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Don Stone: *Shooting the Rapids*

Wetland Aeration for Phosphorus Reduction: Results of Ditch 14 Summer Projects

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Using Wetland Aeration to Reduce Phosphorus Loading: Results of Ditch 14 Summer Projects

1999 Summary

Questions Addressed in Ditch 14 Work for the Summer of 1999

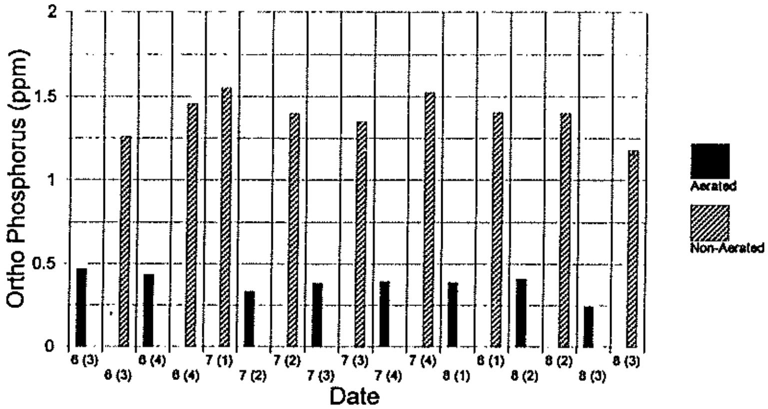
1. Is it feasible to dig a trench through a wetland and aerate the trench?
2. Does aeration reduce phosphorus levels in the wetland trench?
3. How can this be applied to lake management?

What We Found

1. Trenching in wetlands is relatively easy. Aerating the trench can also be performed relatively easily. However, it appears the integrity of the trench could fail in a year or two.
2. Aeration appears to reduce phosphorus concentrations in the wetland trench when compared to concentrations in wetland wells away from the aeration site.
3. In theory, the effects of aeration should cause phosphorus to adsorb to solid iron particles that have reprecipitated because of aeration. Phosphorus should then be tied up making it unavailable for algal uptake. This should reduce the amount of phosphorus available to algae and reduce algae growth. Reducing excessive algae growth is a lake management goal.

What Is Next

Currently, there is no simple solution to reducing the amount of phosphorus coming out of the Ditch 14 wetland complex. A promising approach is to aerate the ditch itself to make phosphorus unavailable for algal uptake. Installation of a field-scale system would cost about $15,000. If it works it would be a breakthrough for reducing phosphorus export from eutrophic wetlands to lakes. Although, there is no guarantee it will work, the field-scale installation is the next step.



This graph shows the orthophosphorus concentrations in an aerated and an unaerated part of the Ditch 14 wetland in 1999. The dates are months with the week of the month in parentheses. Orthophosphorus was lower in the aerated wetland (400 ppb average over the summer) compared to the unaerated wetland (1,300 ppb average over the summer). Now the question becomes if the ditch that receives the high phosphorus loading from the wetland is aerated, will phosphorus availability be lowered in the ditch before it goes into Lake Sallie.

Recap of Ditch 14 Wetland Complex Findings from 1996 through 1999

1996

PRWD staff and Blue Water Science found the following:

- Based on pump tests in wells, hydraulic conductivity ranged from 2.6×10^{-4} to 1.6×10^{-3} cm/sec which is equivalent groundwater movement of 0.72 to 4.5 feet/day.
- Interstitial porewater (water within the peat) was high in phosphorus compared to water coming into Ditch 14 from Lake St. Clair.
- Interstitial porewater was high in iron.
- Peat analysis did not show elevated levels of phosphorus based on agricultural soil test methods. High iron was found.
- We speculated that the wetland could have been phosphorus loaded in the past and was now leaching out phosphorus.

1997

- Barr Engineering Company conducted a groundwater study in 1997 (*A study of the contribution of groundwater to phosphorus loadings for selected lakes in the Pelican River watershed, May 1998*).
- They concluded that phosphorus loading to Ditch 14 was consistent with internal loading (that is, phosphorus release from peat). They speculated if phosphorus was from a stormwater source the loading would be more "spikey". If loading was from an elevated groundwater source then loadings should have been more uniform throughout the year.
- The summer staff from the PRWD and Blue Water Science conducted a pilot experiment with two columns filled with peat to check experimental procedures to determine how much phosphorus release from peat.
- In column A, initial phosphorus levels were high in July, then dipped in August, but were still high through September.
- In column B, initial phosphorus levels were high, but at the end of the experiment in September, phosphorus levels were low.
- It appears peat can be a source of phosphorus, but under some conditions, it does not act as a phosphorus source.

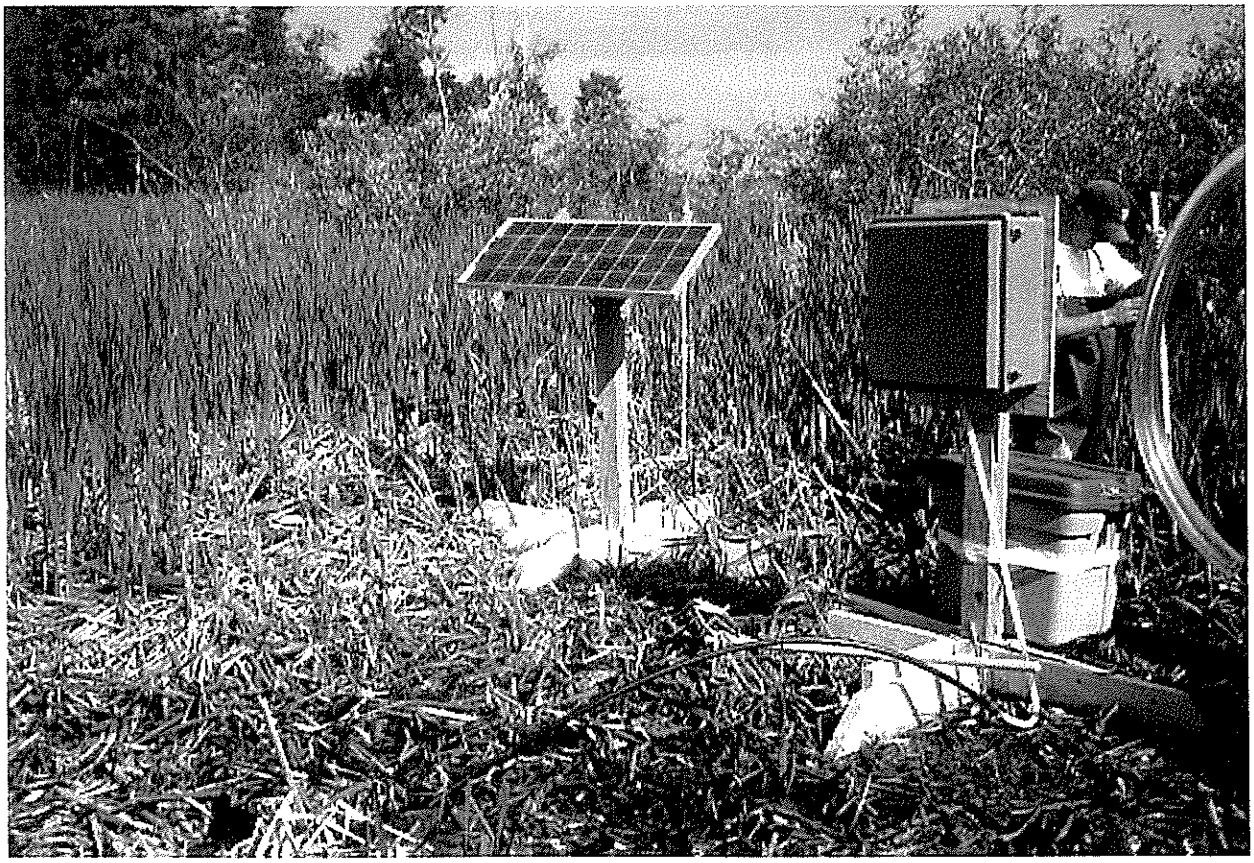
1998

PRWD staff and Blue Water Science found the following:

- Ten columns were filled with peat from four locations in the Ditch 14 wetland complex. Initial phosphorus concentrations collected on June 1 were high.
- Phosphorus release from the peat continued to occur in 3 out of 8 columns, indicating peat is a source of phosphorus.
- Aerating columns of peat through the months of June and July resulted in a porewater phosphorus decline.
- We concluded that the peat was the source of phosphorus and that release was probably microbially driven and aerating peat reduced porewater phosphorus concentrations.

1999

- The PRWD staff and Blue Water Science conducted a small-scale wetland aeration trial using a solar powered aerator to oxygenate a 10-foot long wetland trench.
- At first the aeration trial did not appear to reduce phosphorus concentrations when comparing up gradient and down gradient wells at the aeration site.
- However, when phosphorus concentrations at the aeration site were compared to wells at least 100 meters away, phosphorus levels at the aeration site were lower.
- We conclude that aerating wetland water can reduce phosphorus concentrations. We are not sure how long it takes for that reaction to occur, or if it can be speeded up.
- A full-scale field trial would be the best way to test the phosphorus inactivation potential of linear ditch aeration.



Pictured above is the solar powered aeration system. The solar panel is on the left and the box on the right holds the air compressor. An air line from the compressor delivered compressed air to the wetland trench at 0.18 cubic feet per minute.

Using Wetland Aeration to Reduce Phosphorus Loading: Results of Ditch 14 Summer Projects (in 1999)

Introduction

On an annual basis, from 1995 through 1998, the amount of phosphorus has increased inbetween the stretch of Ditch 14 from the outlet of Lake St. Clair (SC 3) to the outlet of Ditch 14 (SC 4) (Table 1). Apparently, phosphorus is moving into the ditch between SC3 and SC4. The objectives of studies in 1999 were to determine if aerating a wetland trench or a wetland ditch would inactivate phosphorus.

Table 1. Phosphorus loading data for April - October. Loading is in pounds of phosphorus.

	SC 3 St. Clair Outlet to Ditch 14	SC 4 Ditch 14 Outlet	Phosphorus Increase from SC3 to SC4
1995	--	1,002	--
1996	567	1,511	944
1997	783	1,835	1,052
1998	669	1,242	573

The following projects were conducted in the summer of 1999 to address phosphorus inactivation questions.

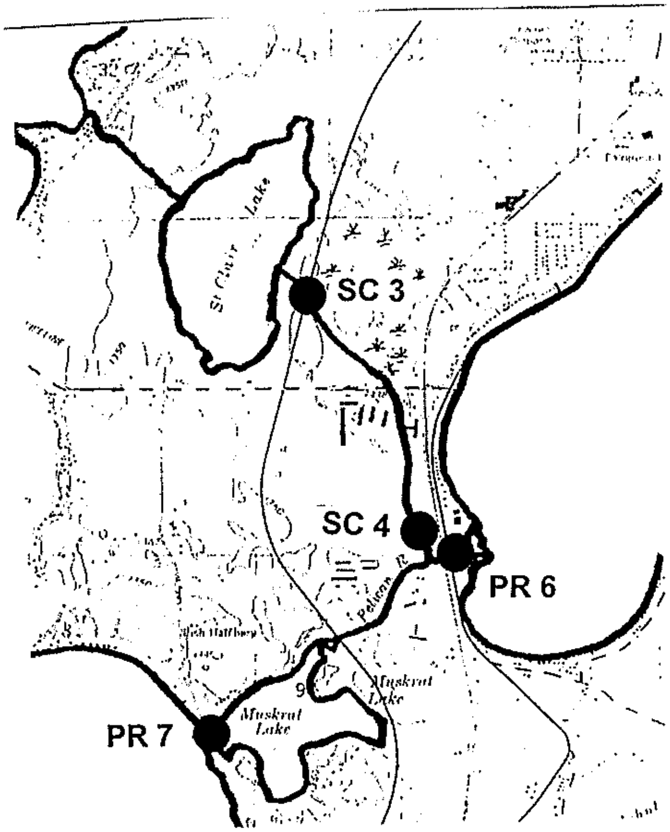
1. Aerated a wetland trench using a solar powered aeration system.
2. Wetland pore water chemistry was monitored by Rochelle Nustad, of the Watershed District.
3. Ditch 14 water chemistry was surveyed on two dates.
4. In laboratory tests, we aerated wetland ditch water to see if phosphorus could be inactivated.
5. A design was prepared for a full-scale aeration system in Ditch 14 that could reduce biologically available phosphorus loading to Muskrat Lake and Lake Sallie.

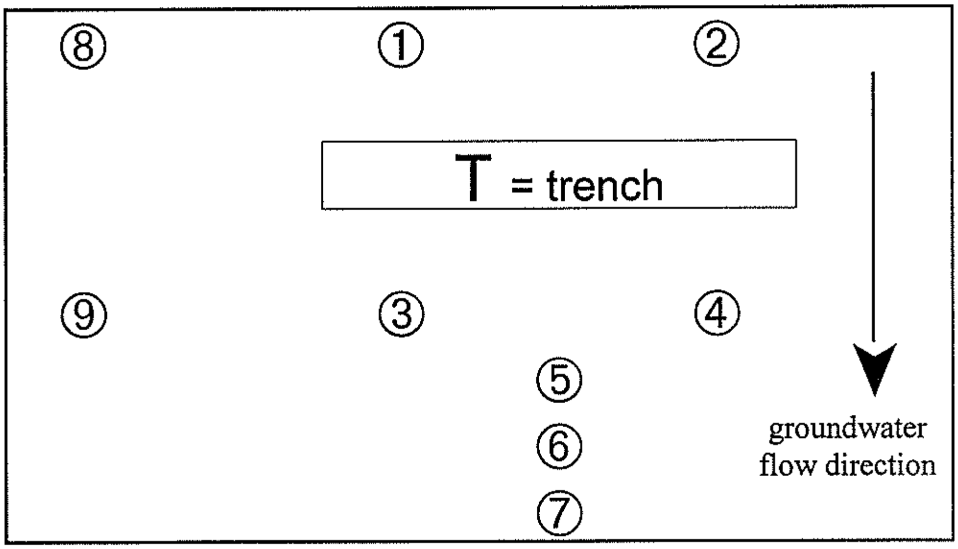
Methods

Aeration of Wetland Trench with a Solar Powered Aerator

A short wetland trench about 10 feet long was cut into a wetland using an ice saw (Figure 1). The wetland trench was located in the SC 4 area (Figure 2). An airline along the bottom of the trench injected compressed air from a nearby solar powered aerator at a rate of 0.18 cfm. The configuration of the sampling wells are shown in Figure 2. The intent was to sample phosphorus and iron 1 meter up gradient of the aerated trench, then sample the trench, and sample down gradient from the trench in wells 3, 4, 5, 6, and 7. Wells 8 and 9 were to be used as background wells.

Figure 1. [left] An ice saw was used to cut the peat in the wetland.
[right] The trench was 10 feet long, 0.5 feet wide and about 3 feet deep. In this area the peat mat was about 1.5 feet thick and was floating on top of about 2.0 feet of peaty water.





Aeration System
Air Flow: 0.18 cubic feet per minute = 5,000 cubic centimeters/minute

Figure 2. [top] Site of wetland aeration was at SC 4, east of the ditch.
[bottom] Nine wells were installed at the wetland monitoring location. Wells were spaced about one meter apart. Well 7 was about four meters from the trench.

Figure 3. [top] Example of a water sampling well used in the wetland.
[bottom] Wetland interstitial pore water was collected from this array of wells to monitor impacts of trench aeration.

Results

Redox, Phosphorus, and Iron Dynamics in the Aerated Wetland Trench

Solar powered aerators can work in Minnesota (Figure 4). Air bubbles were visible in the groundwater in the trench (Figure 5) throughout the project duration except for a one-week period when holes appeared in the feeder line and air was not delivered to the trench. The feeder line was repaired and air flow was restored to the trench.

Dissolved oxygen was found at low levels in all the monitoring wells (Appendix A). Redox measurements (in millivolts) measure the oxidizing or reducing potential in the groundwater. Water in the trench was oxidized based on redox measurements, whereas redox in the monitoring wells, both up gradient and down gradient had reducing conditions (Figure 6). However, redox conditions in the up gradient and down gradient wells were higher (more oxidizing) in July and August compared to initial conditions in June (Figure 6).

Figure 4. The solar powered aeration system ran off of one solar panel and the air compressor delivered 0.18 cubic feet of air per minute.

Figure 5. Air bubbles in the wetland trench originate from the submerged air line which comes from the solar powered aerator. The trench had a positive redox reading in July and August.

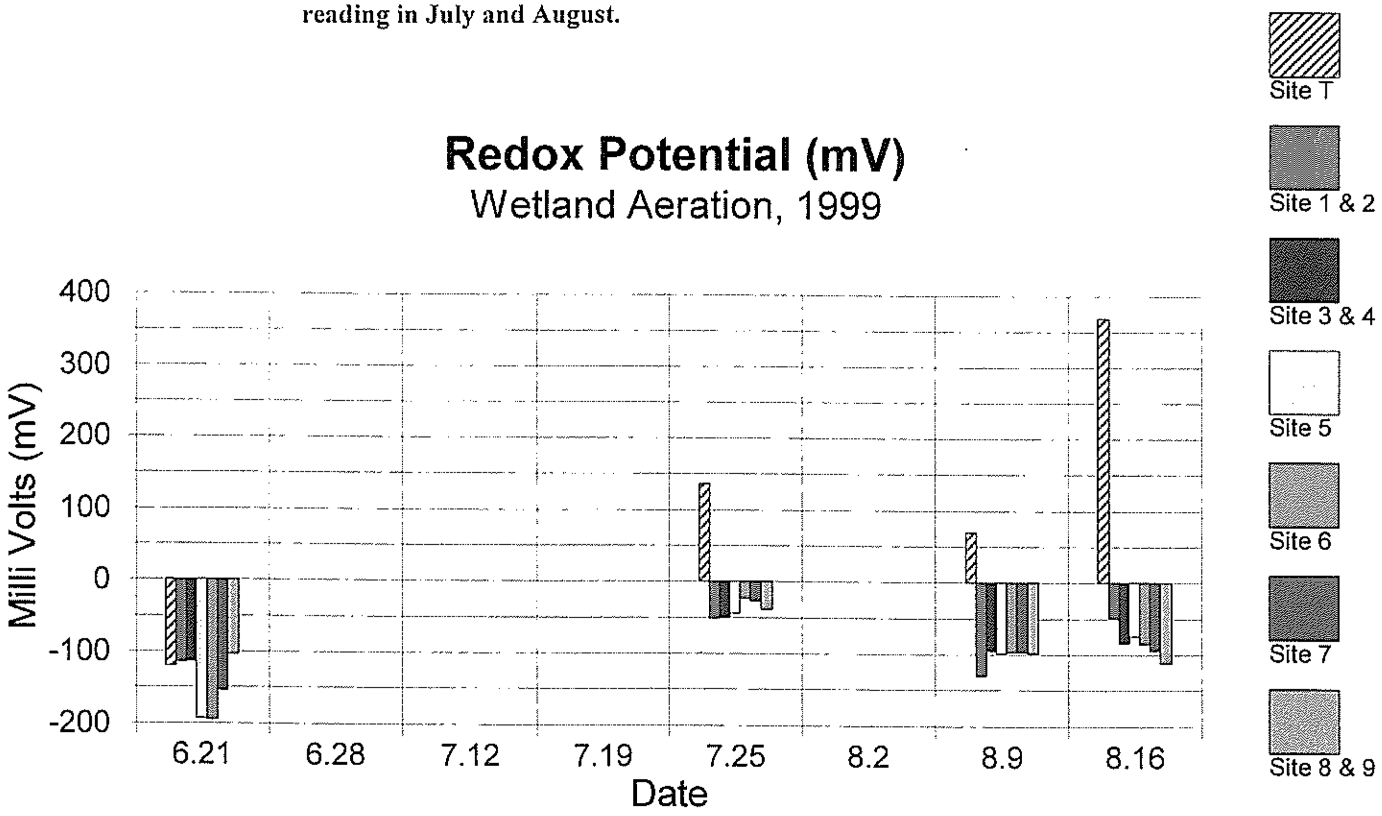


Figure 6. Redox readings (in milliVolts) were taken in June, July, and August from the sample wells. June represents initial conditions. The trench had positive readings in July and August. Sites 1-7 had higher readings compared to initial conditions. Sites 8 and 9 were impacted in July but not in August.

Phosphorus and Iron in the Aerated Wetland:

Phosphorus and iron concentrations were measured weekly from June 21 through August 25. Aeration was initiated on June 19 and ran until August 16. The trench was not aerated on the 7.19 sample date due to holes in the feeder supply line.

Aeration seemed to lower orthophosphorus (OP) concentrations in the aerated trench compared to up gradient and down gradient wells (Figure 7). When air was not delivered to the trench the phosphorus concentration increased (as measured on 7.19). After the airline was fixed, OP in the trench was lower the following week (7.25).

The aeration system was turned off after the 8.16 samples were taken. On 8.25, OP in the background wells rose slightly. The OP in the trench decreased from 8.16 but was higher compared to when the trench was aerated.

Total iron was also analyzed through the aeration period. Total iron was variable in the wells over the course of the monitoring period but seemed to peak on the August 16 sample date (Figure 8). We originally thought iron would be filtered out in the peat matrix and iron levels in the down gradient wells (sites 3-7) would be lower. It is not clear if this is happening. The lowest and the highest iron concentrations were found in the aerated trench samples.

Phosphorus and iron results for individual sample sites over the summer sampling period are shown in Figure 9. Iron levels were almost always greater than 4 mg-Fe/l. Phosphorus ranged from less than 150 μg-P/l up to about 1,000 μg-P/l. The trench samples appeared to best reflect the oxic/anoxic dynamics that may be expected for phosphorus influenced by iron chemistry.

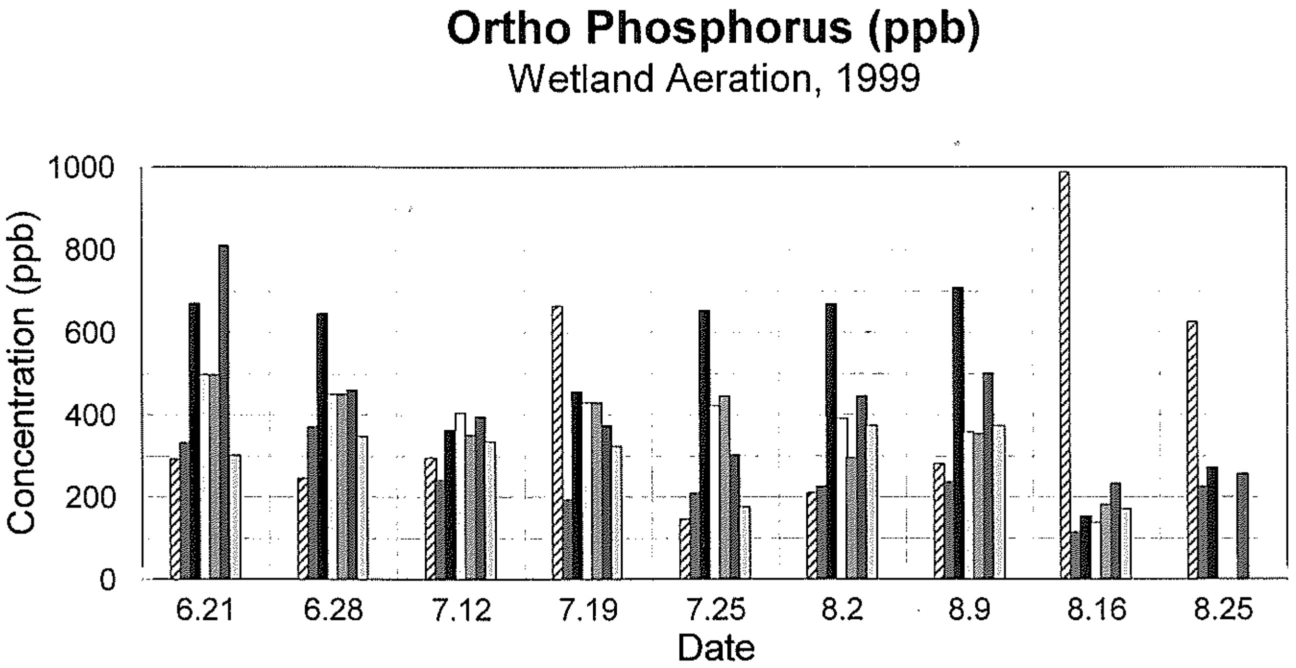


Figure 7. Orthophosphorus concentrations in monitoring wells in the aerated wetland area. Aeration was not operating on the 7.19 date and was turned off after the 8.16 sample date.

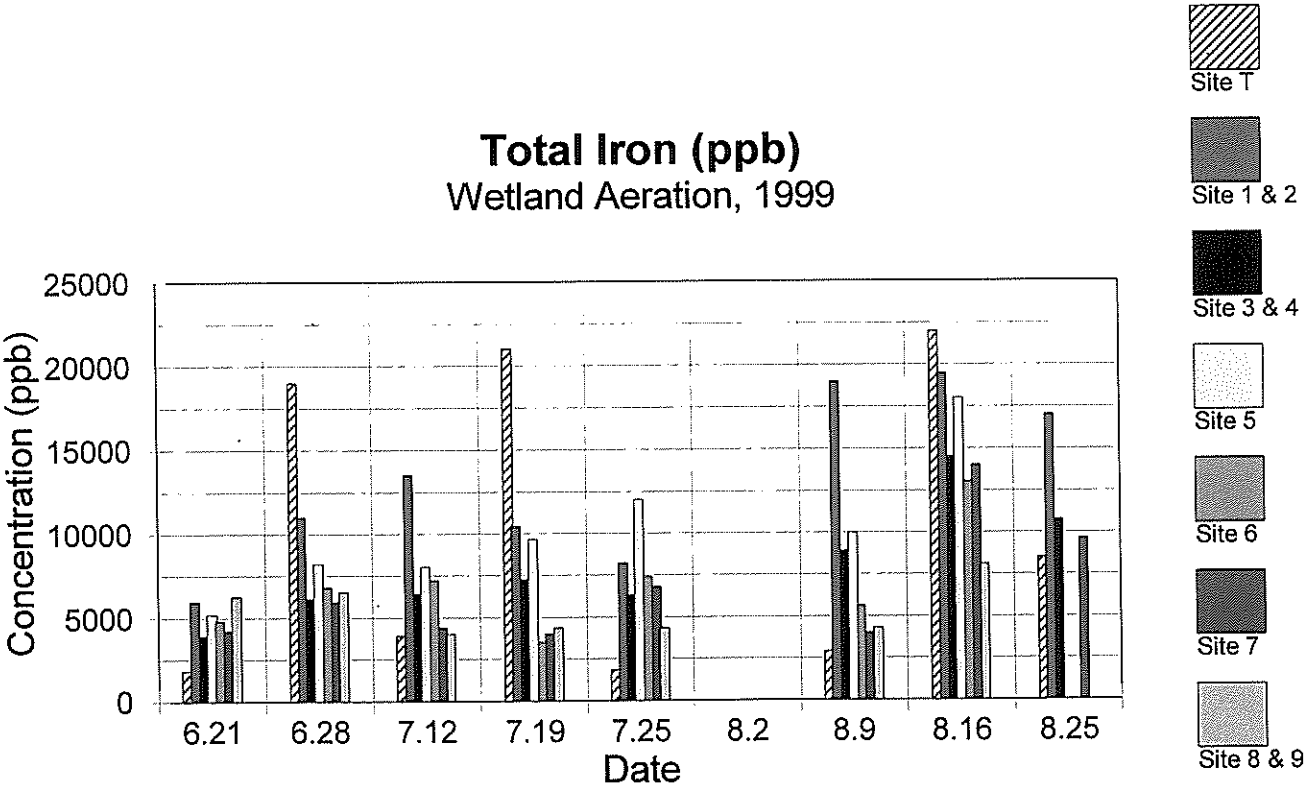


Figure 8. Total iron concentrations in monitoring wells in the aerated wetland area.

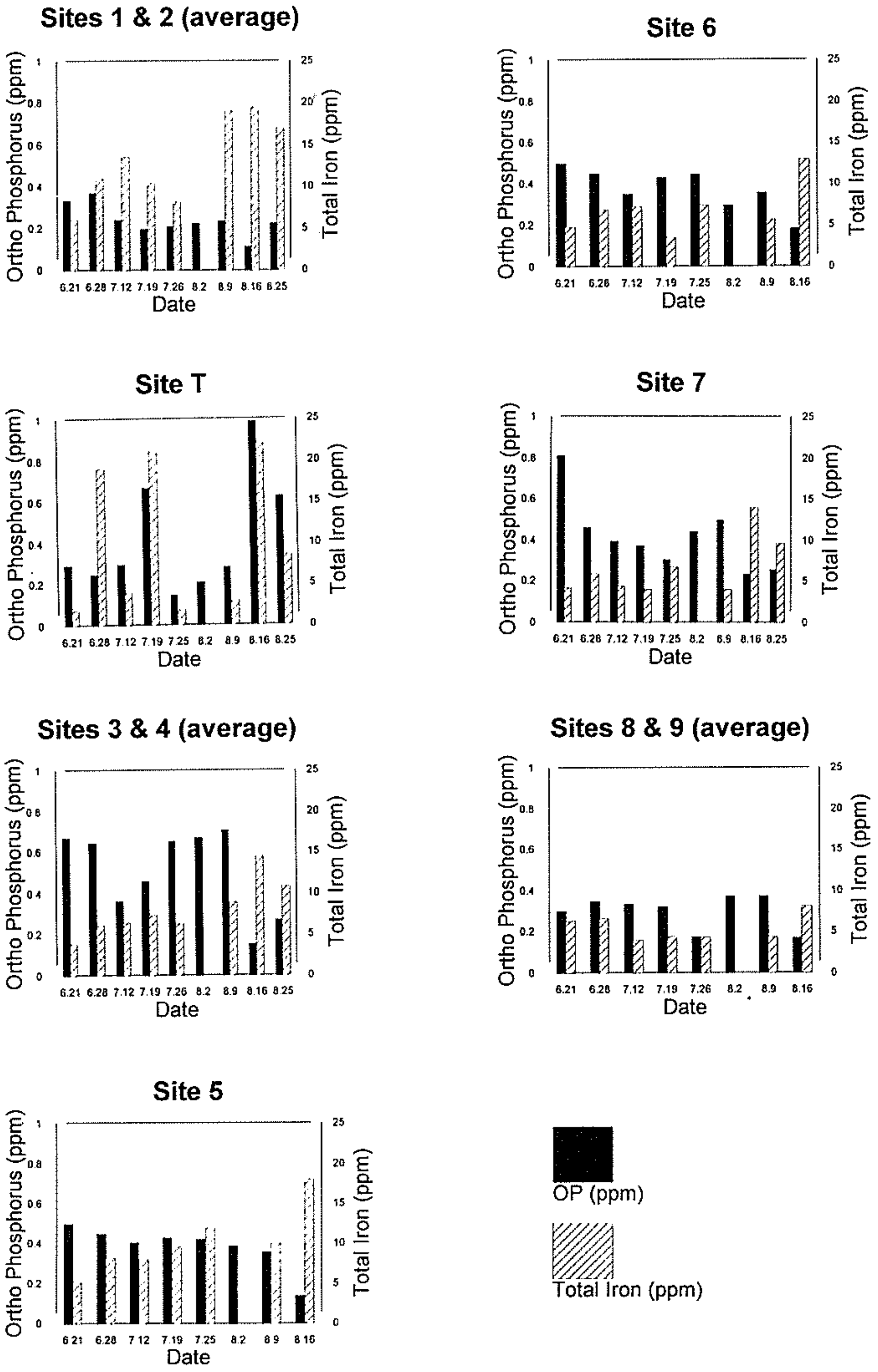


Figure 9. Phosphorus and iron concentrations for individual wells and averages for wells 1 & 2 and 3 & 4.

Comparing Nearby Wetland Water Chemistry Data To the Wetland Trench Data

A potential influence of the aeration system may be obseved when comparing the aerated site to an unaerated site that was 50 meters away and was monitored as part of another study. Phosphorus levels were lower in the wells in the aerated site compared to the wells in the unaerated site (Figure 10). Its possible that aeration may have had a wider influence then expected and both up gradient and down gradient wells may have low phosphorus due to aeration effects.

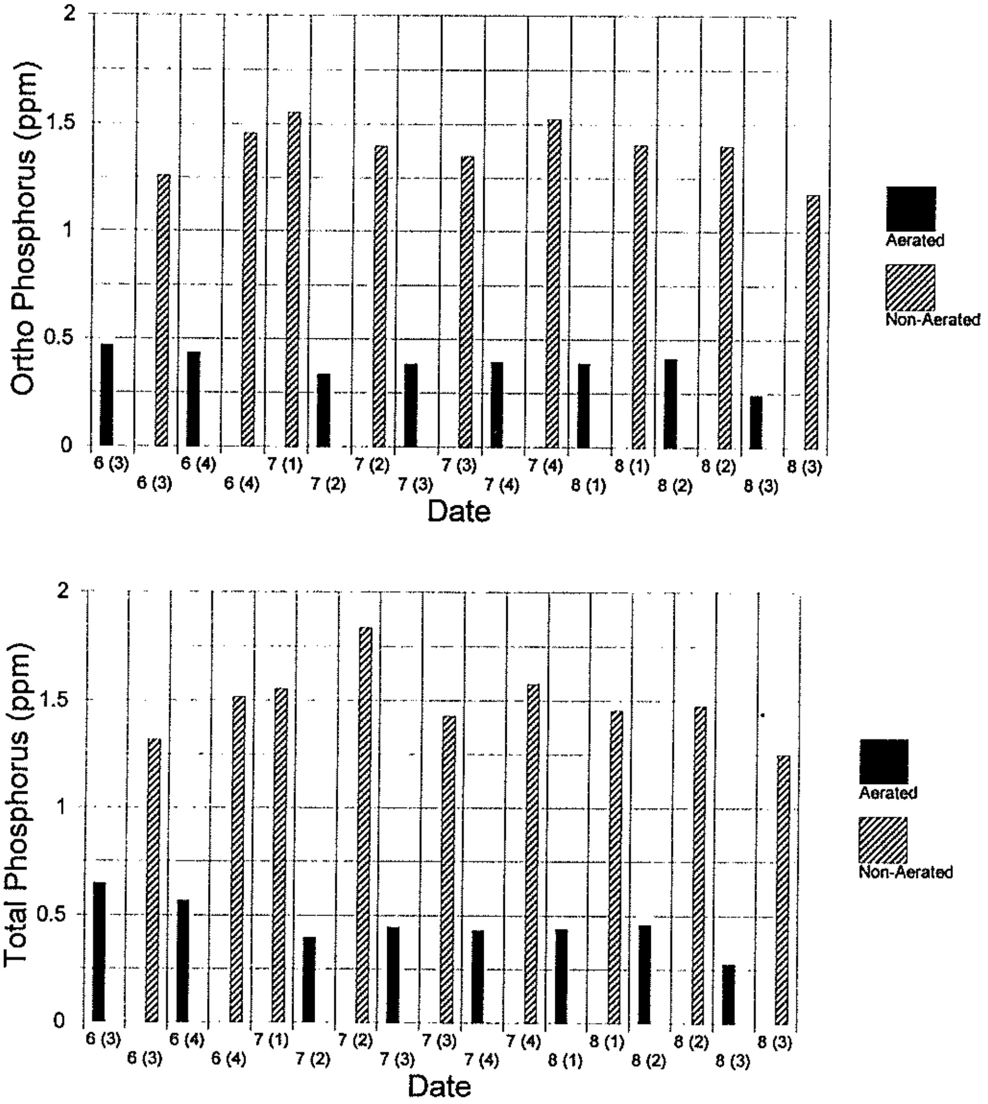
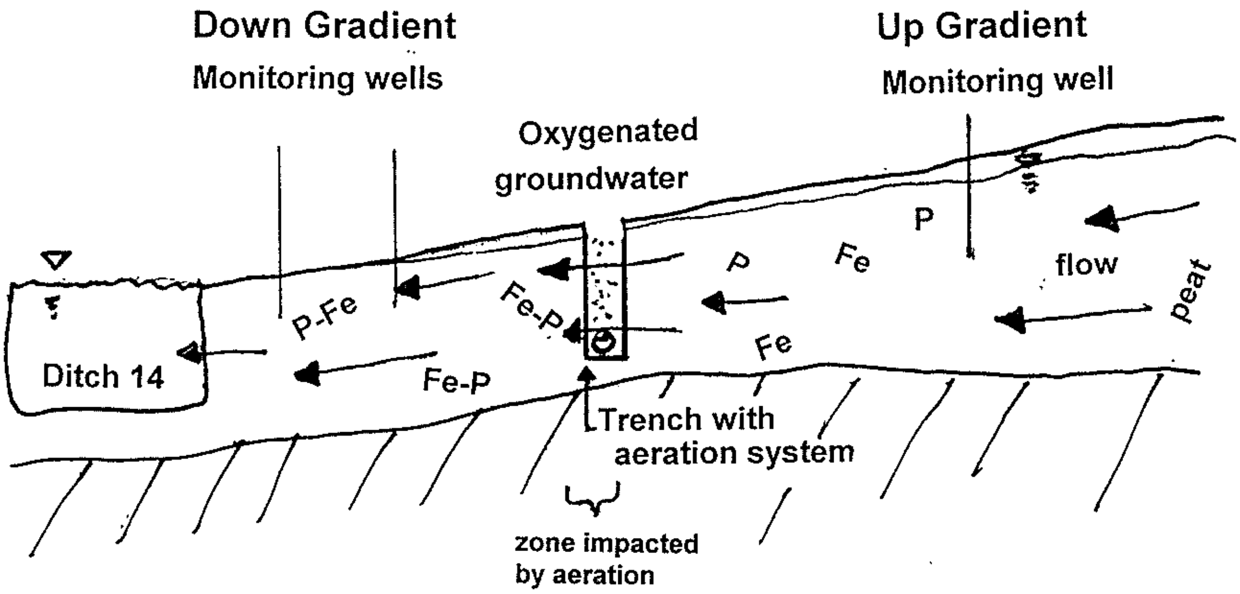


Figure 10. Comparison of aerated to unaerated groundwater results. Aerated results represent the mean of 10 wells and the unaerated results are the mean of 3 wells for each sample date. The week of the month is shown in parentheses.

Discussion: How the Trench Wetland Aeration System Was Theorized to Work

The Ditch 14 wetland aeration system used compressed air to re-aerate anoxic groundwater. It was hoped that dissolved iron in the anoxic groundwater would reprecipitate and remove dissolved phosphorus by way of co-precipitation and absorption processes (Figure 11). Then the iron-phosphorus precipitate would be filtered out in the peat matrix. We expected down gradient wells to have lower OP and Fe concentrations than the up gradient wells.

Side View



OXYGEN PRESENT
Phosphorus is bound with solid iron precipitates. The solids are removed in the peat matrix.

OXYGEN ABSENT
Iron is in the dissolved state and phosphorus moves through the peat with the groundwater flow.

Figure 11. Schematic cross section of the Ditch 14 wetland aeration system. We hoped to create an aerated wall by way of an aerated trench. Groundwater with high iron concentrations would pass through the aerated wall to get to Ditch 14. In the process of passing through the aerated wall, iron would reprecipitate to form solid iron and hopefully remove phosphorus as well. For the pilot study, the trench was 10 feet long and 3 feet deep.

Discussion: How the Trench Wetland System Probably Worked

It appears the aeration system may had a larger zone of influence than we anticipated and both up gradient and down gradient wells had low phosphorus concentrations especially when compared to phosphorus concentrations in wells 50 meters away.

In this part of the wetland complex the cattail root mat is about 1-1.5 feet thick and floats on top of a peat slurry which is about 2 feet deep which in turn flows on top of a compacted peat/till sediment. Our wells punched through the cattail mat and sampled water in the peat slurry. The airline rested on the solid peat/till sediment and may have set up a circulation pattern that aerated the peat slurry, and lowered phosphorus concentrations compared to unaerated areas. We suspect the aeration system must have had at least a 6 to 7 meter horizontal influence.

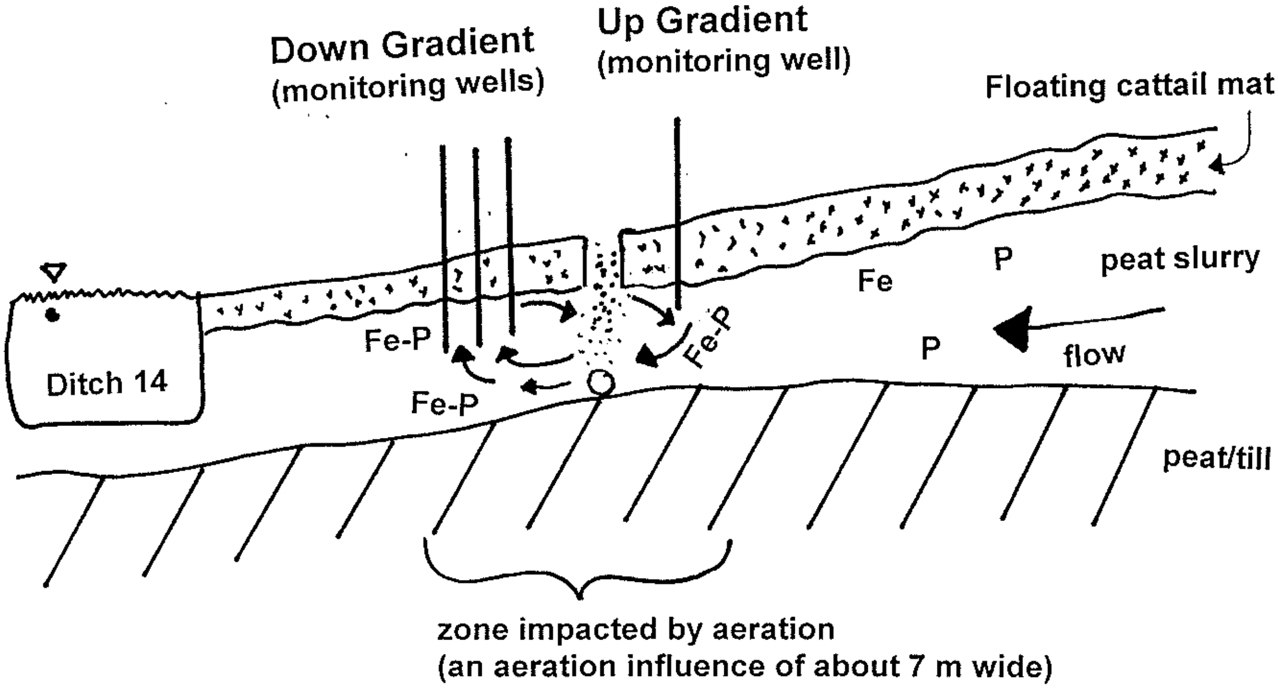


Figure 12. Schematic cross section of the Ditch 14 wetland aeration system.

Summary: The Future of Trench Aeration Systems

Wetlands that export phosphorus can have different peat structures. Some wetlands are packed with solid peat while others, like cattail marshes, may not be solid peat but rather their root mat may float on top of a semi-solid peat slurry. These could be characterized as semi-solid wetlands. Trenches would probably hold up in solid wetlands, but not in semi-solid wetlands. The Ditch 14 wetland test site is located in a semi-solid wetland.

However, ditches that have been dug through wetlands do hold up probably because a current continues to maintain a channel. Ditch 14, cut through the wetland complex, has maintained a channel for over 50 years. Because ditches receive wetland discharges that are high in phosphorus and iron, we thought that the ditch could be a candidate for aeration. Maybe the high concentrations of dissolved iron and phosphorus discharged to the ditch could be lowered. If the ditch could be aerated, we could accomplish the objective of lowering the amount of bioavailable phosphorus to a lake. If this was successful then cutting, trenches into the wetland for aeration purposes would not be necessary.

Figure 13. Rochelle Nustad, PRWD summer staff, has punched through the floating cattail mat and is standing/floating in the peat slurry. We have referred to this type of wetland setting as a semi-solid wetland.

Related Summer Work: Iron and Phosphorus in Ditch 14

By midsummer we realized the wetland trench technique might be unnecessary if we could accomplish the same objectives by just aerating the shallow Ditch 14. Information on Ditch 14 was collected in July and August at several locations (Figure 14).

Figure 14. [top] Tera Guetter, PRWD staff, is downloading data from SC4 a station on Ditch 14. [bottom] Tim James, MPCA, is collecting water samples in the Pelican River downstream from where Ditch 14 discharges into it.

The outlet of Ditch 14 is the established monitoring site SC 4 that has been sampled for at least 10 years by the PRWD. We did additional monitoring in Ditch 14 in July and August.

Redox conditions and dissolved oxygen measurements were taken on July 21, 1999 at the beginning (SC 3), the middle (SC 3a), and the end (SC 4) of Ditch 14 (Table 2). Redox conditions were oxidizing although the early morning reading was low at SC 3a. The redox readings are close to the solid iron/dissolved iron reducing level of around 120 mV. Dissolved oxygen concentrations were low early in the morning and increased in the afternoon.

Two locations in Ditch 14 were sampled on July 26, 199. Redox levels were similar to the July 21 results and phosphorus levels were low (Table 3).

On two occasions in August, Ditch 14 and the Pelican River were monitored for phosphorus and iron (Table 4). Iron and phosphorus concentrations were higher in the wetland than in the ditch, although concentrations in the ditch were higher than the Lake St. Clair outlet (SC 3) and the Pelican River (PR 6 and PR 6a).

Table 2. Diurnal testing at 3 locations in Ditch 14, July 21, 1999. Sunrise was at 5:30 am. Sampled by Rob Spitzley.

	Redox (mV)	Dissolved Oxygen (mg/l)	Time	Increase in DO (mg/l)	Comments
Ditch 14 outlet (SC 4)	136	2.2	5:20 am	2.3	At 5:20, before sunrise, there was a chance to see if DO would go yo 0 overnight, it was not zero on this sample date.
	147	4.6	1:30 pm		
Hwy 6 - middle of Ditch 14 (SC 3a)	96	2.6	5:35 am	2.6	Need to check chl a in the stream.
	127	5.2	1:20 pm		
St. Clair outlet - start of Ditch 14 (SC 3)	131	3.8	5:45 am	3.2	DO is probably influenced by algae.
	136	7.0	1:10 pm		

Table 3. Ditch 14 sample results for July 26, 199. Site 1 was upstream from SC 4, at a fallen tree. Site 2 was closer to SC 4, at green flagging tape, just after the peat bog.

	Site 1			Site 2			
Depth (feet)	surface	1.0	1.5	surface	1.0	1.5	2.0
DO (mg/l)	5.0	4.8	4.6	4.8	4.8	4.7	0.2
Redox (mV)	146	197	--	121	123	131	--
Temp (C)	25.9	25.9	25.9	260	26.0	26.0	25.8
TP (ppb)	119	--	--	117	--	--	--
OP (ppb)	23	--	--	26	--	--	--
pH	7.8	--	--	7.8	--	--	--
Flow (ft/sec)	0.7	--	--	0.8	--	--	--

Table 4. Ditch 14 and Pelican River phosphorus and iron survey results

	8.3.99			8.24.99			
	TP	IRON		OP		IRON	
		Filtered	Total	Filtered	Total	Filtered	Total
SC 3	--	170*	170	12	12	32	210
SC 3a	89	23	210	15	15	48	300
Ditch 14-1	--	--	--	15	15	77	610
Ditch 14-2	--	--	--	12	19	110	420
SC 4	66	31	410	--	--	--	--
PR 6	--	--	--	12	12	<20	120
PR 6a	43	<20	100	15	15	38	350
Aerated Wetland	877	920	7,700	--	330	3,900	11,320

* probably a leaky filter; for all remaining filtering we used a 0.45 μm in-line filter attached to a 10 ml or 20 ml syringe.

Related Summer Work: Laboratory Results from Aerating Wetland Ditch Water for Phosphorus Inactivation

We conducted laboratory aeration trials using ditch water from a ditched wetland in Chisago County, Minnesota. One trial lasted 10 hours (Table 5) and the second trial lasted 20 hours (Table 6). Results were not definitive. We did not see dramatic declines in either filterable phosphorus or filterable iron over a 10 hour period, in either trial although there may have been a decline in filtered iron between 10 and 20 hours in the second trial. Phosphorus levels were low to start with and the effect of aeration was subtle. OP may have increased and then declined in Trial 2 after 6 hours of aeration (Table 6).

Its possible that dissolved iron is complexed with organics and does not easily precipitate with aeration. It may take several hours for the microbial community in the open water to effectively cleave bonds between iron and organics. Another possibility is the iron-phosphorus precipitates are so small they pass through the filters and it may take time to aggregate to larger sizes so they can be filtered. An unknown factor would be the influence of the benthic community living in the bottom of the ditch. A full-scale field trial would include the benthic influence and is a recommended next step.

Table 5. Aerating ditch water for 10 hours from the Sunrise River at Greenway Avenue, Chisago County, August 6, 1999.

Hours	Orthophosphorus (OP) (ppb)		Iron (Fe) (ppb)		Filtered OP/ Total OP (%)	Filtered Fe/ Total Fe (%)	Total Fe/ Total OP Ratio
	Filtered	Total	Filtered	Total			
0*	8	12	510	1,210	67	42	101x
2	15	18	500	1,130	83	44	63x
5	35	35	430	1,050	100	41	30x
10	13	16	430	1,120	123	38	70x

* start time was 9:20 am.

Table 6. Aerating ditch water for 20 hours from the Sunrise River at Greenway Avenue, Chisago County, August 18, 1999. Rain was moderate to light but the River had gone up an inch according to a local resident.

Hours	Orthophosphorus (OP) (ppb)		Iron (Fe) (ppb)		Filtered OP/ Total OP (%)	Filtered Fe/ Total Fe (%)	Total Fe/ Total OP Ratio
	Filtered	Total	Filtered	Total			
0*	12	12	100	270	100	37	23x
2	9	6	240	740	150	32	123x
5	12	9	100	360	133	27	40x
10	<5	19	100	270	<21	37	14x
20	--	--	50	320	--	16	--
30+	--	-	250	700	--	36	--

* start time was 1:00 pm.

Design of an Aeration System in Ditch 14 to Reduce Biologically Available Phosphorus Loading to Muskrat Lake and Lake Sallie

Existing Conditions: Sometimes wetland systems can be a significant source of phosphorus to lakes through the growing season. Wetlands don't seem to export phosphorus under fall and sometimes winter conditions. Sampling results in the Ditch 14 wetland complex confirm that the wetland system is a source of phosphorus in the summer. Few treatment alternatives are available to reduce phosphorus export from this "eutrophic" wetland. Alum and iron dosing are sometimes considered, as is water level manipulation. These alternatives can be costly and sometimes difficult to implement from a regulatory standpoint.

Goal: Test a new phosphorus reduction technique in Ditch 14 to determine if it can reduce biologically available phosphorus loading to Muskrat Lake and Lake Sallie. Basically, mimic fall conditions.

A New Proposed Phosphorus Reduction Technique: Aerating slow flowing ditches that drain wetlands could inactivate orthophosphorus through several possible pathways. The end result would reduce biologically available phosphorus by tying it up in iron-phosphorus compounds. This form of phosphorus would be unavailable for algal uptake when it enters a lake.

Significance: Many watersheds in the State contain eutrophic wetlands that contribute phosphorus to lakes. The Ditch 14 subwatershed in the Lake Sallie watershed is a documented example of a wetland system contributing high phosphorus loads to surface water. Aerating a ditch with an airline would be an inexpensive and ecologically sound way to reduce phosphorus loading to Lake Sallie. The technique could be used for other comparable situations in the state.

Basis for this Approach: Research on ditched wetland dynamics conducted by the Pelican River Watershed District, North Dakota State University, MPCA, and Blue Water Science has found the following:

- Extremely high iron concentrations have been found in wetland pore water measuring over 20 mg-Fe/l.
- Extremely high dissolved phosphorus concentrations also have been found in wetland pore water measuring over 3 mg-P/l.
- The wetland pore water in summer in these wetlands is anoxic.
- We have found wetland pore water moves into ditches.
- High levels of iron and phosphorus have been found in these

drainage ditches.

- Although dissolved oxygen is present at low levels in these ditches, redox conditions are less than 100 mV, and dissolved iron and phosphorus have been present at high concentrations. This is a new finding.
- In 1998, when we aerated a column full of peat with initially high phosphorus concentrations, those phosphorus concentrations dropped dramatically.
- When we aerated a short trench dug into a wetland and aerated the trench, we found phosphorus levels were lower in the aerated area compared to wetland areas that were not aerated.
- When we conducted aeration experiments in the lab on ditch water we found that in some tests dissolved phosphorus levels dropped after it was aerated.
- Ditch 14 has 5 years of automatic sampling data on total and ortho-phosphorus.
- Phosphorus levels are high in midsummer in the ditched wetland channel of Ditch 14.
- There is an ideal test site in the Ditch 14 wetland complex.
- It appears the next step is a field-scale project to determine if ditch aeration is a valid phosphorus reduction option.

Project Proposal: We propose to install a linear ditch aeration system in a drained wetland ditch within the Ditch 14 wetland complex. We will use a conventional 2 hp air compressor and up to 500 feet of perforated airline. We will monitor upstream and downstream conditions from the aeration site to evaluate changes in phosphorus loading as well as to examine potential mechanisms that could account for a phosphorus reduction.

Project Budget

600	Site preparation: access, easements, permits, set up, etc.
9,000	cost of aeration unit, electrical hook-up, and labor for installation
3,000	Project evaluation: upstream and downstream monitoring for March-October, 2000 (not including lab costs)
2,400	Project data analysis and final report
$15,000	

Time Line

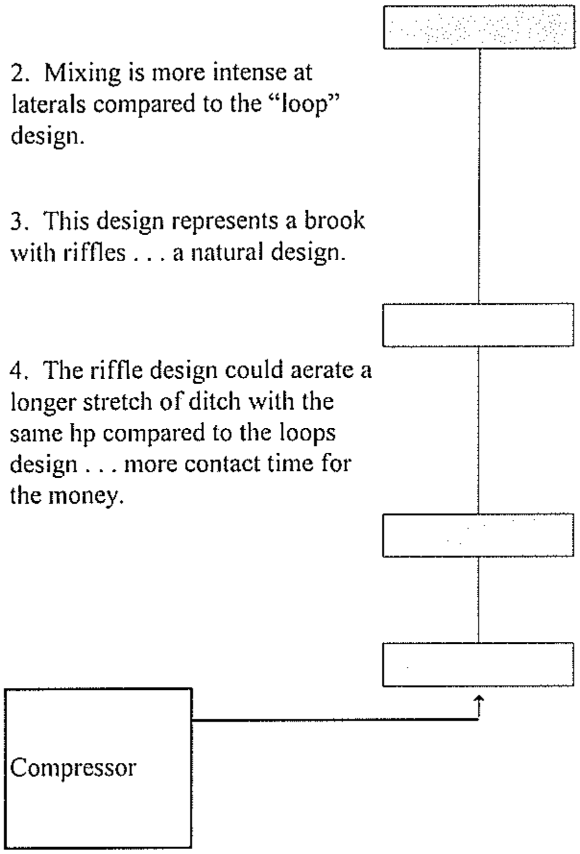
Activity	Timeline	Responsible Party
Site preparation	Jan-Mar, 2000	
Secure easements		Watershed District
Bring power to the site		Electrical contractor
Aeration unit installation	April, 2000	
Set-up cabinet and install airline and test		Watershed District and Steve McComas
Project evaluation	Mar-Oct, 2000	
Sample baseflow and storm events through the growing season		Watershed District
Final report	Feb, 2001	
Prepare final report		Watershed District and Steve McComas

Two aeration Designs for Ditch 14.

A. "Riffles"

Features

1. Aerates entire width of ditch.
2. Mixing is more intense at laterals compared to the "loop" design.
3. This design represents a brook with riffles . . . a natural design.
4. The riffle design could aerate a longer stretch of ditch with the same hp compared to the loops design . . . more contact time for the money.

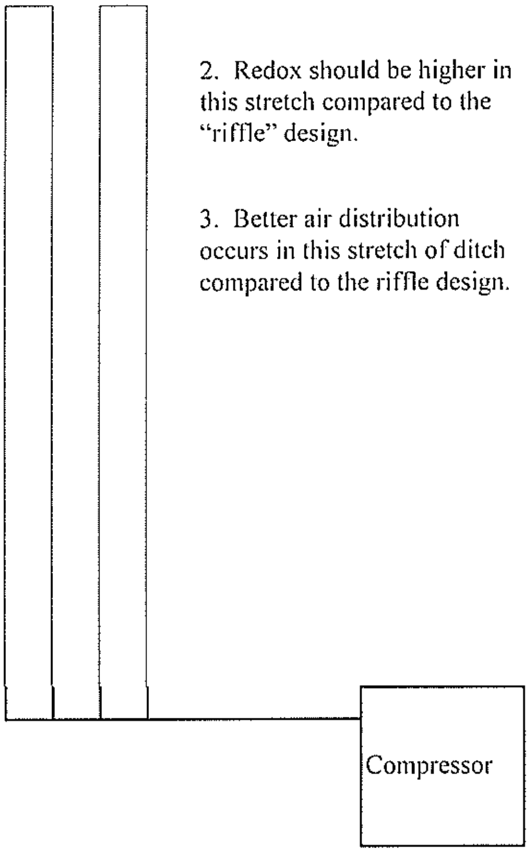


DESIGN A:
Riffles

B. "Loops"

Features

1. Mixing is more pronounced which is better for aggregation.
2. Redox should be higher in this stretch compared to the "riffle" design.
3. Better air distribution occurs in this stretch of ditch compared to the riffle design.



DESIGN B:
Loops

If a field test is conducted we recommend Design A - the riffle design, with the air laterals spaced every 50 feet for a length of 400 to 500 feet using a 3-hp air compressor.

Appendix A

A1. Ditch 14 Summary Data
A2. Aerated and Unaerated Well Data

Table A1. Wetland aeration results for 1999. Aeration was not working for the 7.19 sample date, but was working on 7.12.

Date	Time	Temp (C)	pH	DO (ppm)	Redox Potential (mV)	TP (ppb)	OP (ppb)	Total Iron (ppb)	Dissolved Iron (ppb)
Site T									
6.21	9:45	19.6	6.86	2.22	-121	549	292	1,800	
6.28						453	245	19,000	
7.12	9:30	20.0	6.86	3.90	NA	347	295	3,900	
7.19						743	665	21,000	
7.25	9:30	19.5	7.44	2.80	136	513	146	1,800	
8.2						355	209		
8.9	9:30	19.2	7.50	4.00	70	387	280	2,900	
8.16	9:30	18.4	7.06	1.64	368	1,098	988	22,000	
8.25							626	8,500	5,100
Site 1									
6.21	1:20	20.6	6.92	1.34	-150	533	339	2,900	
6.28						517	355	11,000	
7.12	9:35	16.7	6.56	1.04	NA	283	217	11,000	
7.19						230	170	9,800	
7.26	9:35	19.4	6.81	1.01	-50	185	209	15,000	
8.2						234	209		
8.9	9:35	18.4	6.67	0.90	-151	218	201	25,000	
8.16	9:35	18.3	6.75	1.33	-26	146	122	14,000	
8.25							225	17,000	4,200
Site 2									
6.21	1:25	18.4	6.76	1.60	-80	517	324	9,000	
6.28						405	386	11,000	
7.12	9:40	17.9	6.44	1.36	NA	315	264	16,000	
7.19						254	217	11,000	
7.26	9:40	19.1	6.76	0.79	-54	238		1,400	
8.2						281	240		
8.9	9:40	19.1	6.59	1.29	-109	315	272	13,000	
8.16	9:40	18.7	6.8	0.72	-74	138	107	25,000	
8.25									
Site 3									
6.21	1:30	20.8	6.64	1.90	-87	886	717	3,600	
6.28						854	685	5,400	
7.12	9:45	18.6	6.48	1.73	NA	523	437	7,300	
7.19						569	508	8,100	
7.26	9:45	20.3	6.72	1.03	-52	413	909	5,700	
8.2						908	854		
8.9	9:45	19.1	6.56	0.96	-89	964	870	10,000	
8.16	9:45	18.5	6.87	1.72		210	138	17,000	
8.25							264	9,500	3,600
Site 4									
6.21	1:35	18.9	6.63	1.13	-142	822	622	4,200	
6.28						710	607	6,800	
7.12	9:50	19.3	6.52	1.52	NA	347	288	5,500	
7.19						459	406	6,400	
7.26	9:50	20.1	6.8	1.27	-49	440	398	6,900	
8.2						515	484		
8.9	9:50	19.1	6.58	0.99	-101	593	547	7,800	
8.16	9:50	18.3	6.9	1.6	-83	202	170	12,000	
8.25							280	12,000	3,700

Date	Time	Temp (C)	pH	DO (ppm)	Redox Potential (mV)	TP (ppb)	OP (ppb)	Total Iron (ppb)	Dissolved Iron (ppb)
Site 5									
6.21	1:40	19.2	6.7	1.42	-193	629	497	5,200	
6.28						453	449	8,200	
7.12	9:55	18.4	6.44	1.52	NA	483	406	8,000	
7.19						498	429	9,600	
7.26	9:55	19.7	6.78	0.97	-44	416	421	12,000	
8.2						443	390		
8.9	9:55	18.2	6.58	1.03	-99	411	358	10,000	
8.16	9:55	17.9	6.9	1.05	-75	162	138	18,000	
8.25									
Site 6									
6.21	1:50	17.3	6.74	1.54	-196	629	497	4,800	
6.28						565	449	6,800	
7.12	10:00	18.7	6.37	1.62	NA	459	351	7,200	
7.19						467	429	3,500	
7.26	10:00	19.2	6.75	0.97	-24	448	445	7,400	
8.2						347	295		
8.9	10:00	18.1	6.63	1.18	-97	347	355	5,600	
8.16	10:00	17.9	6.88	1.22	-86	170	182	13,000	
8.25									
Site 7									
6.21	1:55	18.7	6.81	1.58	-155	982	811	4,200	
6.28						549	461	5,900	
7.12	10:05	18.3	6.43	1.68	NA	443	396	4,400	
7.19						451	374	4,000	
7.26	10:05	18.6	6.76	0.97	-28	473	303	6,800	
8.2						491	445		
8.9	10:05	18.1	6.59	1.37	-97	562	500	4,000	
8.16	10:05	18.1	6.82	0.87	-95	250	233	14,000	
8.25							256	9,600	2,900
Site 8									
6.21	2:05	19	6.65	1.00	-86	533	339	7,800	
6.28						774	339	8,300	
7.12	10:10	17.9	6.47	1.80	NA	347	303	4,500	
7.19						372	319	4,100	
7.26	10:10	20.4	6.76	0.94	-42	434	327	3,800	
8.2						427	382		
8.9	10:10	18.7	6.61	1.51	-84	411	390	5,300	
8.16	10:10	17.9	6.89	1.07	-113	170	146	10,000	
8.25									
Site 9									
6.21	2:00	18.4	6.75	1.44	-122	405	261	4,700	
6.28						389	355	4,800	
7.12	10:15	18.3	6.43	1.71	NA	419	366	3,500	
7.19						404	327	4,600	
7.26	10:15	20.3	6.71	0.92	-36	375	24	4,800	
8.2						387	366		
8.9	10:15	18.3	6.66	1.34	-114	371	358	3,300	
8.16	10:15	18.3	7	1.52	-111	218	193	6,200	
8.25									

Date	Time	Temp (C)	pH	DO (ppm)	Redox Potential (mV)	TP (ppb)	OP (ppb)	Total Iron (ppb)	Dissolved Iron (ppb)
Average Sites 1 and 2									
6.21		19.5	6.84	1.47	-115	525	332	5950	
6.28						461	371	11000	
7.12		17.3	6.5	1.20	NA	299	241	13500	
7.19						241	194	10400	
7.26		19.3	6.79	0.9	-52	212	209	8200	
8.2						258	225		
8.9		18.8	6.63	1.10	-129	267	237	19000	
8.16		18.5	6.78	1.03	-50	142	115	19500	
8.25							225	17000	
Average Sites 3 and 4									
6.21				1.52	-114		670	3900	
6.28							646	6100	
7.12				1.63	NA		363	6400	
7.19							457	7250	
7.26				1.15	-50		654	6300	
8.2							669	--	
8.9				0.98	-95		709	8900	
8.16				1.66	-83		154	14500	
8.25							272	10750	
Average Sites 8 and 9									
6.21				1.22	-104		300	6250	
6.28							347	6550	
7.12				1.76	NA		335	4000	
7.19							323	4350	
7.26				0.93	-39		176	4300	
8.2							374	--	
8.9				1.43	-99		374	4300	
8.16				1.30	-112		170	8100	
8.25									

Table A2. Aerated and unaerated well data. Unaerated well site was about 50 m from the aerated site.

Aerated Wells				
Weeks	Date	Site	TP (mg/l)	OP (mg/l)
6 (3)	6.21.99	T	0.549	0.292
		1	0.533	0.339
		2	0.517	0.324
		3	0.886	0.717
		4	0.822	0.622
		5	0.629	0.497
		6	0.629	0.497
		7	0.982	0.811
		8	0.533	0.339
		9	0.405	0.261
		Mean	**0.649**	**0.470**
6 (4)	6.28.99	T	0.453	0.245
		1	0.517	0.335
		2	0.405	0.386
		3	0.854	0.685
		4	0.710	0.607
		5	0.453	0.449
		6	0.565	0.449
		7	0.549	0.481
		8	0.774	0.339
		9	0.389	0.335
		Mean	**0.567**	**0.435**
7 (2)	7.12.99	T	0.347	0.295
		1	0.283	0.217
		2	0.315	0.264
		3	0.523	0.437
		4	0.347	0.288
		5	0.483	0.406
		6	0.459	0.351
		7	0.443	0.398
		8	0.347	0.303
		9	0.419	0.366
		Mean	**0.397**	**0.333**
7 (3)	7.19.99	T	0.743	0.665
		1	0.230	0.170
		2	0.254	0.217
		3	0.569	0.508
		4	0.459	0.406
		5	0.498	0.429
		6	0.467	0.429
		7	0.451	0.374
		8	0.372	0.319
		9	0.404	0.327
		Mean	**0.445**	**0.384**

Unaerated Wells - 50 m from aerated wells				
Weeks	Date	Site	TP (mg/l)	OP (mg/l)
6 (3)	6.23.99	S1A	1.107	1.079
		S1B	1.028	0.921
		S1C	1.817	1.771
		Mean	**1.317**	**1.257**
6 (4)	6.30.99	S1A	1.139	1.031
		S1B	1.438	1.409
		S1C	1.975	1.928
		Mean	**1.517**	**1.456**
7 (1)	7.6.99	S1A	1.107	1.110
		S1B	1.407	1.409
		S1C	2.148	2.133
		Mean	**1.554**	**1.550**
7 (2)	7.14.99	S1A	1.06	1.031
		S1B	2.416	1.204
		S1C	2.022	1.96
		Mean	**1.833**	**1.398**
7 (3)	7.21.99	S1A	1.076	0.984
		S1B	1.297	1.236
		S1C	1.912	1.834
		Mean	**1.428**	**1.351**

Aerated Wells				
Weeks	**Date**	**Site**	**TP (mg/l)**	**OP (mg/l)**
7 (4)	7.26.99	T	0.513	0.146
		1	0.165	0.209
		2	0.238	0.878
		3	0.909	0.413
		4	0.440	0.398
		5	0.416	0.421
		6	0.448	0.445
		7	0.473	0.303
		8	0.327	0.343
		9	0.375	0.024*
		Mean	**0.430**	**0.395**
8 (1)	8.2.99	T	0.355	0.209
		1	0.234	0.209
		2	0.291	0.240
		3	0.908	0.854
		4	0.515	0.484
		5	0.443	0.390
		6	0.343	0.295
		7	0.491	0.445
		8	0.427	0.382
		9	0.387	0.366
		Mean	**0.439**	**0.387**
8 (2)	8.9.99	T	0.387	0.280
		1	0.218	0.201
		2	0.315	0.272
		3	0.964	0.870
		4	0.593	0.547
		5	0.411	0.358
		6	0.347	0.335
		7	0.562	0.500
		8	0.411	0.390
		9	0.371	0.358
		Mean	**0.458**	**0.411**
8 (3)	8.16.99	T	1.098	0.988
		1	0.146	0.122
		2	0.138	0.107
		3	0.210	0.138
		4	0.202	0.170
		5	0.162	0.138
		6	0.170	0.162
		7	0.250	0.233
		8	0.170	0.146
		9	0.218	0.193
		Mean	**0.276**	**0.240**

Unaerated Wells - 50 m from aerated wells				
Weeks	**Date**	**Site**	**TP (mg/l)**	**OP (mg/l)**
7 (4)	7.28.99	S1A	1.091	1.047
		S1B	1.884	1.834
		S1C	1.754	1.692
		Mean	**1.576**	**1.524**
8 (1)	8.4.99	S1A	1.170	1.094
		S1B	1.486	1.440
		S1C	1.707	1.676
		Mean	**1.454**	**1.403**
8 (2)	8.10.99	S1A	0.982	0.890
		S1B	1.628	1.535
		S1C	1.817	1.771
		Mean	**1.476**	**1.399**
8 (3)	8.18.99	S1A	0.838	0.764
		S1B	1.281	1.189
		S1C	1.628	1.582
		Mean	**1.249**	**1.178**

Aerated Wells				
Weeks	**Date**	**Site**	**TP (mg/l)**	**OP (mg/l)**
8 (4)	8.25.99	T	--	0.626
		1	--	0.225
		2	--	--
		3	--	0.264
		4	--	0.280
		5	--	--
		6	--	--
		7	--	0.256
		8	--	--
		9	--	--
		Mean	--	**0.330**

Unaerated Wells - 50 m from aerated wells				
Weeks	**Date**	**Site**	**TP (mg/l)**	**OP (mg/l)**
8 (4)	8.23.99	S1A	0.934	0.918
		S1B	1.470	1.378
		S1C	1.880	1.739
		Mean	**1.428**	**1.345**
9 (1)	9.1.99	S1A	0.902	0.843
		S1B	1.344	1.252
		S1C	1.297	1.252
		Mean	**1.181**	**1.116**

* not used in calculations.

Appendix B

Ditch Data from Rush Lake

Table B1. Iron and orthophosphorus in streams on the Rush Lake Watershed.

8.25.99	**Orthophosphorus** (ppb)			**Iron** (ppb)		
	Filtered	Total	Filtered/Total-OP (%)	Filtered	Total	Filtered/Total Iron (%)
Site 1	120	198	60	2,220	4,170	53
Site 3	240	251	96	1,730	3,850	45
Site 4	159	131	121	1,070	1,940	55
Site 5	117	50	234	2,010	1,590	126
Site 6	240	176	136	510	850	60
Site 9	81	24	337	100	260	38