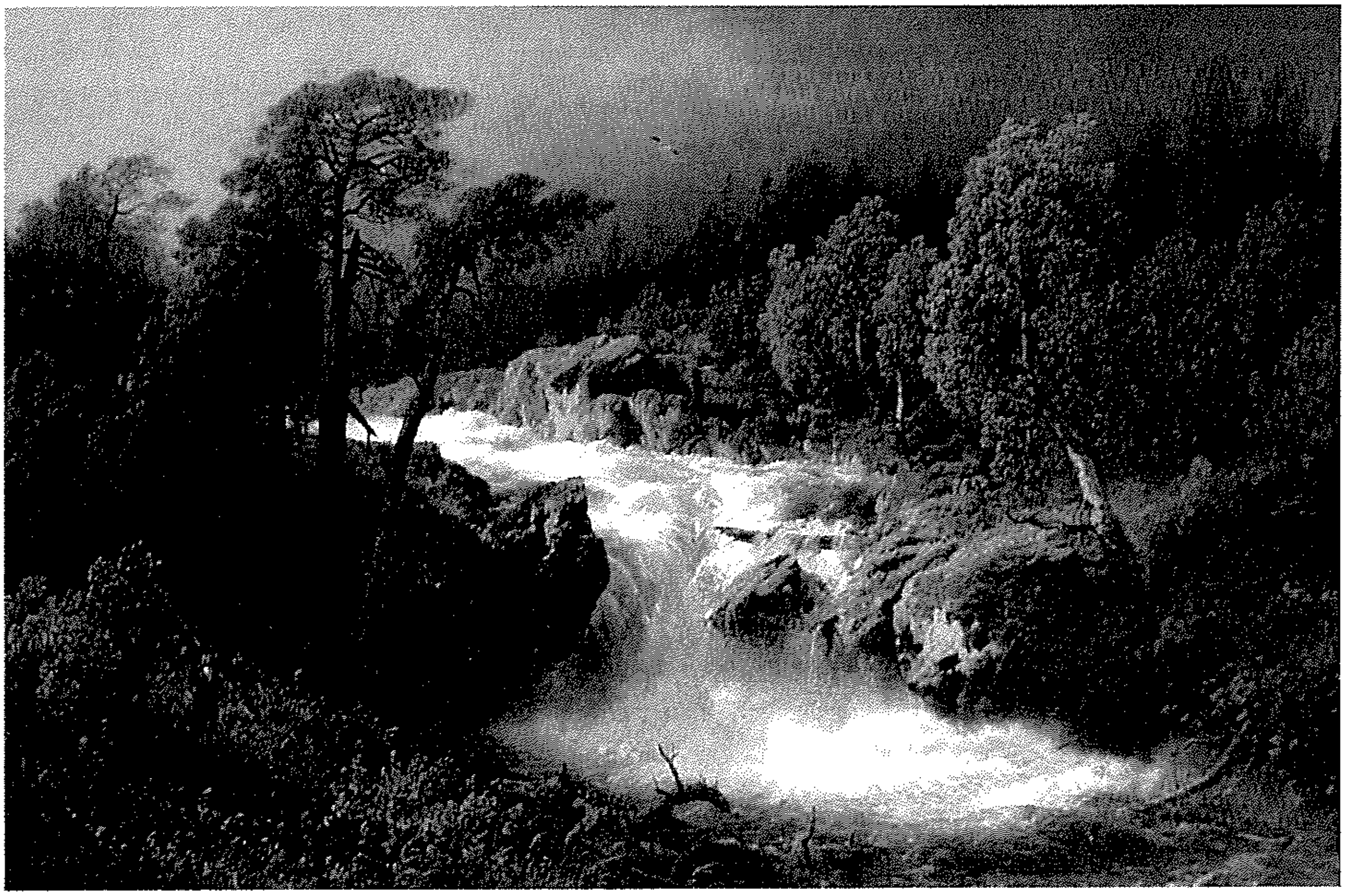

Hermann Herzog: *Fisherman Near River*, n.d.

Impacts of Ditch Aeration on Bioavailable Phosphorus in Ditch 14, Pelican River Watershed District, Minnesota

January 2002

Prepared for:
Pelican River Watershed District
Detroit Lakes, Minnesota

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Impacts of Ditch Aeration on Bioavailable Phosphorus in Ditch 14,
Pelican River Watershed District, Minnesota

SUMMARY

Question Addressed by Ditch 14 Research in 2001:

Does the ditch aeration system reduce bioavailable phosphorus in Ditch 14?

Results for the Summer of 2001 are Summarized Below:

1. Comparing total phosphorus (TP) and orthophosphorus (OP) concentrations at the outlet of Ditch 14 (SC4) to previous years: [*If aeration was working, OP concentrations should be lower in aerated years compared to unaerated years.*] TP and OP concentrations were lower during the aerated years compared to the unaerated years of 1996-1998.

2. Comparing the increase of pounds of TP and OP from the outlet of St. Clair (SC3) to the outlet at Ditch 14 (SC4): [*We know the pounds of phosphorus increase from the St. Clair outlet to the Ditch 14 outlet. If aeration is effective, we would expect a smaller increase in phosphorus in aerated years compared to unaerated years.*] For the aerated years of 2000 and 2001, the increase in pounds of TP and OP from the St. Clair outlet to the Ditch outlet was less compared to unaerated years. However, other factors are involved. For example, the last 2 years have also been low flow years.

3. Comparing the ratio of OP to TP for aerated and unaerated years: *[Ditch aeration should convert OP to TP thus lowering the OP/TP ratio.*] When comparing aerated to unaerated years, the OP to TP ratio at the Ditch 14 outlet did not decrease as we might expect if aeration converted OP to TP.

4. Monitoring dissolved oxygen in the ditch, downstream of the aeration system: *[The ditch aeration system is suppose to aerate all the water in the ditch.*] Dissolved oxygen was present in the top 1.5 feet of the ditch 24 hours a day. Aeration only slightly boosted the levels in the upper water. However, near the stream bottom (from 2 to 5 inches off the bottom) there was no dissolved oxygen. The aeration system was not aerating the bottom waters. This is of some concern.

5. Bioassay to monitor algae growth: [*Ditch water was aerated in 5-gallon containers to simulate aerated ditch conditions. If aeration reduces bioavailable phosphorus, then there should be less algae growth int he aerated containers compared to the unaerated containers.*] Very little open water algae grew in any of the containers including the unaerated reference containers. It appears algal growth consisted largely of diatoms attached to the sides of the container. Phosphorus levels did not decrease significantly.

6. Light/dark bottle trial: [*Light and dark bottles check algae growth by measuring the amount of dissolved oxygen produced in the light bottle compared to the dark bottle. If aeration is working, there should be little evidence of algae growth in the light bottle.*] Results showed very little indication of open water algae in Ditch 14. It was concluded most of the algae growth in the ditch is periphyton, meaning it is attached to weeds and sediments in the ditch.

7. Muskrat Lake water clarity: *[Aeration should reduce bioavailable phosphorus to Muskrat Lake and improve clarity.*] Muskrat Lake water clarity for June-September in 2000 and 2001 was good but similar to unaerated years of 1998 and 1999.

8. Lake Sallie water clarity: [*Aeration should improve water quality in Muskrat, which in turn will improve water quality in Sallie.*] Lake Sallie water clarity has been slightly better in the aerated years of 2000 and 2001 compared to years from 1995-1999. However, many factors have contributed to improved water clarity in 2000 and 2001.

Conclusion

The impact of the Ditch 14 aeration system on reducing bioavailable phosphorus is inconclusive. It is difficult to assign Ditch 14 water quality improvements to the aeration system. We know we have not caused any adverse impacts, but our monitoring results have not isolated any improvements that could be attributed specifically to ditch aeration.

What's Next

Before abandoning the ditch aeration concept, it would be informative to place a submerged weir which would resemble an underwater ramp on the ditch bottom to force the bottom water up and then aerate it. If the bottom water can be aerated it should reduce phosphorus release from the bottom sediments as well as converting OP to an unavailable form of phosphorus.

The cost would be modest, around $100 - for materials, and 3 or 4 days of consulting time for installation, reconfiguration of the aeration system, and monitoring over June, July, and August.

Background on Wetland Ditch Aeration from 1996-2001

Listed below are findings from previous related work on Ditch 14 wetlands and ditch aeration:

- Wetland porewater in the Ditch 14 wetland in the Detroit Lakes watershed has high concentrations of ortho phosphorus and dissolved iron.
- Because the wetland is ditched, wetland porewater flows toward the open channel, which is Ditch 14.
- Therefore, Ditch 14 carries this source of phosphorus into the Pelican River and into Muskrat Lake.
- The mechanisms to explain the phosphorus wetland source are: as the summer progresses and temperatures increase, microbial activity increases and dissolved oxygen levels are depleted in the pore water. Next, iron dissolves and phosphorus is released into the porewater. Because there is a down slope groundwater gradient to Ditch 14 (based on previous measurements), the elevated concentrations of phosphorus and iron move toward the Ditch.
- Experiments with columns of peat verified that peat could be a source of phosphorus in wetlands along Ditch 14.
- Experiments with paired aerated and unaerated columns of peat showed aeration reduced phosphorus release from peat.
- Additional experiments showed that aerating a small trench in a wetland lowered phosphorus concentrations within 3 meters of the trench.
- For the aerated wetland trench experiment, the proposed mechanism to explain the decline in phosphorus in the observation wells was that the trench aeration precipitated iron creating a reactive iron-hydroxy surface which in turn scavenged phosphate anions from the water column.
- An initial field-scale project idea was to dig a trench parallel to Ditch 14 and lay aeration lines in the trench. However, as planning evolved, we proposed to put an aeration line right in the ditch and aerate ditch water rather than dig a parallel trench to be used for aeration.
- In the summer of 2000, an experimental ditch aeration project was initiated. Air lines were installed in Ditch 14 covering a length of 250 feet of Ditch 14. Results for OP reduction were inconclusive.
- It was proposed for 2001, to try several additional monitoring methods to determine if ditch aeration could lower OP concentrations. Additional information is found in Appendix A.

Methods

The project location is in a wetland complex adjacent to Little Detroit Lake (Figure 1). The aeration site lies between upstream and downstream monitoring stations. Two upstream stations were SC3 and SC3A (both above the aeration system) and the downstream station was SC4 (below the aeration system). The components of the aeration system and installation are shown in Figure 2. The configuration of the aeration system as it was installed on June 20, 2000 is shown in Figure 3.

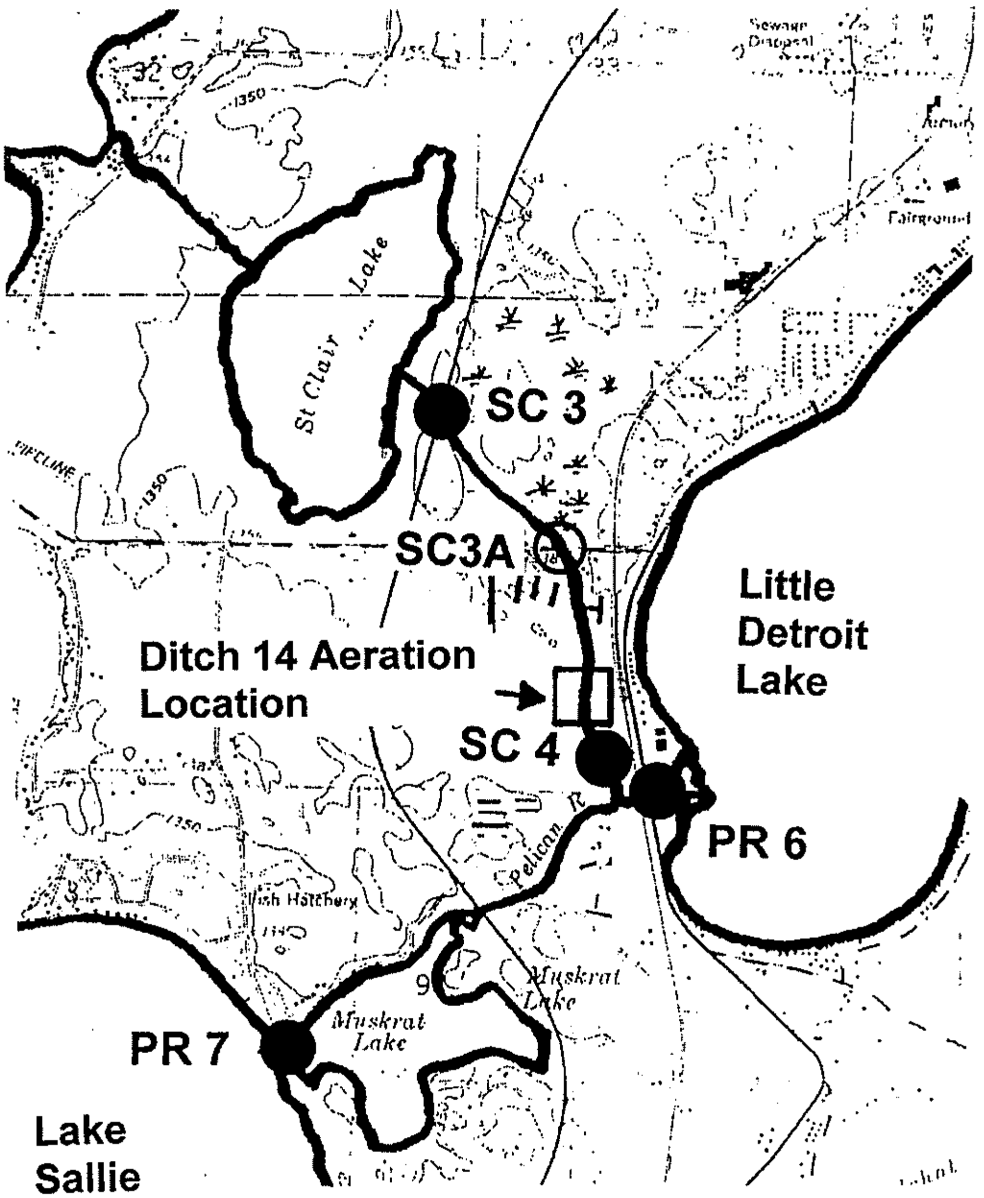

Figure 1. Location of the Ditch 14 aeration system and monitoring stations. The primary monitoring stations were at the outlet of Lake St. Clair (SC3) and the outlet of Ditch 14 (SC4). Some measurements were taken at SC3A.

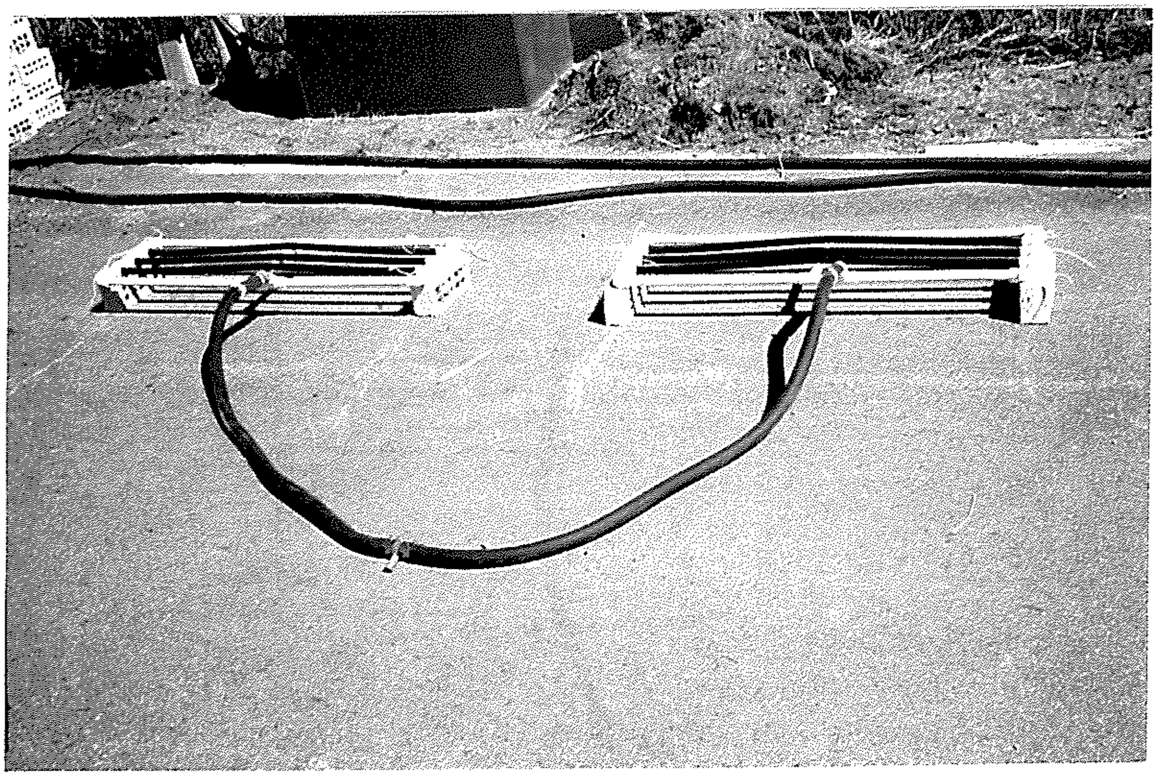

Figure 2. [top] Two diffuser heads set up in parallel.
[bottom] Two diffusers in place on the ditch bottom and bubbling.

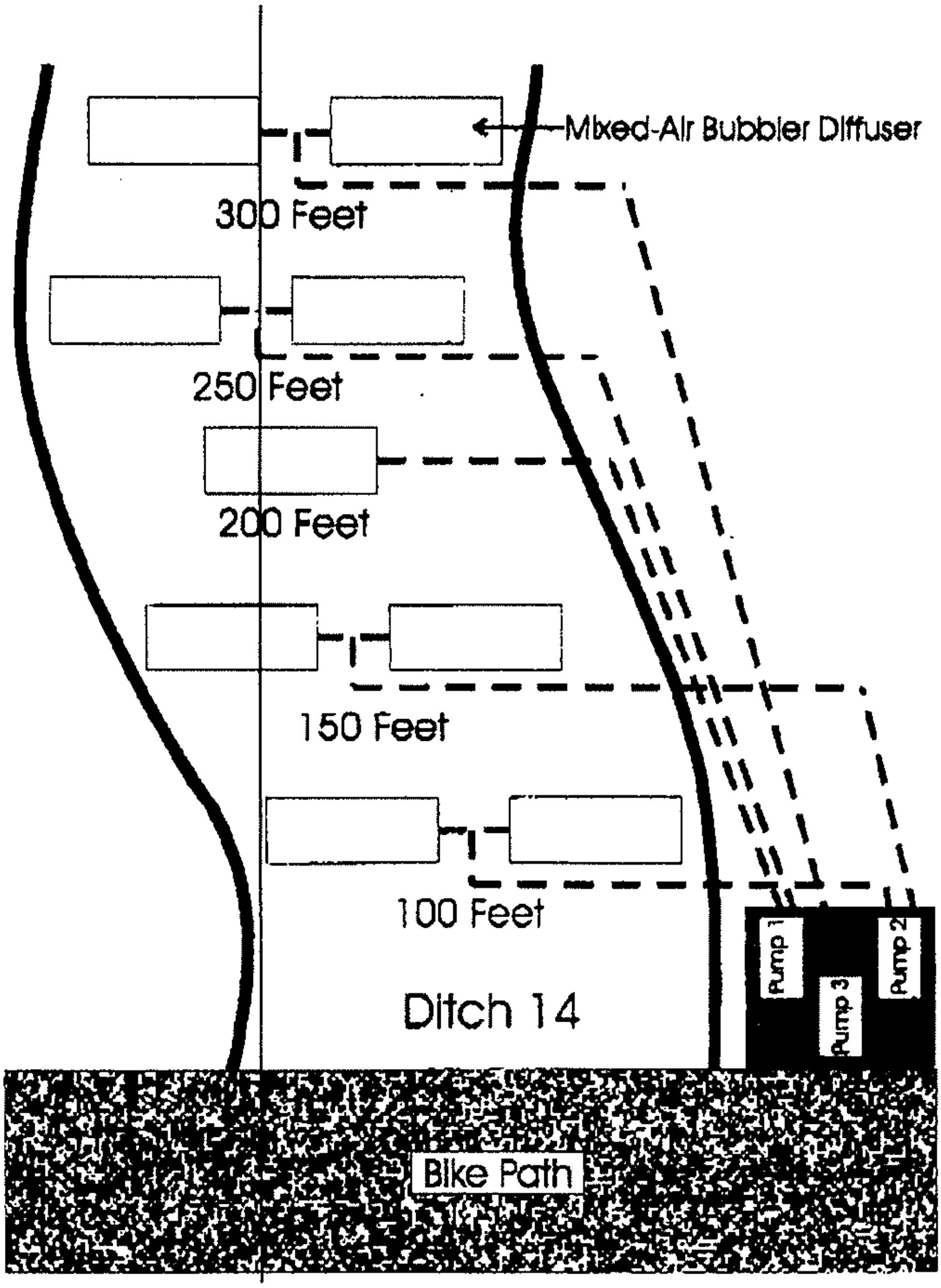

Figure 3. Configuration of diffuser installation. Air was supplied by three 1-hp compressors.

Results

The Ditch 14 aeration system began operation for the second year starting in June 2001 and running nearly continuously till the end of September 2001. Three 1-hp air compressors supplied approximately 30 cfm (cubic feet per minute) of air over a 250-feet length of ditch. There was approximately a 6 to 14 minute aeration contact time based on a flow velocity of 0.3 to 0.6 feet per second over a 250-foot length of ditch.

Several types of results are presented in this section and include:

1. Comparing total phosphorus (TP) and orthophosphorus (OP) concentrations at the outlet of Ditch 14 (SC4) to previous years.
2. Comparing the increase of pounds of TP and OP from the outlet of ST. Clair (SC3) to the outlet at Ditch 14 (SC4).
3. Comparing the ratio of OP to TP for aerated and unaerated years.
4. Monitoring dissolved oxygen in the ditch, downstream of the aeration system.
5. Bioassay to monitor algae growth.
6. Light/dark bottle trial.
7. Muskrat Lake water clarity.
8. Lake Sallie water clarity.

1. Comparing total phosphorus (TP) and orthophosphorus (OP) concentrations at the outlet of Ditch 14 (SC4) to previous years: [*If aeration was working, OP concentrations should be lower in aerated years compared to unaerated years.*] TP and OP concentrations were lower during the aerated years compared to the unaerated years of 1996-1998.

Phosphorus concentrations for stations SC3 (upstream-the Lake St. Clair outlet) and SC4 (downstream-the Ditch 14 outlet) are shown in Figures 3 and 4. The alum application in St. Clair in 1998 is responsible for some of the reduction, but flow weighted loads were lower in 2000 and 2001 than 1999 at SC4 (Appendix B).

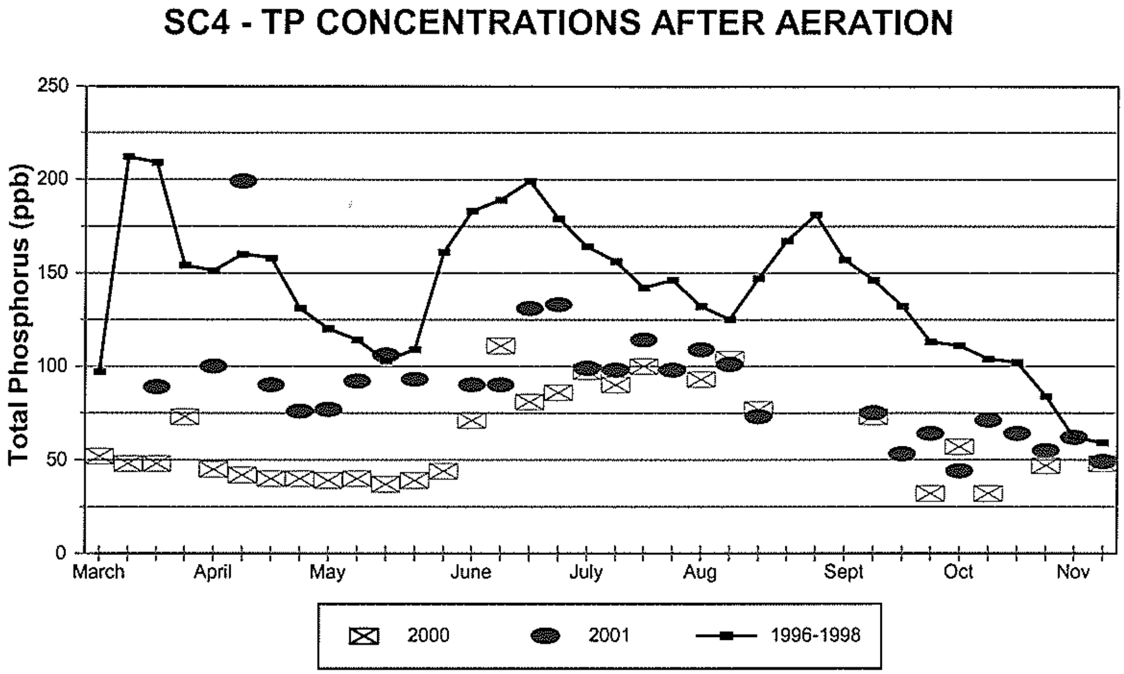

Figure 3. Total phosphorus (TP) concentrations at SC4.

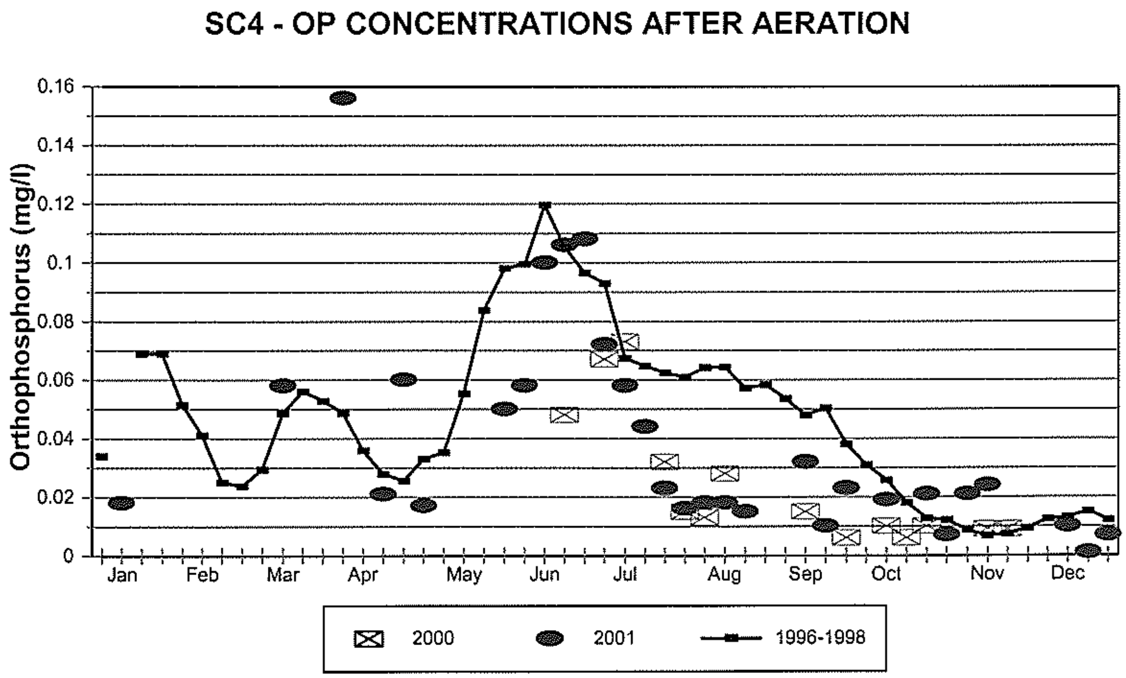

Figure 4. Orthophosphorus concentrations (OP) at SC4.

2. Comparing the increase of pounds of TP and OP from the outlet of St. Clair (SC3) to the outlet at Ditch 14 (SC4): [*We know the pounds of phosphorus increase from the St. Clair outlet to the Ditch 14 outlet. If aeration is effective, we would expect a smaller increase in phosphorus in aerated years compared to unaerated years.*] For the aerated years of 2000 and 2001, the increase in pounds of TP and OP from the St. Clair outlet to the Ditch outlet was less compared to unaerated years, especially in August and September (Figure 5). However, other factors are involved that could account for the decrease. For example, the last 2 years have also been low flow years which may reduce the increase in pounds of phosphorus from SC3 to SC4.

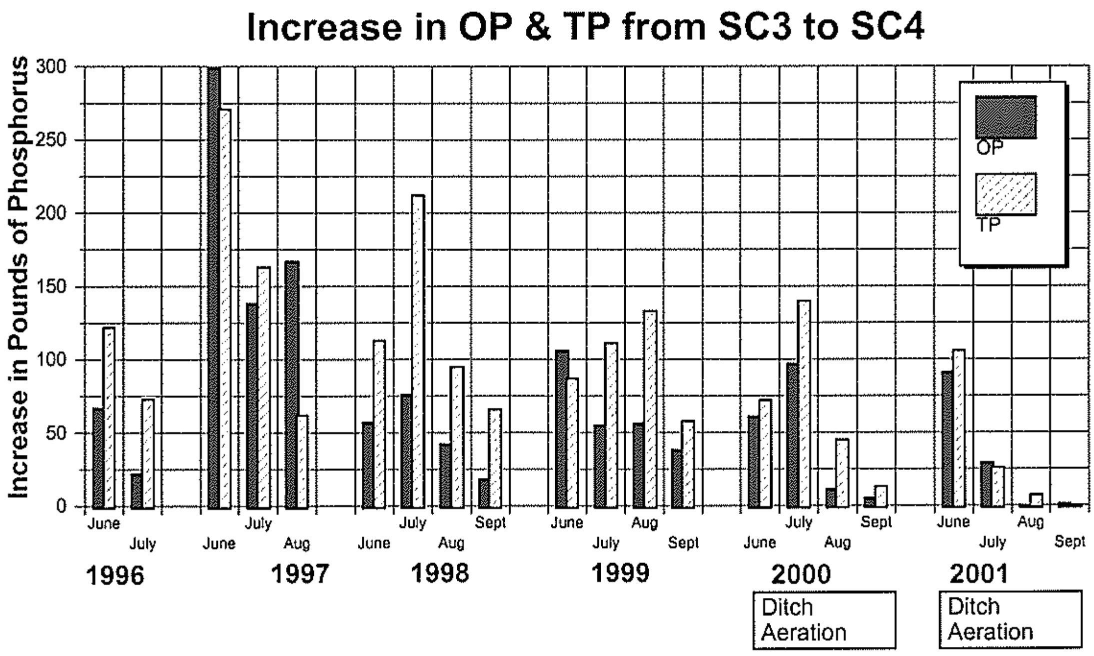

Figure 5. Increase in pounds of phosphorus from SC3 to SC4 for the summer months of June through September. However, in 1996, August and September data were incomplete and not used and in 1997, September data were not available.

3. Comparing the ratio of OP to TP for aerated and unaerated years: *[Ditch aeration should convert OP to TP thus lowering the OP/TP ratio.]* When comparing aerated to unaerated years, the OP to TP ratio at the Ditch 14 outlet did not decrease for all months as we might expect if aeration converted OP to TP (Figure 6). The OP/TP ratio has been high in June and July for 2000 and 2001 indicating there are high levels of OP coming into the ditch, and it is not being significantly converted to TP.

On a side note, the OP/TP ratio was low in 1999 at the St. Clair outlet (SC3). This was probably due to the alum treatment applied to Lake St. Clair in October of 1998. OP/TP ratios at SC3 have been higher in 2000 and 2001 compared to 1999.

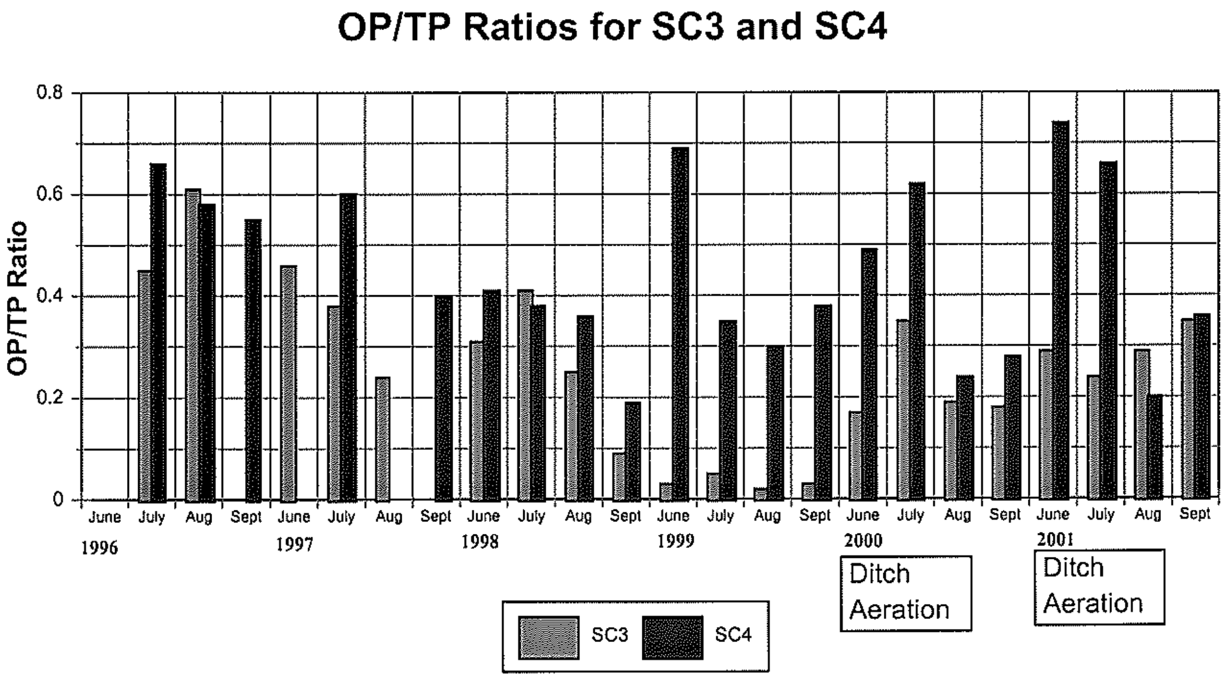

Figure 6. The ratio of orthophosphorus (OP) to total phosphorus (TP) for the Lake St. Clair outlet (SC3) and the Ditch 14 outlet (SC4).

4. Monitoring dissolved oxygen in the ditch, downstream of the aeration system: *[The ditch aeration system is suppose to aerate all the water in the ditch.]* Dissolved oxygen was present in the top 1.5 feet of the ditch 24 hours a day at SC4. The fluctuation from the high reading to the low reading over a 24-hour period is shown in Figure 7. Aeration only slightly boosted the levels in the upper water. However, when the probe was moved near the stream bottom (from 2 to 5 inches off the bottom) on August 28, 2001 there was no dissolved oxygen. The aeration system was not aerating the bottom water. This is of some concern.

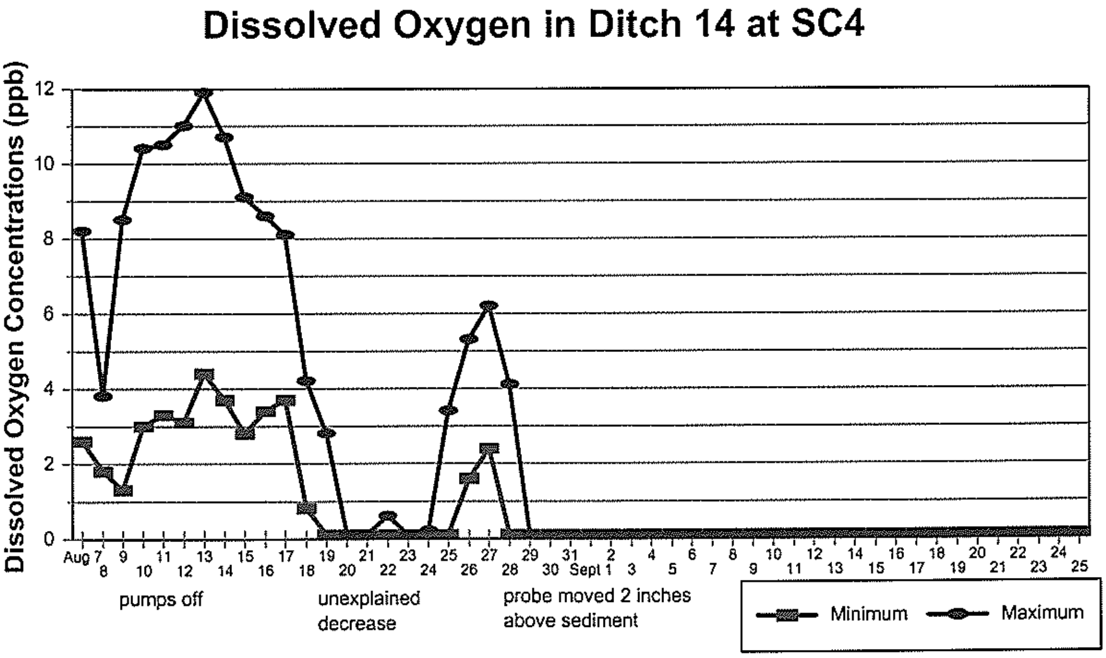

Figure 7. Dissolved oxygen readings in Ditch 14 at the ditch outlet (SC4). The 24 hours minimum and maximum readings are shown. From August 20-24 there is an unexplained DO decrease. On August 28 the probe was moved to two inches above the sediment. No DO was recorded for the remainder of the time when the probe was at that location.

5. Bioassay to monitor algae growth: [*Ditch water was aerated in 5-gallon containers to simulate aerated ditch conditions. If aeration reduces bioavailable phosphorus, then there should be less algae growth in the aerated containers compared to the unaerated containers.*] Very little open water algae grew in any of the containers including the unaerated reference containers. It appears algal growth consisted largely of algae attached to the sides of the container.

Another parameter monitored in the bioassay was phosphorus. Phosphorus levels did not decrease significantly compared to the reference (Figure 8). Three conditions were tested on two occasions, and each condition had a replicate. The first condition (ref) was the reference. No vigorous aeration was used, but a slow bubbler was used in the containers. The second condition (8 min) was intended to mimic the ditch aeration system. Vigorous aeration occurred for 8 minutes, the length of contact time found in the ditch, and then conditions reverted to a slow bubble action. The third condition (cont.) was continuous vigorous aeration for the duration of the bioassay.

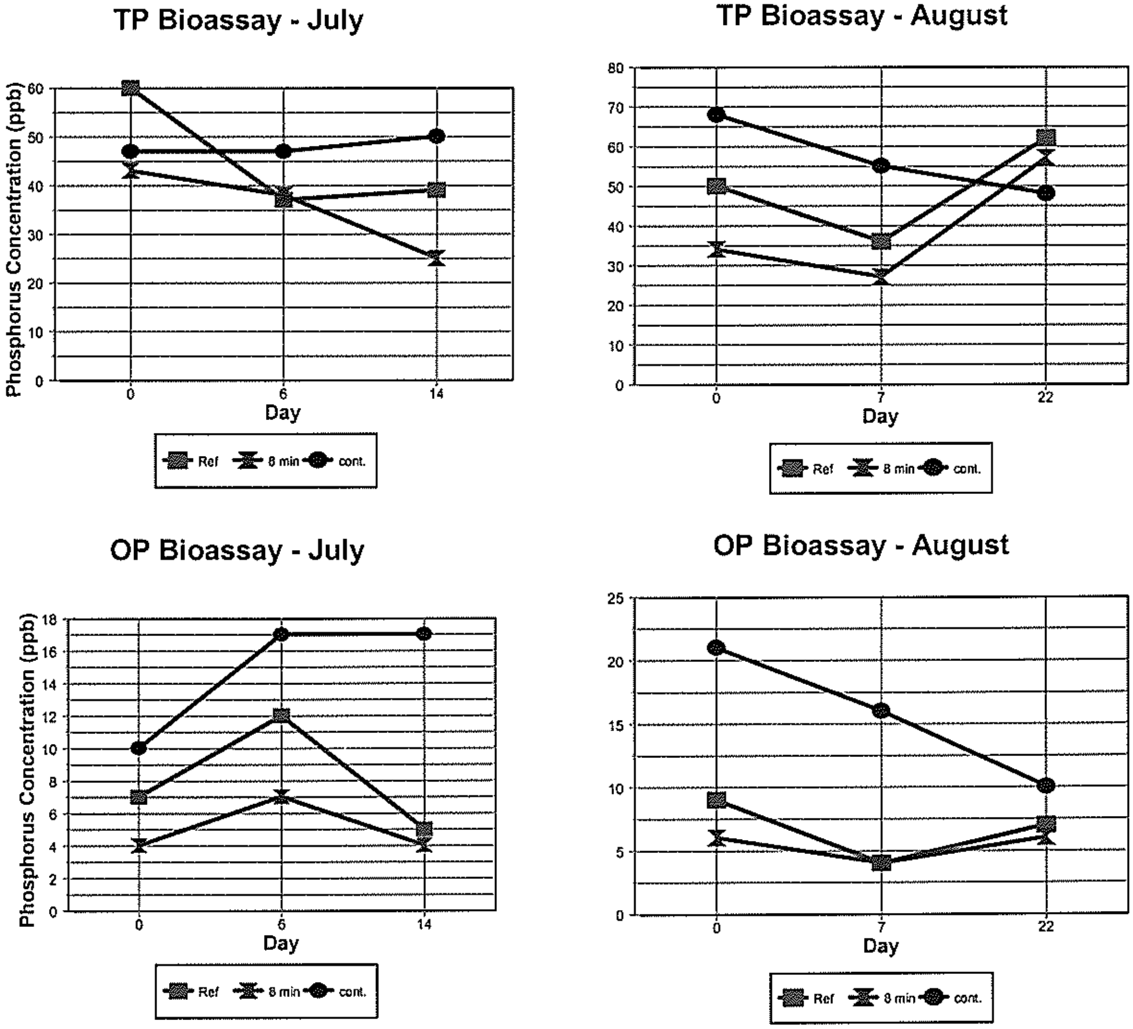

Figure 8. TP and OP concentrations in the bioassay containers over the duration of the test. Each point represents the average from 2 containers.

6. Light/dark bottle trial: [*Light and dark bottles check algae growth by measuring the amount of dissolved oxygen produced in the light bottle compared to the dark bottle. If aeration is working, there should be little evidence of algae growth in the light bottle.*] Results showed very little indication of open water algae in Ditch 14. It was concluded most of the algae growth in the ditch is periphyton, meaning it is attached to weeds and sediments in the ditch.

[The following work was conducted by John Peterka and this is his write-up (13 July 2001).]

BOD bottles were filled (crew of Paula, Scott, and John) with water from the stream surface, and incubated for about 5 h (5.25 to 5.5 h) in a tray at the water surface in the stream. At both upstream and downstream sites there was no to little increase of DO in the light bottles (LB), and no to little decrease in DO in the dark bottles (DB), compared with DO in the initial bottles (IB) (Table 1). The algal community must be near absent in the stream, and primary production from phytoplankton was nil.

Although there was no to little primary production by phytoplankton recorded by this preliminary light/dark bottle experiment, there is considerable primary productivity in the marsh as indicated by the marked increases in DO in the stream as measured with the YSI DO meter. The DO in the stream was about 3 mg/l at 9:30 AM, reflecting overnight decomposition activities, and was 10 mg/l by 4:00 PM, indicating considerable oxygen production during the 5.5-hour period of full sunlight. The major primary production is likely from the periphyton community encrusting surfaces of macrophytes and bottom sediments, and from submergent macrophytes. Because the light/dark experiment indicate extremely low phytoplankton production, the best measure of primary production would be to conduct diurnal oxygen measures in upstream and downstream reaches (method described in Standard Methods for Water and Wastewater) . . . (but would not recommend detailed study to quantify primary production — I think data from a few measures of DO at daylight and near sunset will establish there is high primary productivity during the growing season).

Because of the high primary production by periphyton communities there is probably continual sloughing of particulate and soluble phosphorus into the stream. Measures of particulate and dissolved phosphorus components would be helpful. Filtering water samples through a filter and analyzing the total phosphorus, i.e. total soluble phosphorus as well as other phosphorus measurements, described in Standard Methods, would be helpful in partitioning the various kinds of phosphorus . . . these only need to be done on a seasonal basis.

The high phosphorus readings in the spring/summer can probably be best explained by activities of microbial (periphyton and bacterial) communities metabolizing nutrients and they "leak" soluble and particulate P to the stream.

Table 1. Results of light/dark bottle trials.

	IB (DO mg/l)	LB (DO mg/l)	DB (DO mg/l)	Time In	Time Out
Upstream from first two sets of diffusers					
Rep 1	2.4	2.7	2.4	9:30 am	4:00 pm
Rep 2	2.4	2.8	2.5		
Downstream from diffusers, at culvert					
Rep 1	2.6	2.6	2.3	9:45 am	4:00 pm
Rep 2	2.7	2.6	2.4		

7. Muskrat Lake water clarity: *[Aeration should reduce bioavailable phosphorus to Muskrat Lake and improve clarity.]* Muskrat Lake water clarity for June-September in 2000 and 2001 was good but similar to unaerated years of 1998 and 1999 (Figure 9).

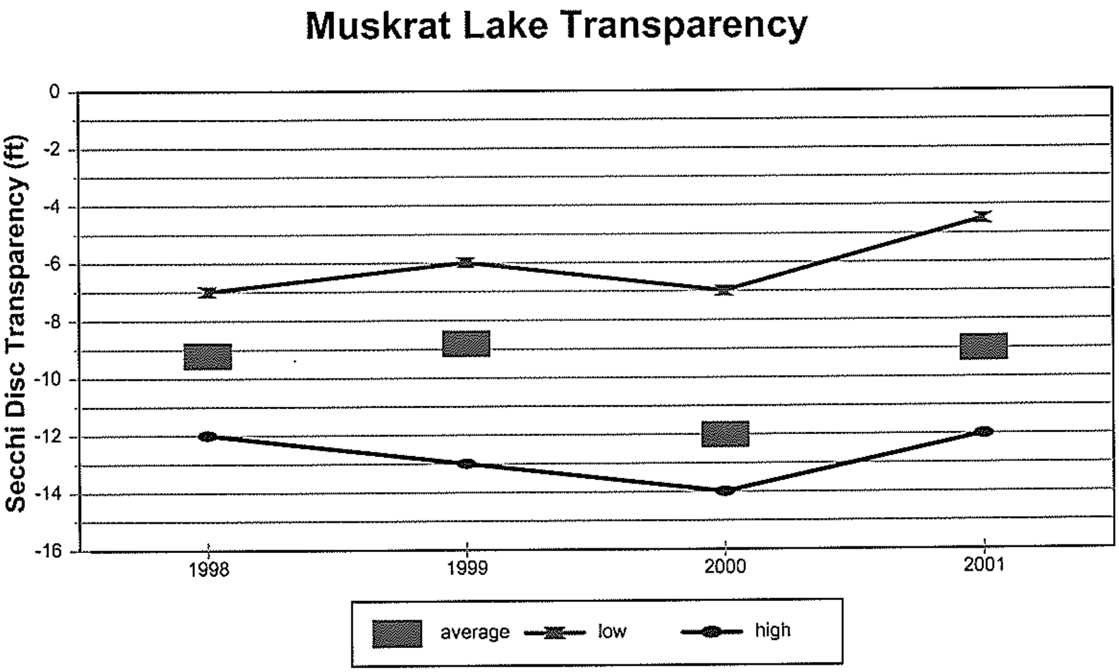

Figure 9. Muskrat Lake average summer transparency from 1998 through 2001.

8. Lake Sallie water clarity: [*Aeration should improve water quality in Muskrat, which in turn will improve water quality in Sallie.*] Lake Sallie water clarity has been slightly better in the aerated years of 2000 and 2001 compared to years from 1995-1999 (Figure 10). However, many factors have contributed to improved water clarity in 2000 and 2001.

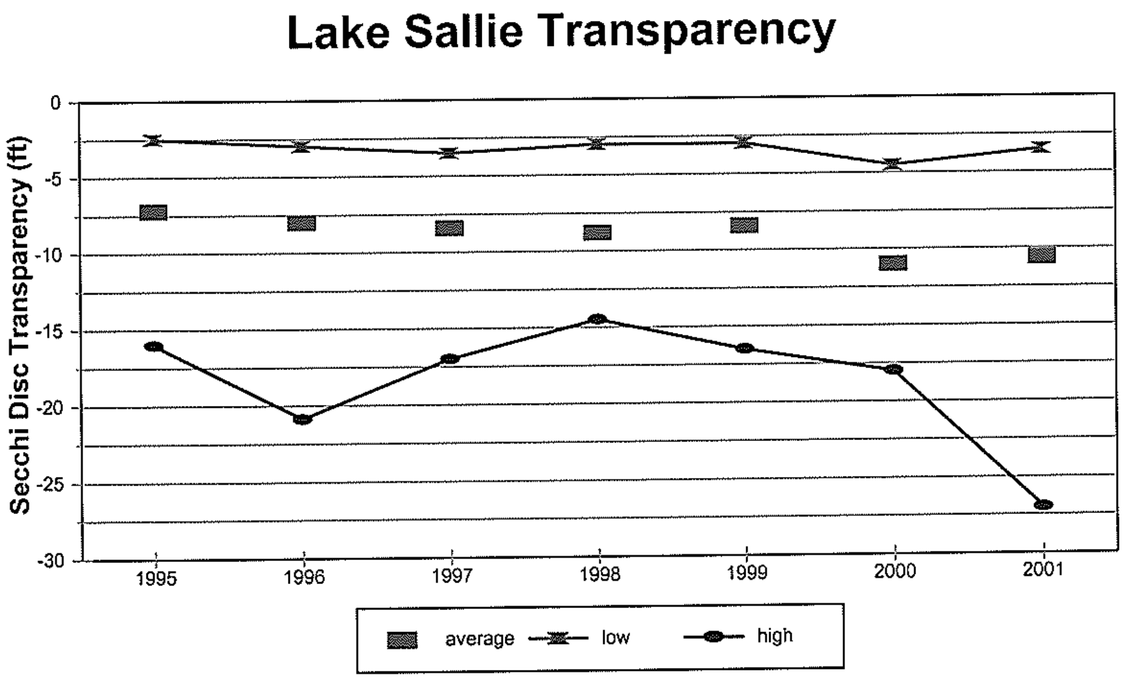

Figure 10. Lake Sallie average summer transparency from 1995 through 2000.

Conclusion

The impact of the Ditch 14 aeration system on reducing bioavailable phosphorus is inconclusive. It is difficult to assign Ditch 14 water quality improvements to the aeration system. We know we have not caused any adverse impacts, but our monitoring results have not isolated any improvements that could be attributed specifically to ditch aeration.

What's Next

Before abandoning the ditch aeration concept, it would be informative to place a submerged weir which would resemble an underwater ramp on the ditch bottom to force the bottom water up and then aerate it. If the bottom water can be aerated it should reduce phosphorus release from the bottom sediments as well as converting OP to an unavailable form of phosphorus.

The cost would be modest, around $100 - for materials, and 3 or 4 days of consulting time for installation, reconfiguration of the aeration system, and monitoring over June, July, and August.

Observations and Comments on the Ditch 14 Aeration Project for the Two Aerated Summers of 2000 and 2001

- The 2000 and 2001 summers may have been atypical. The two lowest nutrient loads recorded since records have been kept were recorded in 2000 and 2001.

- Ditch aeration may not have been totally efficient because there was DO present in the upper strata of the ditch water. Dissolved iron and orthophosphorus were at low levels in 2000.

- Laboratory analytical methods need to be reviewed. The method used for OP laboratory analysis lowers pH and may release phosphorus that is tied up with iron. The OP analytic method may have to be replaced with some other analysis.

- pH varies from 6 to 8 in the ditch. We are not as interested in iron-phosphate co-precipitation which is sensitive to pH as we are in iron-phosphate adsorption processes. Iron is in the solid form over a broad pH range. Redox is the more critical factor. Nighttime dynamics as well as the benthic boundary layer may be a big influence in phosphorus movement.

- Muskrat Lake is improving and at least six things may be contributing: 1) lower phosphorus load from St. Clair because of the alum treatment, 2) curlyleaf harvesting in Pelican River, 3) custom harvesting in Muskrat Lake for biomanipulation influences, 4) lower loads coming from Little Detroit Lake [PR6], 5) low flows in 2000 and 2001 may have resulted in lower nutrient loads, and 6) aeration system in Ditch 14 lowering bio-available phosphorus.

- Lake Sallie was slightly better in 2000 and 2001. This may be due to lower loads from Muskrat. The same six factors that contributed to improved water quality in Muskrat Lake may have had an influence in Lake Sallie.

The effectiveness of the ditch aeration system hinges on iron precipitation. Two iron pathways occur in the switch from anoxic to oxic conditions, which in turn affect the concentration of bioavailable phosphorus. In one pathway, soluble iron co-precipitates with phosphate, which inactivates phosphorus. This occurs over a wide pH range but requires a relatively high concentration of phosphate (over 100 ppb). This is considered to be the secondary phosphate removal mechanism. The primary removal mechanism is an adsorption process.

With the adsorption process, soluble iron is precipitated as iron hydroxide ($Fe(OH)_3$) when conditions transition from anoxic to oxic. This reaction occurs with a broad pH range (Figure 11). The iron hydroxide surface is "reactive" and anions, such as phosphate, will stick to it (adsorb to it). This is postulated to be the primary phosphate removal mechanism. The necessary pH conditions are found in Ditch 14 for the reaction to occur. However an additional variable that plays an undetermined role in the Ditch 14 setting is the dissolved organic carbon (DOC) parameter. DOC can interfere with iron precipitation by either complexing with soluble iron to prevent iron precipitation or by coating iron hydroxide particles and preventing phosphate adsorption. Algal bioassays conducted in 2001 to determine if phosphate was inactivated were inconclusive.

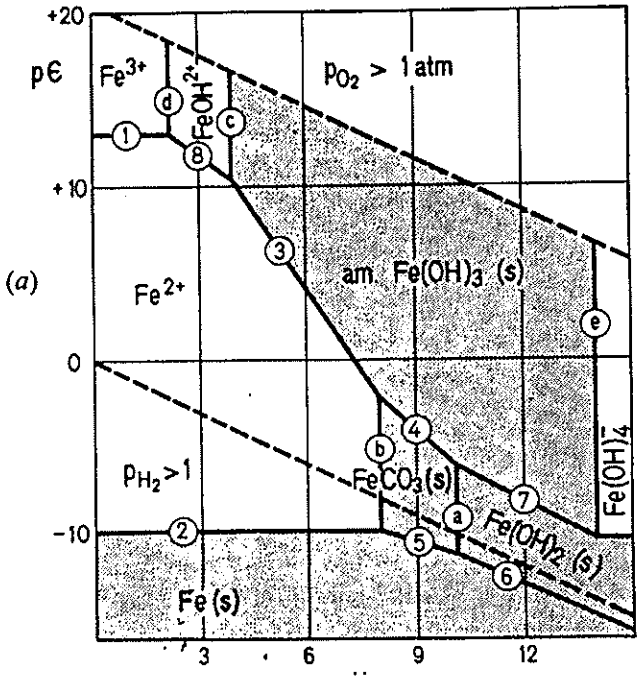

Figure 11. pε-pH diagrams for the Fe, CO_2 and H_2O systems (25°C). (a) Solid phases considered: amorphous Fe $(OH)_3$, $FeCO_3$ (siderite), Fe, $C_T = 10^{-3}$ M. (From: Stumm and Morgan, 1981. Aquatic Chemistry. Academic Press)

Conclusions of the Ditch Aeration System

From a thermodynamic and kinetic perspective, dissolved iron should precipitate in the ditch based on contact time. Previous, research sponsored by the Pelican River Watershed District in 1999 showed that an aerated wetland trench lowered TP and OP concentrations compared to unaerated areas in the wetland (Figure 12). However, water chemistry results in 2000 and 2001 that compared upstream to downstream iron and phosphorus values are inconclusive. There are no striking reductions in OP between upstream and downstream results. However, there are several water quality indicators that are positive such as reduced OP loads at SC4 and improvements in Muskrat Lake.

Results in 2000 and 2001 show orthophosphorus concentrations at SC4 are below the average of the years 1996, 1997, and 1998 (Figures 3 and 4). Most of the decrease is attributed to the alum treatment in Lake St. Clair in October 1998 and low flows for 2000 and 2001. However, OP values are even lower at SC4 in 2000 compared to 1999 from July through October (Figure 3). The 2000 and 2001 results may be influenced by the aeration system, but because there are many variables that impact OP at SC4, we can't assign the OP decrease to just the ditch aeration system.

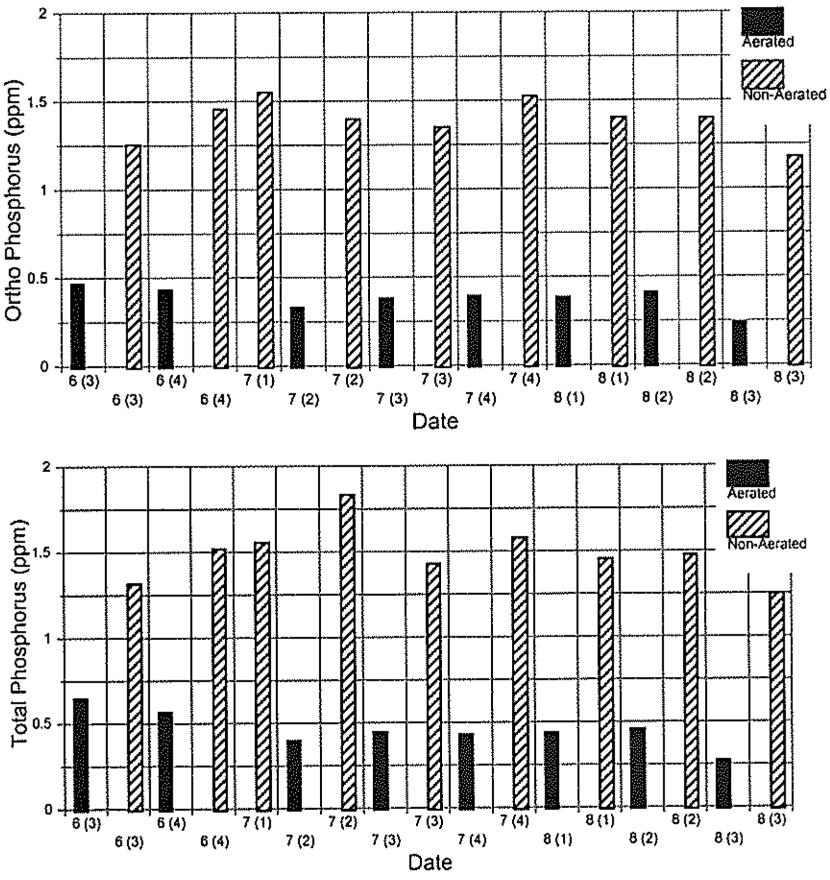

Figure 12. Comparison of aerated to unaerated groundwater results from a ditched wetland in the Detroit Lakes area. Results showed that aeration could reduce TP and OP concentrations in groundwater. Aerated results represent the mean of 10 wells and the unaerated results are the mean of 3 wells for each sample date. The week of the month is shown in parentheses. [from: McComas, S. 1999. Wetland aeration for phosphorus reduction: results of Ditch 14 summer projects. Prepared for Pelican River Watershed District.]

Proposed Aeration Activities and Monitoring for 2002

There is a large benefit if ditch aeration is effective at reducing soluble phosphorus to lakes from the view that it is inexpensive and ecologically sound compared to other options.

It seems premature to abandon aeration at this time especially when there is a new idea to test. The new idea is the installation of a submerged weir followed by the aeration diffusers. I would recommend another summer of using the aeration system, along with the installation of the structural component.

The weir will force the anoxic boundary layer up into the oxic region. To see if this is an improvement, obtain nighttime measurements above and below the aeration system and measure for DO, pH, redox, T Fe, Diss Fe, TP, and OP should take place. Six sample dates after the course of the summer would be helpful.

Future Options

If additional research finds that the ditch aeration technique is ineffective for reducing bioavailable phosphorus to Muskrat Lake and Lake Sallie, then "Plan B" may have to be considered. "Plan B" is an alternative to aeration that accomplishes the Watershed District's objective of lowering summertime phosphorus at the SC4 station. Several options that address nutrient reductions in the Ditch 14 wetland are described in Table 2.

Table 2. Options to consider for addressing Ditch 14 wetland phosphorus loading if ditch aeration turns out to be ineffective.

Options	Comment	Costs
1. Remove the floating mat of cattails near SC4 to create open water conditions and promote phosphate inactivation.	Cattail mat removal restores open water conditions in the wetland by SC4. Open water will be aerated naturally and may reduce OP concentrations. Also water retention time would probably be increased and some sedimentation would occur.	$40,000
2. Raise water levels in the wetland complex especially north of Highway 6.	Maintaining a pool in the wetland complex keeps conditions anoxic and, in the long term, reduces phosphorus export. It is tricky to maintain saturated conditions.	$80,000 (sheet pile dam and easements)
3. Impound water in Lake St. Claire to reduce summer flows.	Reducing summer flows in Ditch 14 would reduce nutrient loading. Installing a dam or water control structure at the Lake St. Claire outlet would give more storage in the lake and reduce summer flows to Ditch 14.	$110,000 (dam with water level control features)
4. Inject alum into wetlands.	Alum injection results at this time have been ineffective in other trials. Alum has to come into contact with phosphate to be effective. This is difficult to accomplish. Also, pH can drop in the peat which would solubilize aluminum.	$100,000
5. Add an alum dosing station that injects alum into the ditch. A sedimentation pond is needed to capture the floc before it reaches the Pelican River.	Several dosing stations are operating in Minnesota and several more in Florida. They remove about 50% of the soluble phosphorus. There is ongoing operation and maintenance costs. Also alum sludge production has to be dealt with. Dredging the sedimentation pond will be an additional cost.	$200,000 to $400,000 (includes cost of dredging a pond)
. No additional Ditch 14 projects are implemented. Tolerate existing conditions.	Maybe the alum treatment in Lake St. Claire sufficiently reduces nutrient loads to Muskrat Lake and wetland projects are unnecessary.	$0

APPENDIX

A. Summary of Ditch 14 observations from 1996-2001
B. Summary of monitoring data for 2001
C. Phosphorus analytic methods

APPENDIX A.
Summary of Ditch 14 observatins from 1996-2001

Recap of Ditch 14 Project Findings from 1996 through 2001

1996

PRWD staff and Blue Water Science found the following:

- Based on pump tests in wells, hydraulic conductivity ranged from 2.6 x 10^{-4} to 1.6 x 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 determine how much phosphorus was released from peat.

- In column A, initial phosphorus levels were high in July, then dipped in August, but then were high through September.
- In column B, initial phosphorus levels were high, but at the end of the experiment in September, phosphorus levels were low.
- We concluded that 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 in the columns at the beginning of the experiment, tested on June 1 were high. We suspect significant p-release already occurred.
- Over the next 40 days, 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. We also concluded aerating peat reduced porewater phosphorus concentrations.

1999

PRWD staff and Blue Water Science found the following:

- A small-scale wetland aeration trial was conducted 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.
- It was concluded that aerating wetland water can reduce phosphorus concentrations. However, it was not known how long it would take for that reaction to occur.
- A full-scale field trial using a ditch aeration system would be the best way to test the phosphorus inactivation potential of linear ditch aeration.

2000

PRWD staff and Blue Water Science found the following:

- A linear ditch aeration system was installed on June 21, 2000. Three 1-hp air compressors generating 30 cubic feet of air per minute delivered air to nine diffusers spaced over a length of 250 feet of ditch.
- Water samples were collected upstream and downstream of the aerator. In terms of phosphorus reductions, results were inconclusive.
- New monitoring approaches were recommended to evaluate the effectiveness of the ditch aeration system.

2001

PRWD staff and Blue Water Science found the following:

- The ditch aeration system was operated for a second summer. It operated throughout the summer without any major problems.
- Water samples were collected upstream and downstream of the aerator and in term of phosphorus reduction, results were inconclusive.
- 24-hour dissolved oxygen monitoring results showed that the bottom water in the ditch was not being aerated. It has been proposed for 2002 to install an underwater weir in the ditch bottom to force bottom water up into the water column so it can be aerated.

APPENDIX B.
Summary of monitoring data for 2001

Table A-1. Summary of monthly flows and phosphorus loads for SC3 for 1995-2001.

TOTAL PHOSPHORUS (pounds)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual (lbs)
1995	15	35	139	140	70	63	100	70	121	187			940
1996	101	166	193	318	152	64	29	21	22	27	36	23	1152
1997	42	72	75	368	82	66	196	71					972
1998					72	86	201	83	58	170	39	53	762
1999	30	24	49	88	89	72	50	61	46	35	24	18	586
2000	18	16	50	27	27	76	34	21	15	15	30	24	353
2001				60	76	31	29	17	14	20	39	14	300

ORTHO PHOSPHORUS (pounds)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual (lbs)
1996							13	13					26
1997					36	31	75	17					159
1998					31	26	84	21	5	26	13	33	239
1999	10	10	27	41	6	2	2	2	1	2	1	0	104
2000	6	7	13	5	4	12	11	4	3	4	8	6	83
2001				9	20	9	7	5	5	6	20	3	84

DISCHARGE (millions of cubic feet)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Total
1995	2.7	3.2	14.1	13.9	12	11.7	10.2	4.2	8.6	32.7			113.3
1996	14.6	13.5	11.9	25.3	20.5	12.1	5.7	3.4	2.9	5.1	8.5	7.4	130.9
1997	12.2	14.0	6.4	50.5	16.5	12.7	44.0	9.4					165.7
1998	6.6	5.6	16.0	16.0	13.7	21.9	39.4	7.3	4.3	19.4	14.8	15.9	180.9
1999	9.1	7.0	11.7	22.2	28.3	21.3	13.2	14.2	11.8	8.5	7.0	8.0	162.3
2000	7.9	7.2	17.9	12	8.6	21.7	16.8	4.5	5.6	6.9	16.1	15.7	140.6
2001				12	14.6	8.1	6.5	3.8	3.5	6.4	11.3	6.3	72.0

TOTAL PHOSPHORUS FLOW-WEIGHTED LOAD (pounds per million cubic feet)*

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Total
1995	5.6	10.9	9.9	10.1	5.8	5.4	9.8	16.7	14.1	5.7			8.3
1996	6.9	12.3	16.2	12.6	7.4	5.3	5.1	6.2	7.6	5.3	4.2	3.1	8.8
1997	3.4	5.1	11.7	7.3	5.0	5.2	4.5	7.6					5.9
1998					5.3	3.9	5.1	11.4	13.5	8.8	2.6	3.3	4.2
1999	3.3	3.4	4.2	4.0	3.1	3.4	3.8	4.3	3.9	4.1	3.4	2.3	3.6
2000	2.3	2.2	2.8	2.3	3.1	3.5	2.0	4.7	2.7	2.2	1.9	1.5	2.5
2001	0.0	0.0	0.0	5.2	5.2	3.8	4.5	4.5	4.0	3.1	3.5	2.2	4.2

ORTHO PHOSPHORUS FLOW-WEIGHTED LOAD (pounds per million cubic feet)*

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Total
1995													
1996							2.3	3.8					0.2
1997					2.2	2.4	1.7	1.8					1.0
1998					2.3	1.2	2.1	2.9	1.2	1.3	0.9	2.1	1.3
1999	1.1	1.4	2.3	1.8	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.0	0.6
2000	0.8	1.0	0.7	0.4	0.5	0.6	0.7	0.9	0.5	0.6	0.5	0.4	0.6
2001				0.8	1.4	1.1	1.1	1.3	1.4	0.9	1.8	0.5	1.2

* multiply "pounds per million cubic feet" by 16 to convert to micrograms per liter (ppb).

Table A-2. Summary of monthly flows and phosphorus loads for SC4 for 1995-2000.

TOTAL PHOSPHORUS (pounds)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual (lbs)
1995	47	43	188	200	69	186	102	114	44	65			1058
1996			299	504	317	413	120	60	53	45	66		1877
1997			49	469	308	337	359	133	101	87	45	49	1937
1998	108	89	102	152	117	199	413	178	124	189	56	73	1800
1999			75	132	214	159	161	194	104	45	25	26	1135
2000	4		46	40	56	148	174	66	28	17	42	20	641
2001	7	6	38	177	137	137	55	24	11	19	31	14	656

ORTHOPHOSPHORUS (pounds)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual (lbs)
1995													
1996							80	35	29	15	5		
1997			40	236	144	521	213	184	40	33	16	15	1442
1998	58	48	33	45	42	83	160	63	23	36	21	35	647
1999			32	67	91	108	57	58	39	24	14	17	507
2000	3		11	9	18	73	108	15	8	3	11	6	265
2001	6	7	25	89	34	100	36	5	4	6	23	4	339

DISCHARGE (millions cubic feet)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual (lbs)
1995	9.5	8.6	21.1	30.1	26.5	12.6	9.2	6.5	8.2	12.9			145.2
1996			17.1	35.8	38	25.1	9.7	6.2	5.3	7.9	14.3		159.4
1997			4.1	72.5	58.1	29.4	57.7	21.2	19.2	19.5	19	24.2	324.9
1998	29.2	20.3	23.7	24.6	24	41	58.3	25.5	8.9	22.8	25.8	25.2	329.3
1999			15.8	33.2	45.9	33.1	22.4	21.4	22	13.4	12.7	11.9	231.8
2000	1.8		12.5	16	20.5	27.9	30.2	12	6	6	18	13	163.9
2001	6.9	6.4	6.8	29	23.8	18.9	7.7	4.1	2.8	5.1	9.3	7.2	128.3

TOTAL PHOSPHORUS FLOW-WEIGHTED LOAD (pounds per million cubic feet)*

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual (lbs)
1995	4.9	5.0	8.9	6.6	2.6	14.8	11.1	17.5	5.4	5.0			7.3
1996			17.5	14.1	8.3	16.5	12.4	9.7	10.0	5.7	4.6		11.8
1997			12.0	6.5	5.3	11.5	6.2	6.3	5.3	4.5	2.4	2.0	6.0
1998	3.7	4.4	4.3	6.2	4.9	4.9	7.1	7.0	13.9	8.3	2.2	2.9	5.5
1999			4.7	4.0	4.7	4.8	7.2	9.1	4.7	3.4	2.0	2.2	4.9
2001	1.0	0.9	5.6	6.0	5.8	7.2	7.1	5.9	3.9	3.7	3.3	1.9	5.1

ORTHOPHOSPHORUS FLOW-\WEIGHTED LOAD (pounds per million cubic feet)*

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual (lbs)
1995													0.0
1996							8.2	5.6	5.5	1.9	0.3		0.0
1997			9.8	3.3	2.5	17.7	3.7	8.7	2.1	1.7	0.8	0.6	4.4
1998	2.0	2.4	1.4	1.8	1.8	2.0	2.7	2.5	2.6	1.6	0.8	1.4	2.0
1999			2.0	2.0	2.0	3.3	2.5	2.7	1.8	1.8	1.1	1.4	2.2
2000	1.7		0.9	0.6	0.9	2.6	3.6	1.3	1.3	0.5	0.6	0.5	1.6
2001	0.9	1.1	3.7	3.0	1.4	5.3	4.7	1.2	1.4	1.2	2.5	0.6	2.6

* multiply "pounds per million cubic feet" by 16 to convert to micrograms per liter (ppb).

APPENDIX C.
Phosphorus analytic methods

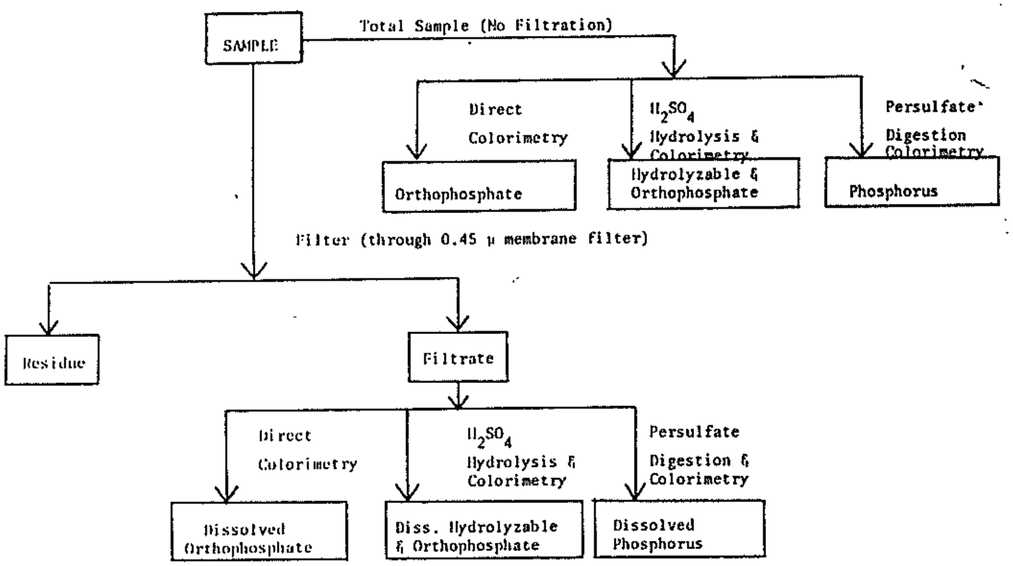

FIGURE 1. ANALYTICAL SCHEME FOR DIFFERENTIATION OF PHOSPHORUS FORMS

EPA 365.1

EPA Method 365.1

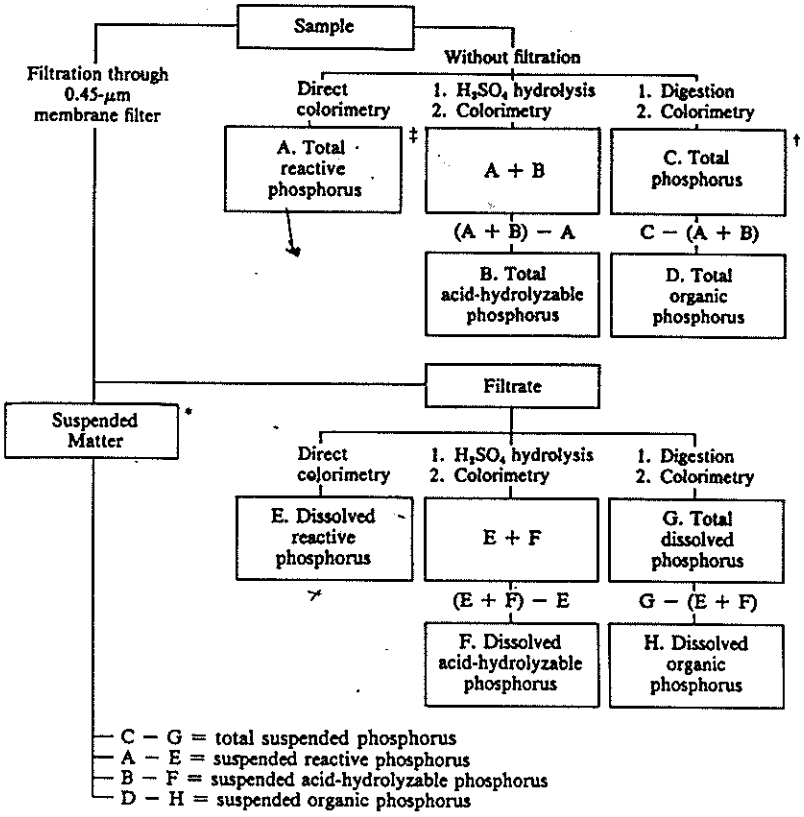

Figure 424:1. Steps for analysis of phosphate fractions.

Standard Methods 424

Analytical schemes for phosphorus fractions.

PHOSPHORUS, ALL FORMS

Method 365.1 (Colorimetric, Automated, Ascorbic Acid)

STORET NO. See Section 4

1. Scope and Application
   - 1.1 These methods cover the determination of specified forms of phosphorus in drinking, surface and saline waters, domestic and industrial wastes.
   - 1.2 The methods are based on reactions that are specific for the orthophosphate ion. Thus, depending on the prescribed pre-treatment of the sample, the various forms of phosphorus given in Figure 1 may be determined. These forms are defined in Section 4.
     - 1.2.1 Except for in-depth and detailed studies, the most commonly measured forms are phosphorus and dissolved phosphorus, and orthophosphate and dissolved orthophosphate. Hydrolyzable phosphorus is normally found only in sewage-type samples. Insoluble forms of phosphorus are determined by calculation.
   - 1.3 The methods are usable in the 0.001 to 1.0 mg P/1 range. Approximately 20–30 samples per hour can be analyzed.
2. Summary of Method
   - 2.1 Ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate complex. This complex is reduced to an intensely blue-colored complex by ascorbic acid. The color is proportional to the phosphorus concentration.
   - 2.2 Only orthophosphate forms a blue color in this test. Polyphosphates (and some organic phosphorus compounds) may be converted to the orthophosphate form by manual sulfuric acid hydrolysis. Organic phosphorus compounds may be converted to the orthophosphate form by manual persulfate digestion(2). The developed color is measured automatically on the AutoAnalyzer.
3. Sample Handling and Preservation
   - 3.1 If benthic deposits are present in the area being sampled, great care should be taken not to include these deposits.
   - 3.2 Sample containers may be of plastic material; such as cubitainers, or of Pyrex glass.
   - 3.3 If the analysis cannot be performed the same day of collection, the sample should be preserved by the addition of 2 ml conc. H_2SO_4 per liter and refrigeration at 4°C.
4. Definitions and Storet Numbers
   - 4.1 Total Phosphorus (P) – all of the phosphorus present in the sample regardless of form, as measured by the persulfate digestion procedure. (00665)
     - 4.1.1 Total Orthophosphate (P-ortho)–inorganic phosphorus $[(PO_4)^{-3}]$ in the sample as measured by the direct colorimetric analysis procedure. (70507)

Approved for NPDES
Issued 1971
Editorial revision 1974 and 1978