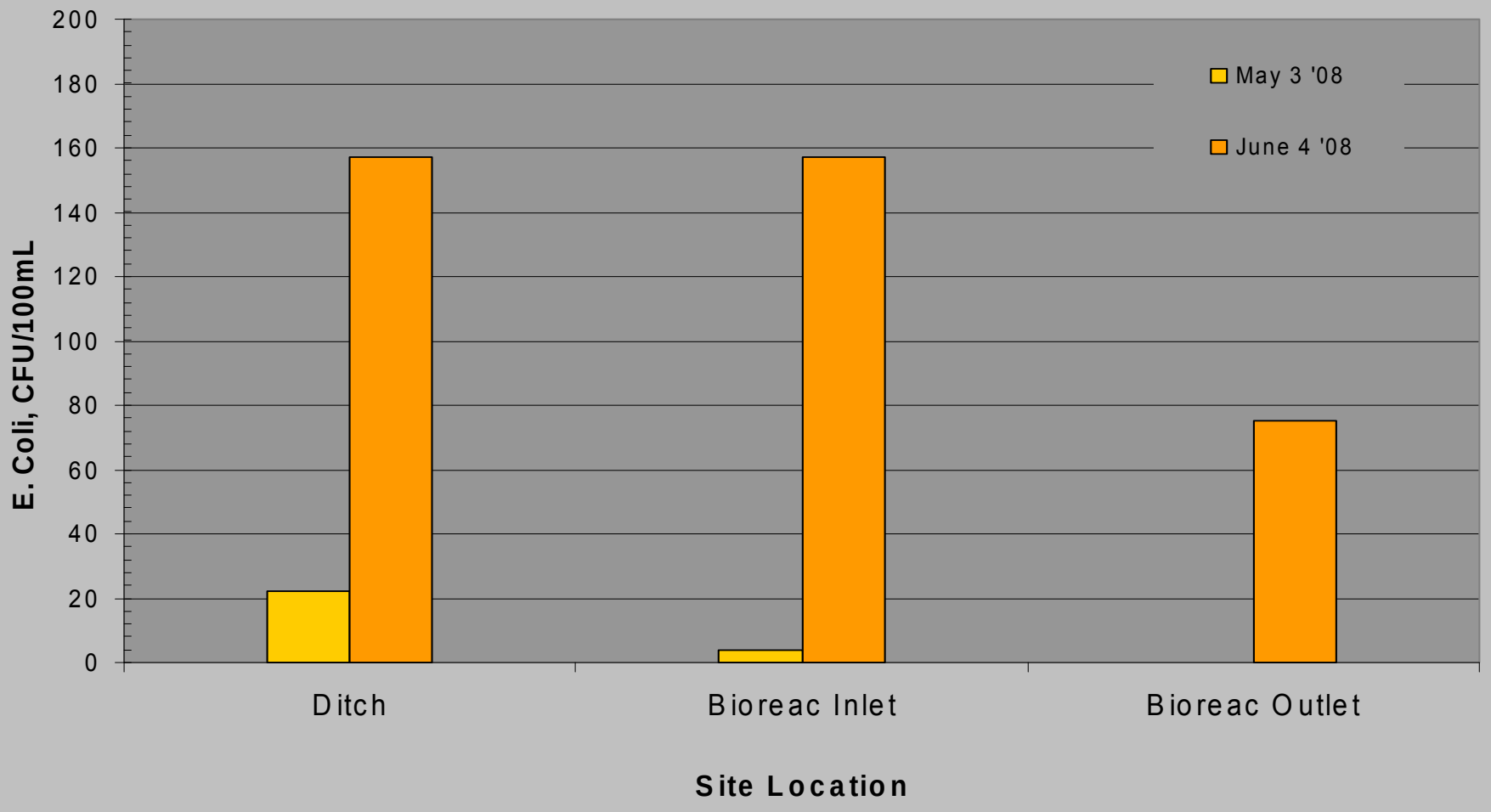
Period	CD	UCD	Rain
April	0.89	1.00	2.02
May	0.29	0.54	1.72
June	1.10	1.96	2.91
Total	2.29	3.51	7.15

Units are inches; CD: Controlled Drainage; UCD : Uncontrolled Drainage


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Proportion of Runoff
1
10
100
1000
10000
HRT, hr
April Event
May Event
June Event
50% of April runoff has a HRT of 16 hr or more
50% of May runoff has a HRT of 32 hr or more
50% of June runoff has a HRT of 17 hr or

E. coli Count Reduction thru Bioreactor

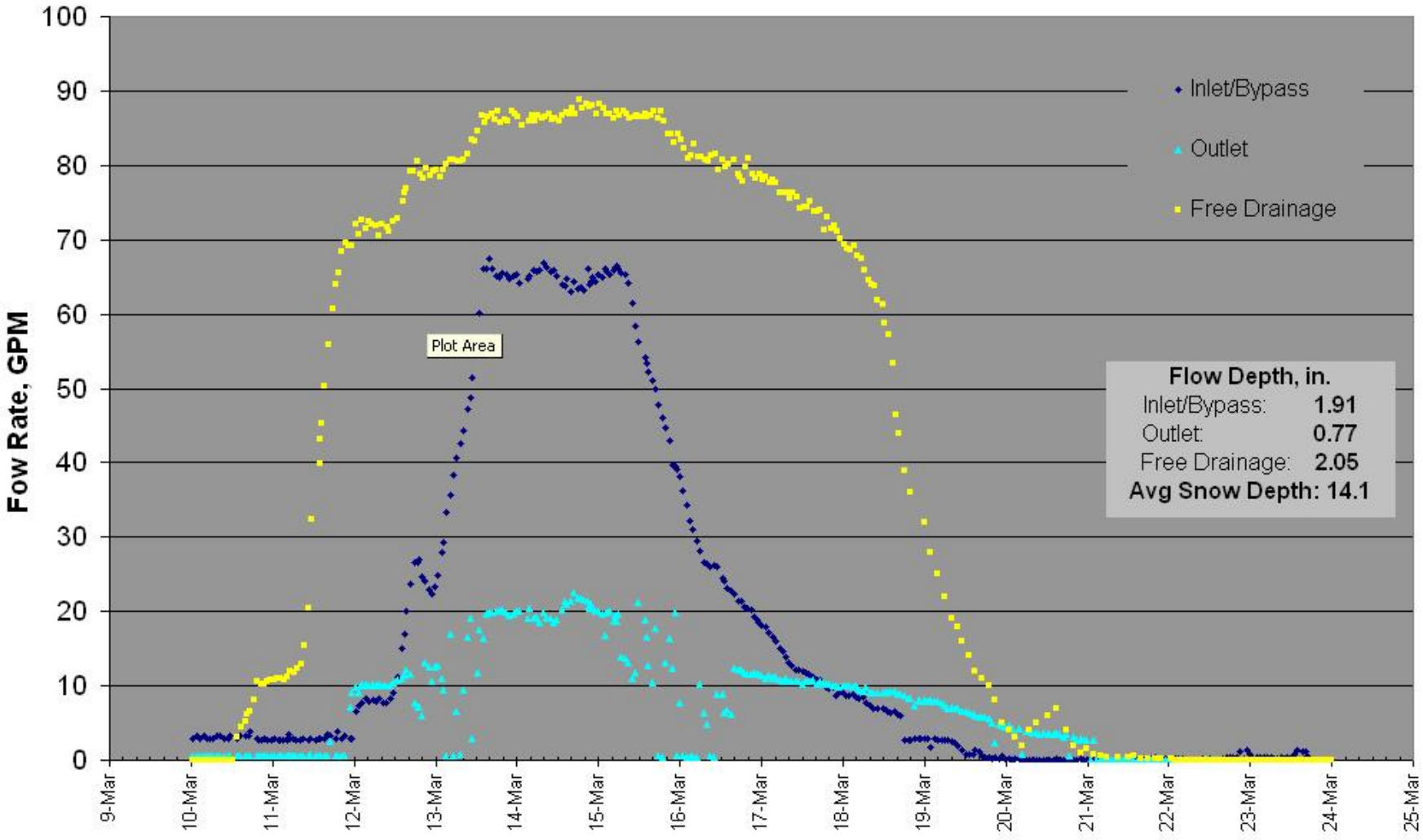
Dundas Site, May-June 2008



Loading Table for Dundas Site

CONTAMINANT	UNITS	DRAINAGE	BIOREAC.	% REDUCT.
TSS	lbs/ ac	12.4	3.4	85%
N-NO3	lbs/ ac	6.5	4.1	45%
TOT-P	lbs/ ac	0.080	0.018	82%
ORTHO-P	lbs/ ac	0.059	0.012	85%
FECAL COLIFO	cfu/ 100ml	165.0	57.0	69%
E COLI	cfu/ 100ml	157.0	75.0	61%

Dundas: 2010 Snowmelt

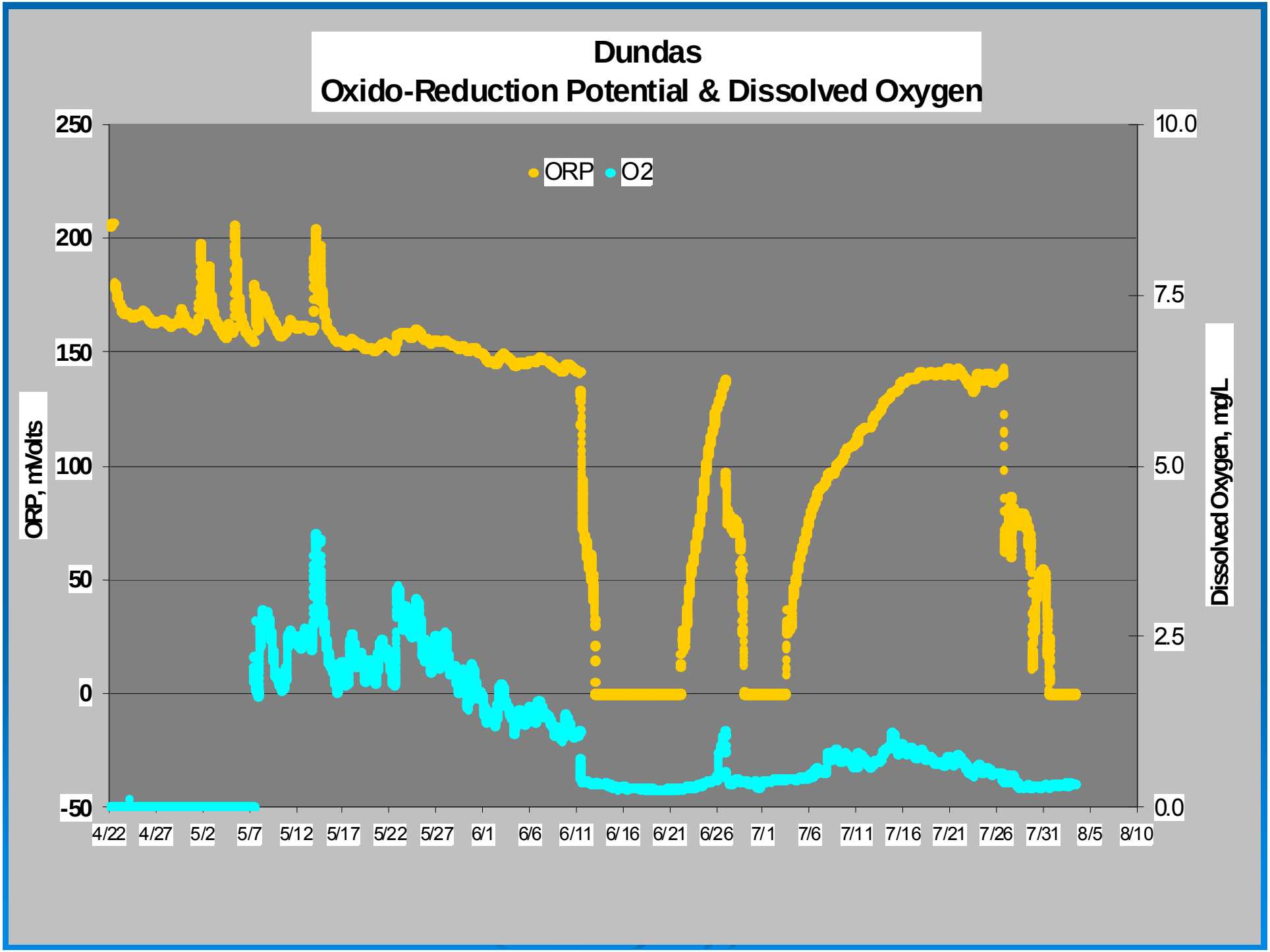


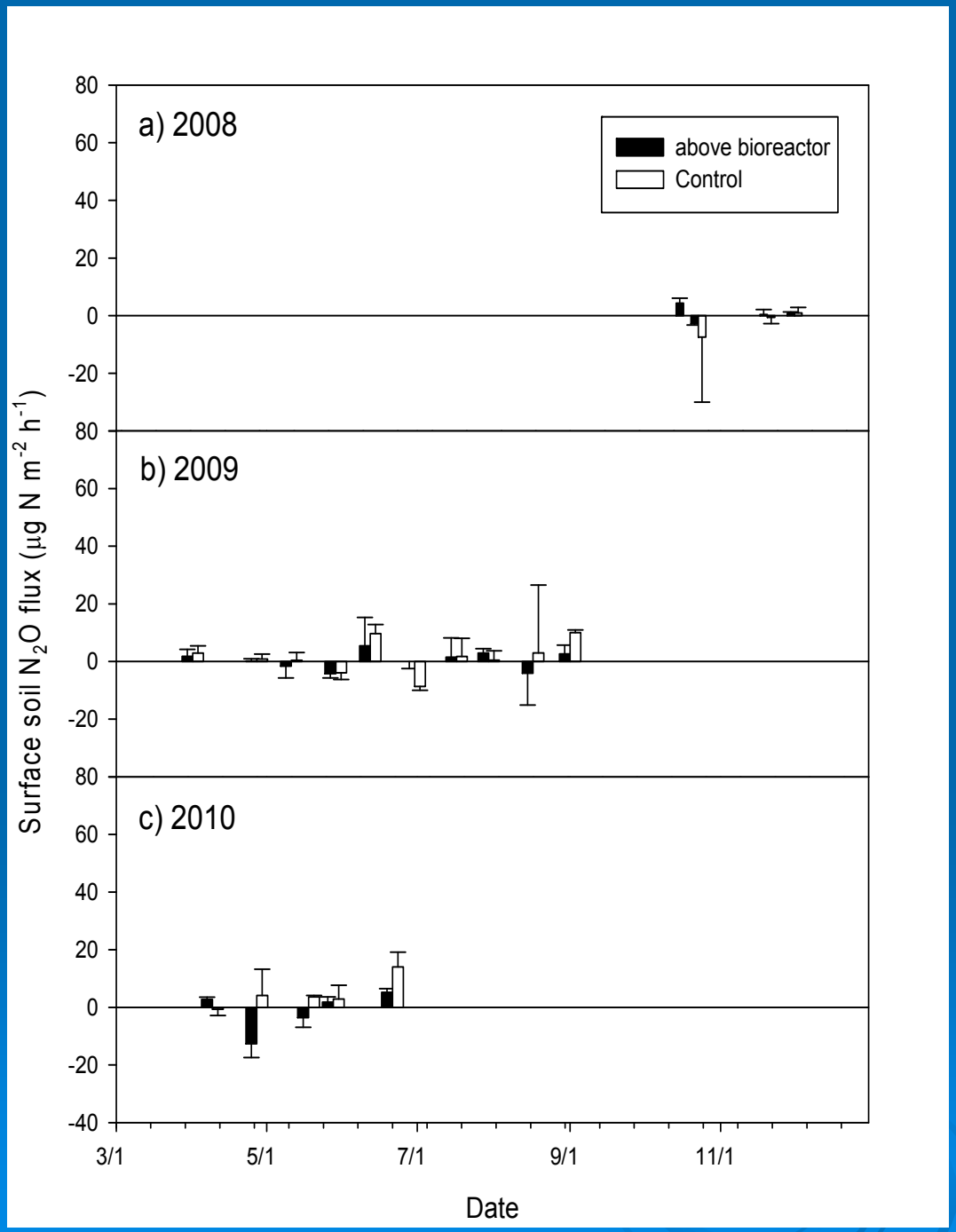
2010 Snowmelt Table

Station	Flow Depth, in.	Nitrate Load, lbs/ac	Tot P Load, lbs/ac
inlet	0.77	2.18	0.019
outlet	0.77	2.02	0.013
Reduction		7%	30%

2010 April-June Table

Station	Flow Depth, in.	Nitrate Load , lbs/ac	Tot P Load , lbs/ac
Inlet	0.11	1.52	0.0038
Outlet	0.11	0.98	0.0033
Reduction		35%	15%


Dundas
Oxido-Reduction Potential & Dissolved Oxygen
ORP
O2
ORP, mVolts
Dissolved Oxygen, mg/L
250
200
150
100
50
0
-50
10.0
7.5
5.0
2.5
0.0
4/22
4/27
5/2
5/7
5/12
5/17
5/22
5/27
6/1
6/6
6/11
6/16
6/21
6/26
7/1
7/6
7/11
7/16
7/21
7/26
7/31
8/5
8/10

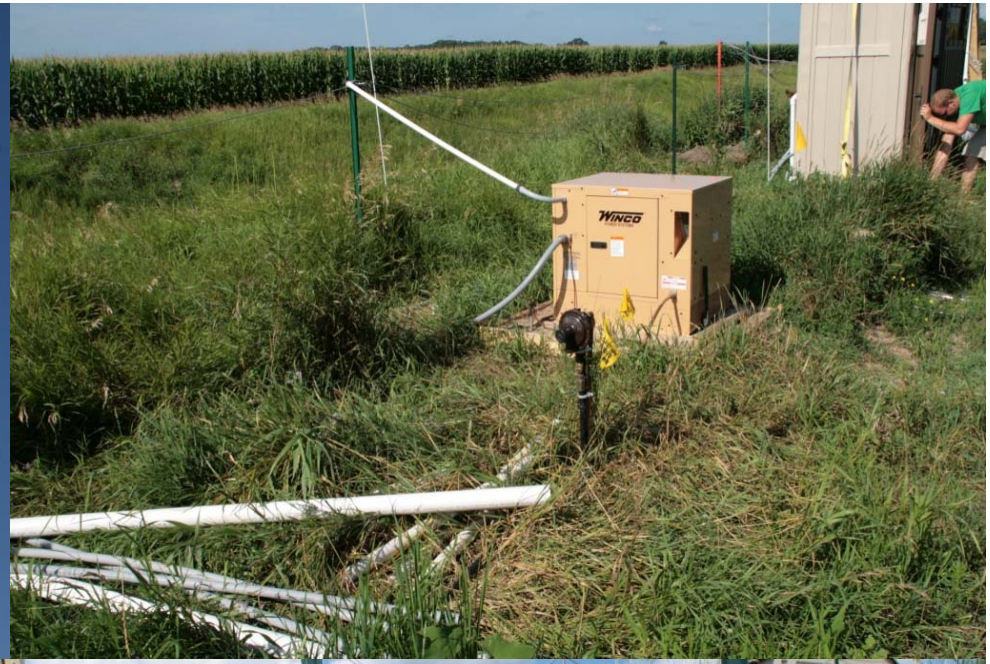


N_2O emissions at Dundas, MN

N_2O-N loading (unit: g N ha^{-1})

	Bioreactor	Control
2009	925.9 (820.8)	309.9 (144.8)
2010*	-32.0 (31.8)	122.6 (43.2)

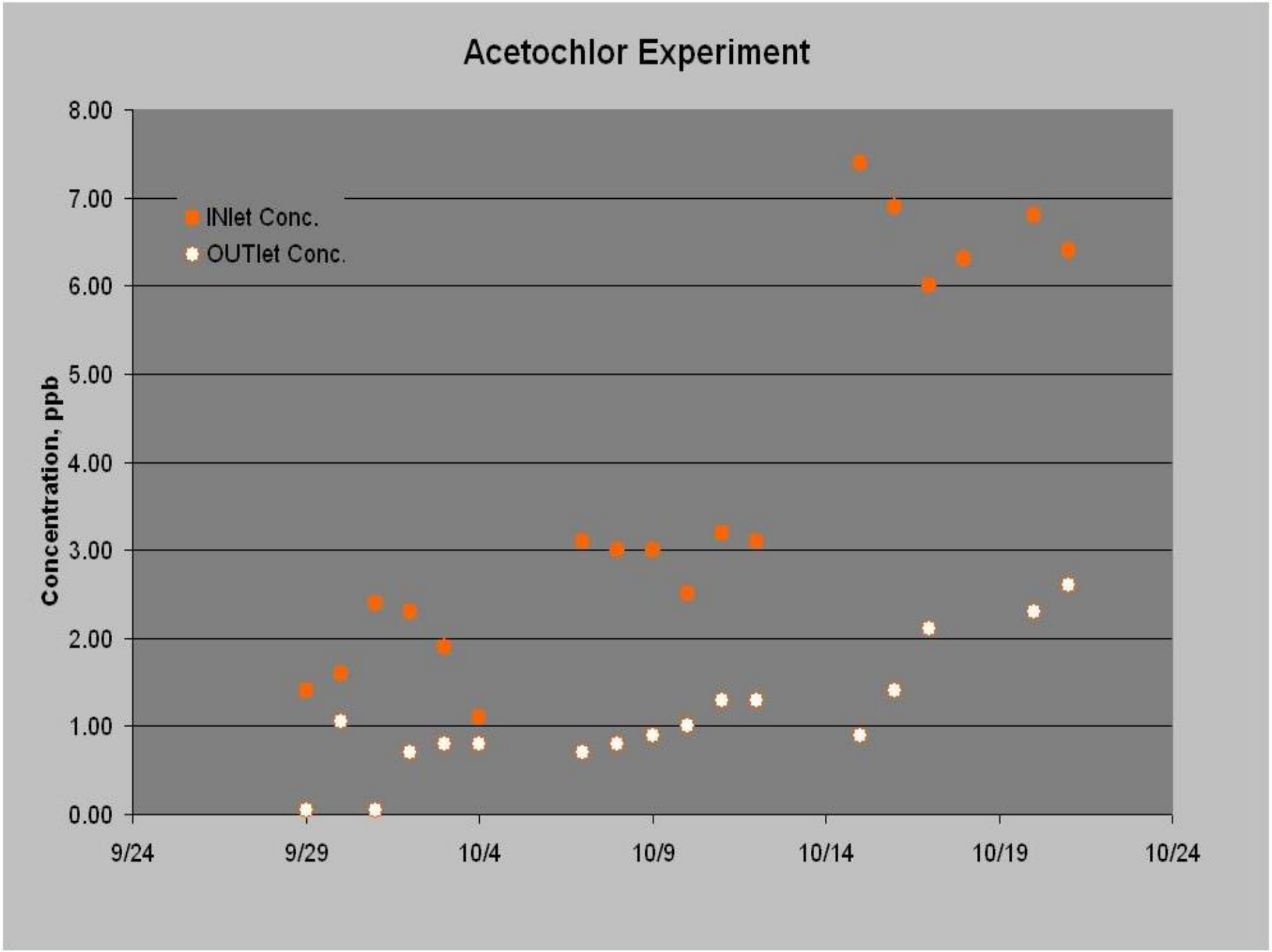
*from April through June

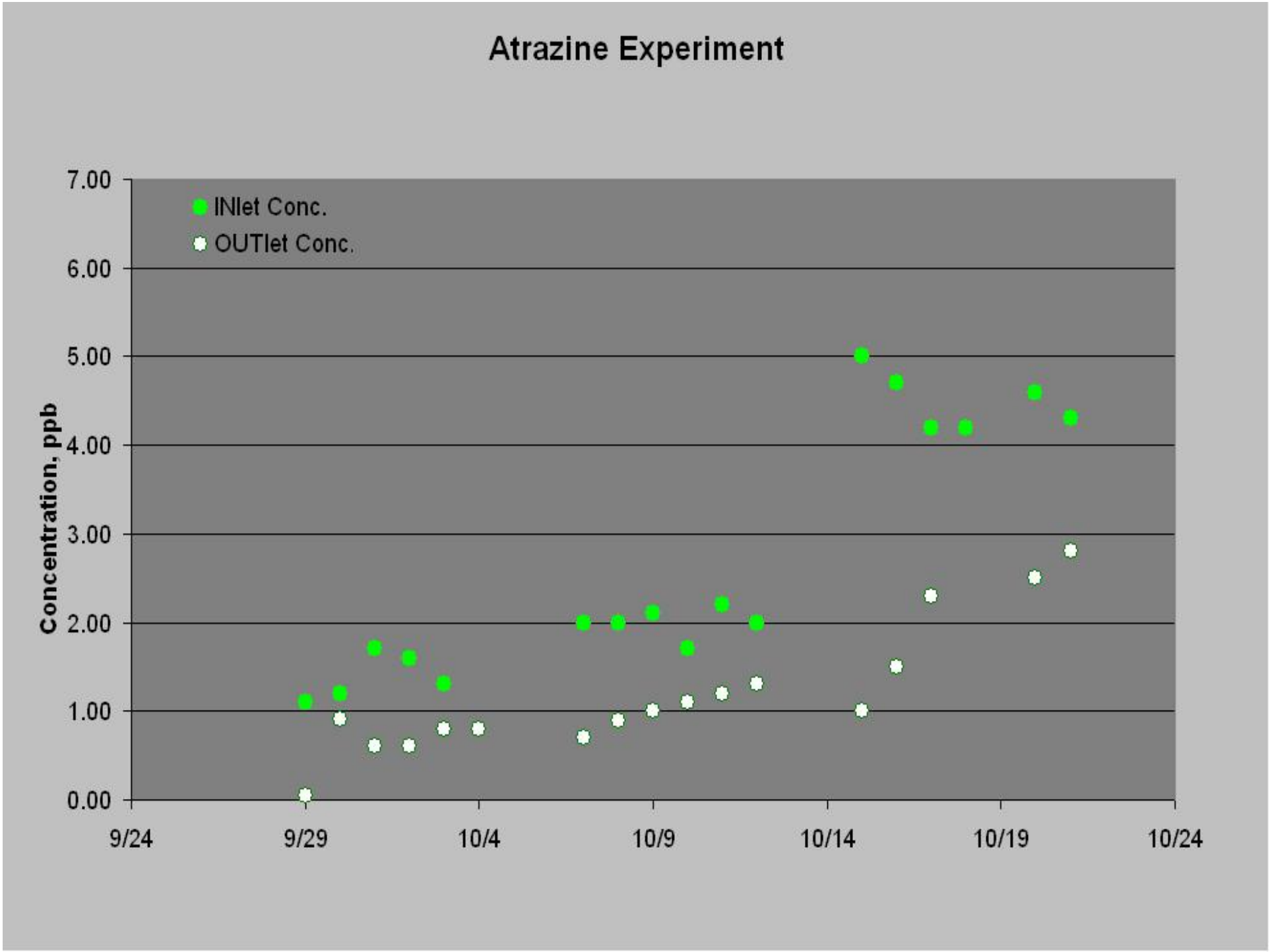

WINCO

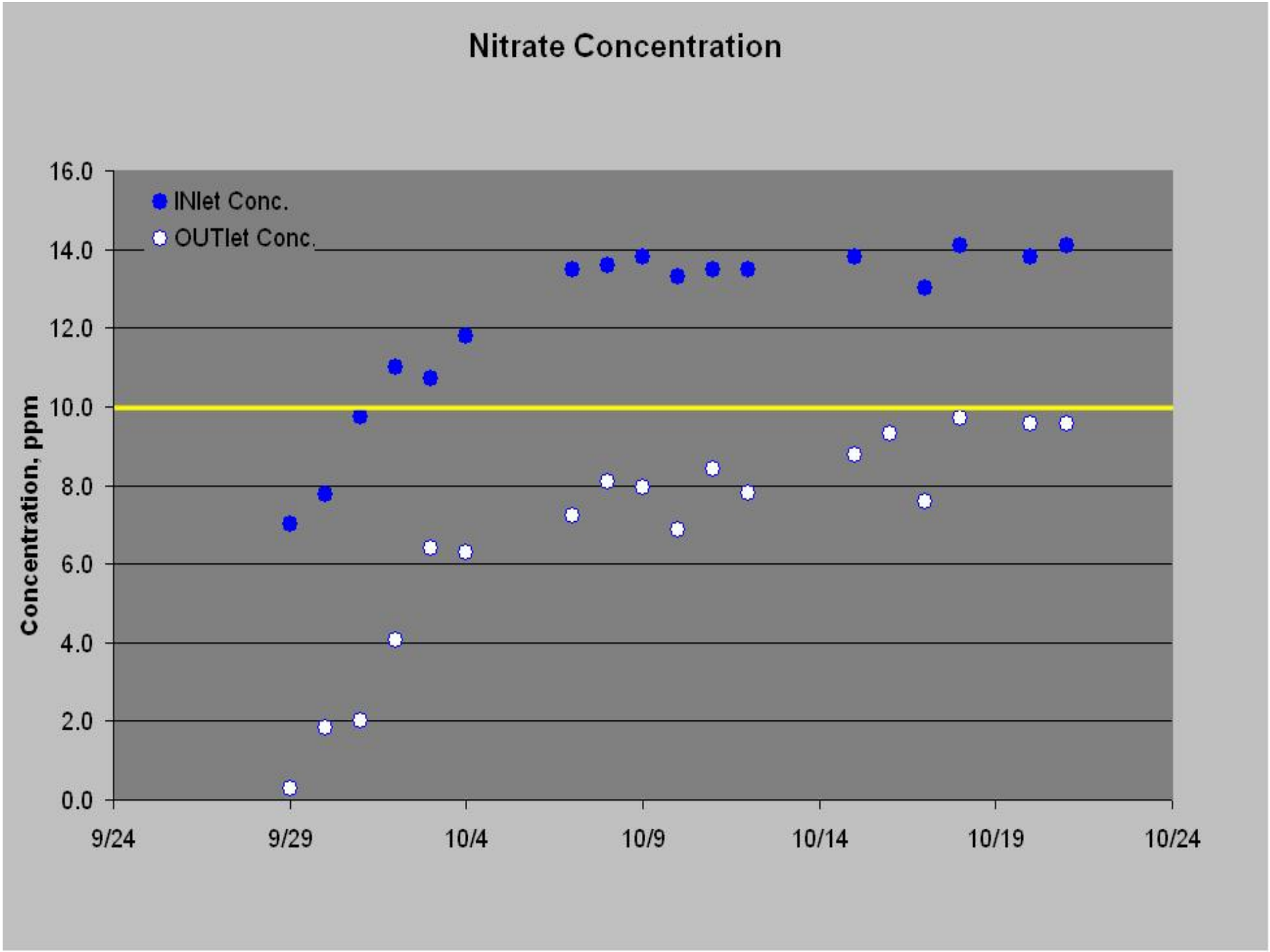
16
PROPANE
NO SMOKING

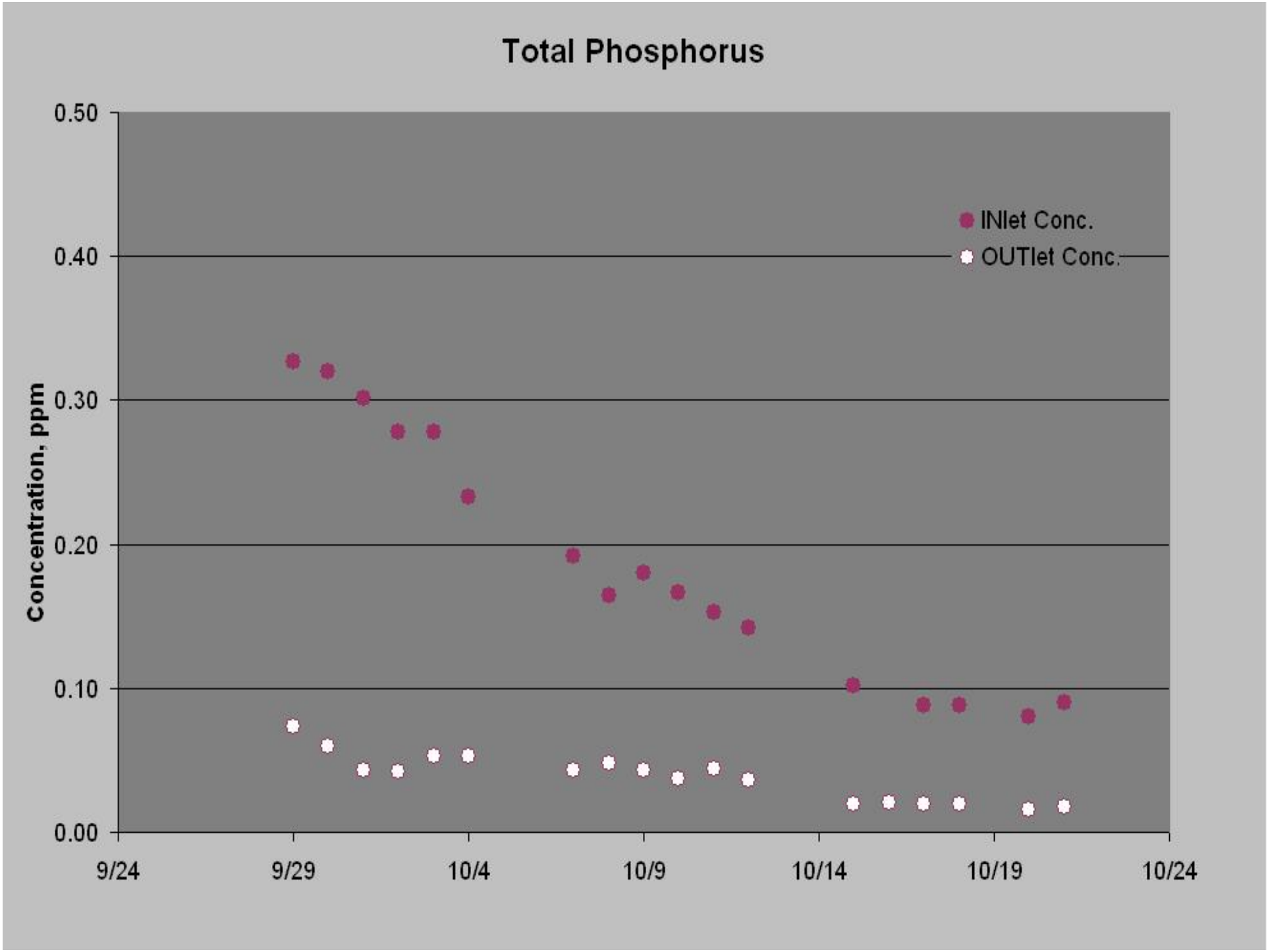
Herbicide Experiment

- Acetochlor & Atrazine
- "Controlled" Conditions in the Field:
  - Increasing and fixed concentrations of herbicides: 2.0 ppb, 3.5 ppb, & 7.5 ppb
  - 3 runs of 6-day cycle
  - Fixed concentrations of nitrate: 5.0 ppm
  - Ditch water concentrations for total phosphorus
- Flow Rate: 4 GPM


Acetochlor Experiment
INlet Conc.
OUTlet Conc.
Concentration, ppb
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
9/24
9/29
10/4
10/9
10/14
10/19
10/24


Atrazine Experiment
INlet Conc.
OUTlet Conc.
Concentration, ppb
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
9/24
9/29
10/4
10/9
10/14
10/19
10/24


Nitrate Concentration
INlet Conc.
OUTlet Conc.
Concentration, ppm
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
9/24
9/29
10/4
10/9
10/14
10/19
10/24


Total Phosphorus
Concentration, ppm
0.50
0.40
0.30
0.20
0.10
0.00
9/24
9/29
10/4
10/9
10/14
10/19
10/24
INlet Conc.
OUTlet Conc.

Acetochlor				
Conc, ppb	Stats	IN	OUT	% Red.
2.0	Average	1.78	0.57	67.8%
	St Dev	0.51	0.31	
	CV	29%	54%	
3.5	Average	2.98	1.00	66.5%
	St Dev	0.25	0.25	
	CV	8%	25%	
7.5	Average	6.63	1.86	72.0%
	St Dev	0.50	0.69	
	CV	8%	37%	

Atrazine				
Conc, ppb	Stats	IN	OUT	% Reduct.
1.6	Average	1.28	0.62	51.4%
	St Dev	0.33	0.31	
	CV	26%	50%	
2.8	Average	2.00	1.03	48.3%
	St Dev	0.17	0.19	
	CV	8%	19%	
6.0	Average	4.50	1.86	58.7%
	St Dev	0.32	0.75	
	CV	7%	40%	

Nitrate				
Conc, ppm	Stats	IN	OUT	% Reduct.
5.0	Average	12.24	6.77	44.7%
	St Dev	2.24	2.86	
	CV	18%	42%	

Total P				
Conc, ppm	Stats	IN	OUT	% Reduct.
0.0	Average	0.19	0.038	79.5%
	St Dev	0.087	0.016	
	CV	46%	43%	

Summary

- Proportion of water treated through the bioreactor: snowmelt (30%-60%) spring & summer (13%-60%)
- Temperature trend
  - bioreactor is sink of heat energy during snowmelt period only,
  - Otherwise, bioreactor is a source of heat energy by losing it to the surrounding soil.
- pH, redox potential, and dissolved oxygen: significant contrast between the two sites, one is reducing (Claremont) and the other oxidizing (Dundas).

Summary

- Nitrate concentrations in patterned tile field ranged from 11 to 28 mg/l.
- During snowmelt,
  - nitrate reduction ranged from 7% to 50%
  - total phosphorus from no reduction to 30%
- During spring and summer time,
  - the percentage of nitrate reduction ranged from 10-100% with an average of 47% in 2009.
  - A 50% reduction in nitrate concentration required a residence time of 1-2 days
  - Most of the total phosphorus was in the soluble form
  - Total phosphorus reduction (by bioreactor) reached 54%
- E. Coli count were reduced by 61%

Summary

- For incoming concentrations of 2.0 ppb, 3.5 ppb, and 7.5 ppb of Acetochlor (1.6 ppb, 2.8 ppb, and 6.0 ppb for Atrazine) :
  - Acetochlor concentrations dissipation was 69%
  - Atrazine was dissipated at a rate of 53%
- On average, nitrate concentration was reduced to 45% with herbicide dissipation
- Total Phosphorus was reduced to 80% with herbicide dissipation