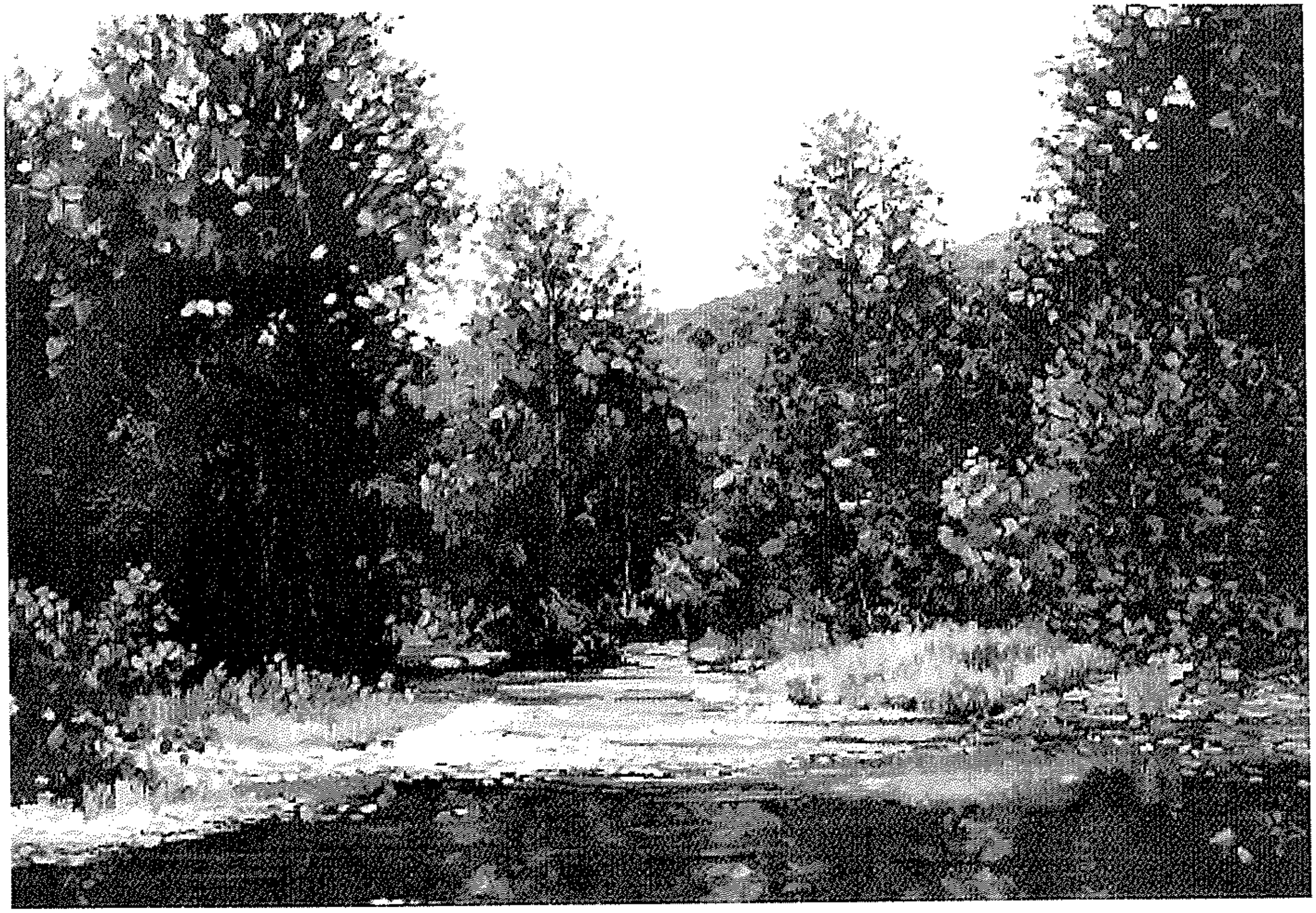


Donald S. Lewis, Jr: *Jackson River*, 1998

Wetland Ditch Aeration for Phosphorus Inactivation in Ditch 14, Pelican River Watershed District, Minnesota

April 2001

Prepared for:
Pelican River Watershed District
Detroit Lakes, Minnesota

Prepared by:
Steve McComas
Blue Water Science
St. Paul, MN
651.690.9602

Wetland Ditch Aeration for Phosphorus Inactivation in Ditch 14, Pelican River Watershed District, Minnesota

Summary

Questions Addressed in Ditch 14 Work for 2000

1. Will an aeration system work in the ditch or will it sink into the peat?
2. Does the aeration system reduce bioavailable phosphorus in Ditch 14?

What We Found

1. The ditch aeration system was installed in one day and operated without major problems from June 21 to the end of September. The diffusers did not sink into the peat. Full air flow was delivered to the ditch water.
2. Monitoring results comparing upstream to downstream iron and phosphorus values were inconclusive. There were no striking reductions in phosphorus from the upstream to the downstream monitoring stations. However, there were several positive water quality improvements observed in Muskrat Lake, which is downstream of the aeration system. Muskrat Lake improvements cannot be attributed to the aeration system because of other variables involved.

What Is Next

Another summer of monitoring is recommended. To address the question of possible bioavailable phosphorus reductions from aeration, an algal bioassy along with special phosphorus testing is recommended. Also, monitoring at night would be informative to see if conditions change from daylight to night time. Another summer of monitoring would allow us to check aeration effectiveness with a different set of hydrologic and nutrient conditions. Flows and nutrient loads were below average in 2000 and 2001 is expected to have higher flows.

Aeration system in operation in Ditch 14. A wall of bubbles perpendicular to the flow was created.

Recap of Ditch 14 Project Findings from 1996 through 2000

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. We suspect significant p-release already occurred.
- 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

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.

Background Information on Wetland Ditch Aeration

- Wetlands can be a source of phosphorus.
- When wetlands are ditched, phosphorus export is facilitated.
- Wetland porewater in the Detroit Lakes watershed has high concentrations of ortho phosphorus and dissolved iron.
- 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. This is the proposed mechanism to explain increasing summer phosphorus concentrations in Ditch 14.
- 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.
- 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.

Methods

The project location is shown in 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 Figures 2 through 5. The configuration of the aeration system as it was installed on June 20, 2000 is shown in Figure 6.

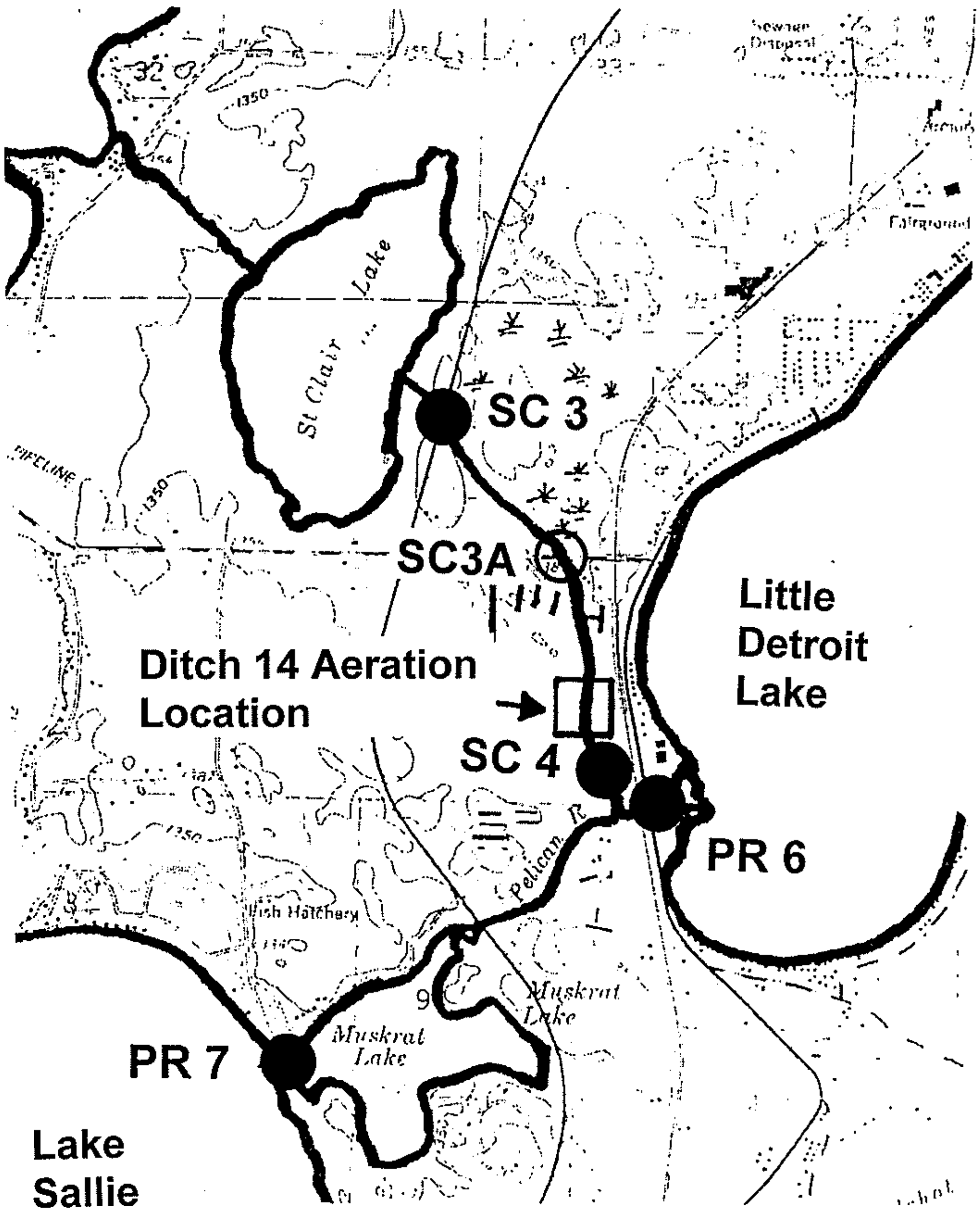


Figure 1. Location of the Ditch 14 aeration system and monitoring stations. The primary monitoring stations were at the outlet of Lake St. Clair (SC3) and the outlet of Ditch 14 (SC4). Some measurements were taken at SC3A.

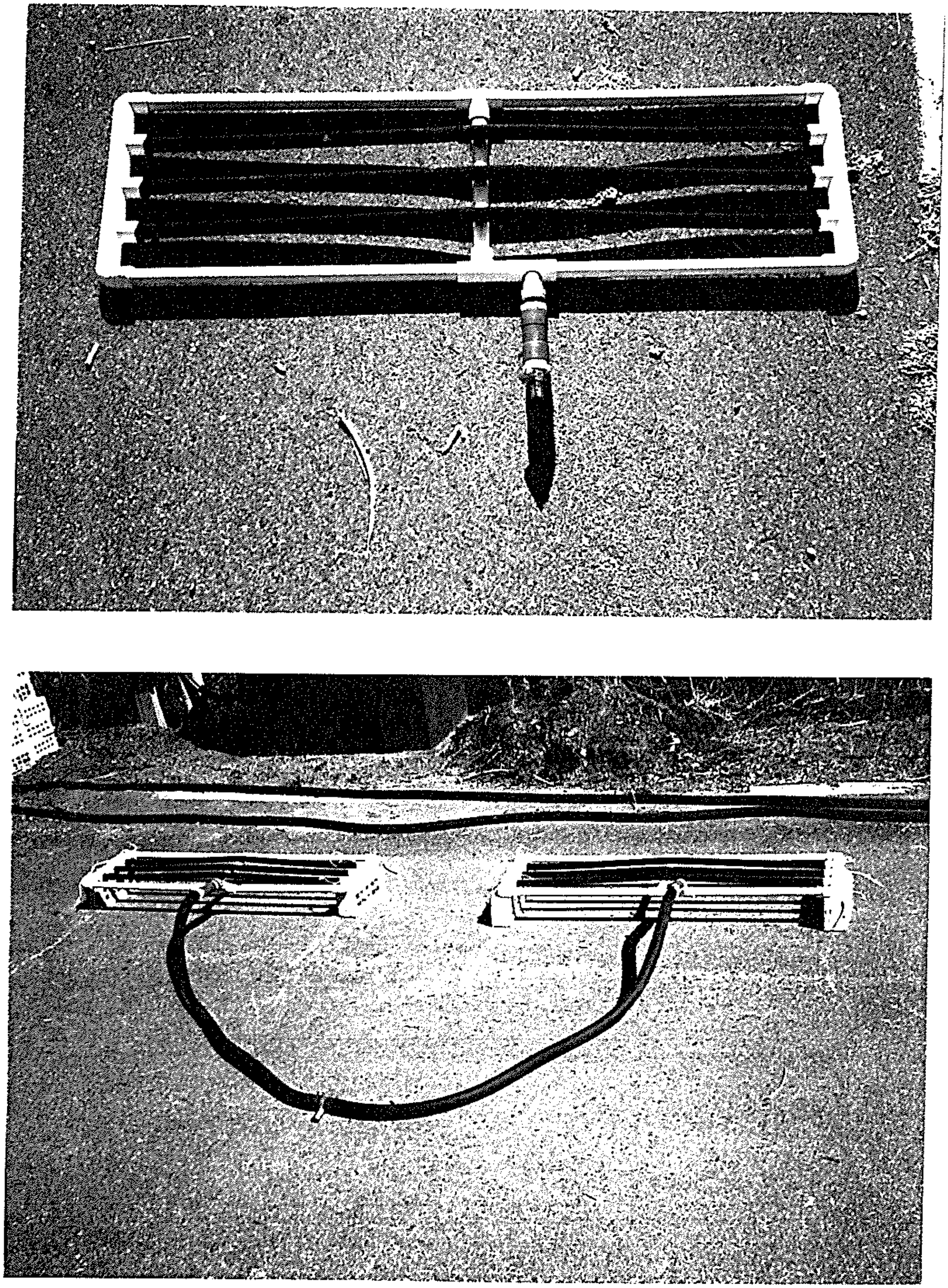


Figure 2. [top] Single diffuser head.
[bottom] Two diffuser heads set up in parallel.

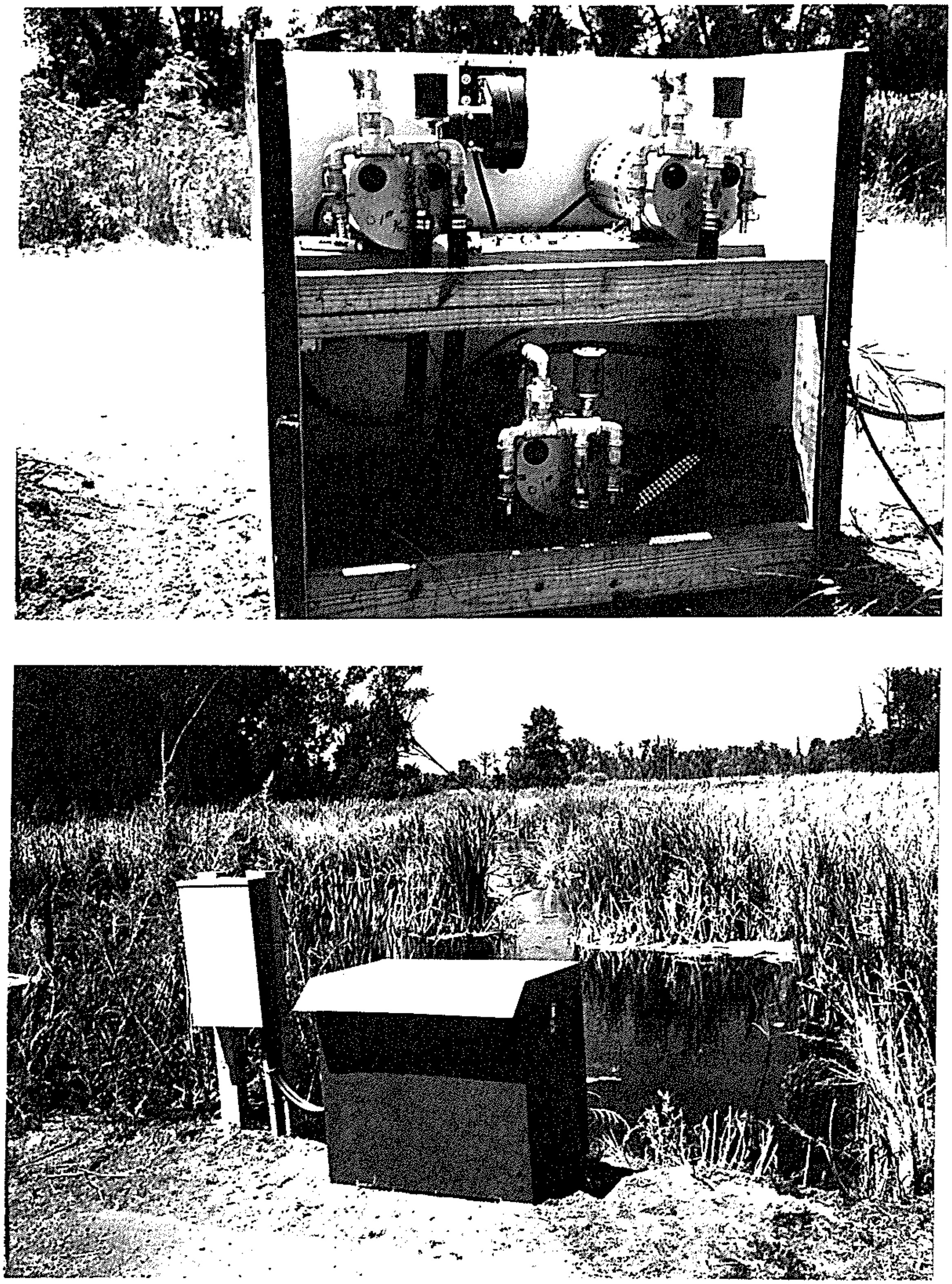


Figure 3. [top] Three 1-hp air compressors delivered air to nine diffuser heads. [bottom] Compressor housing and 220-volt service to the compressors.

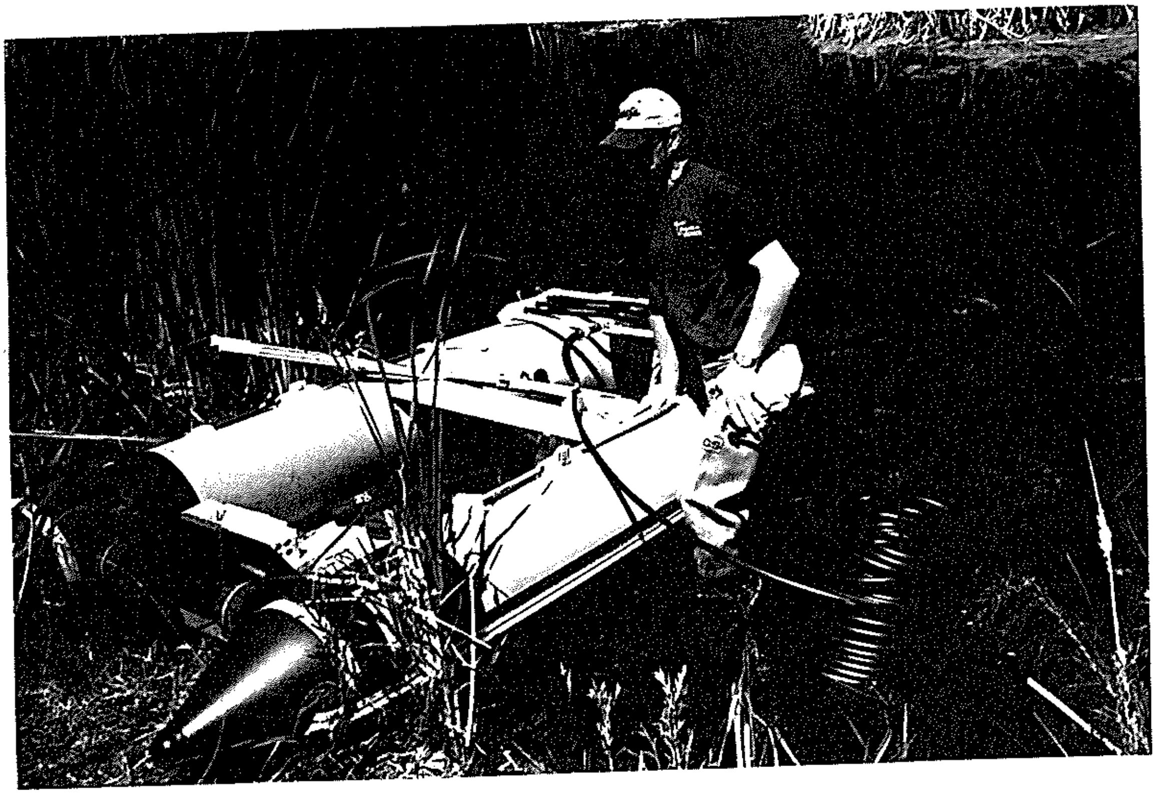


Figure 4. An inflatable boat was used to deliver the diffusers along the ditch bed. Water depth was about 4 feet.

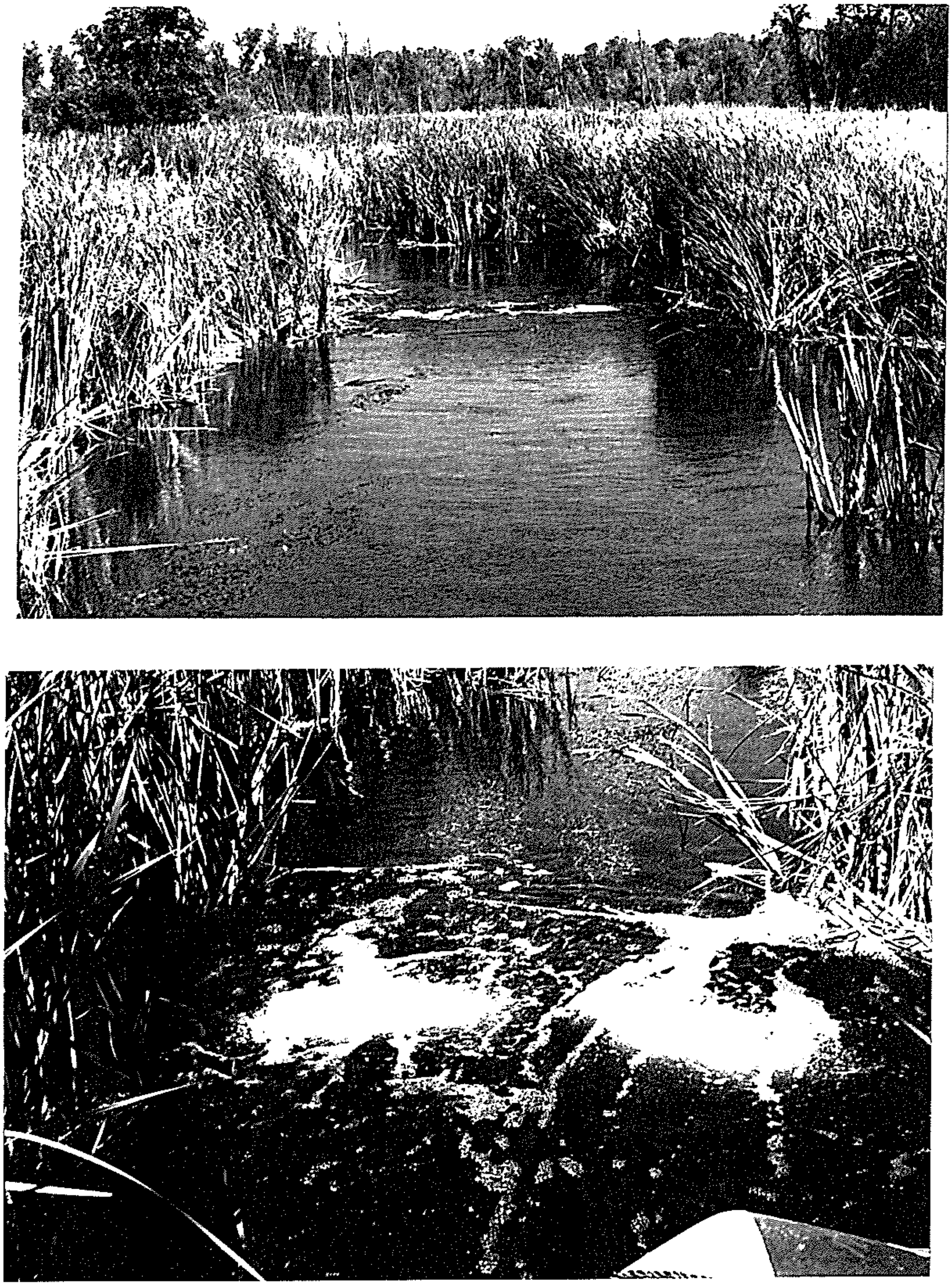


Figure 5. Diffusers in place and bubbling. Ditch channel was fairly well defined.

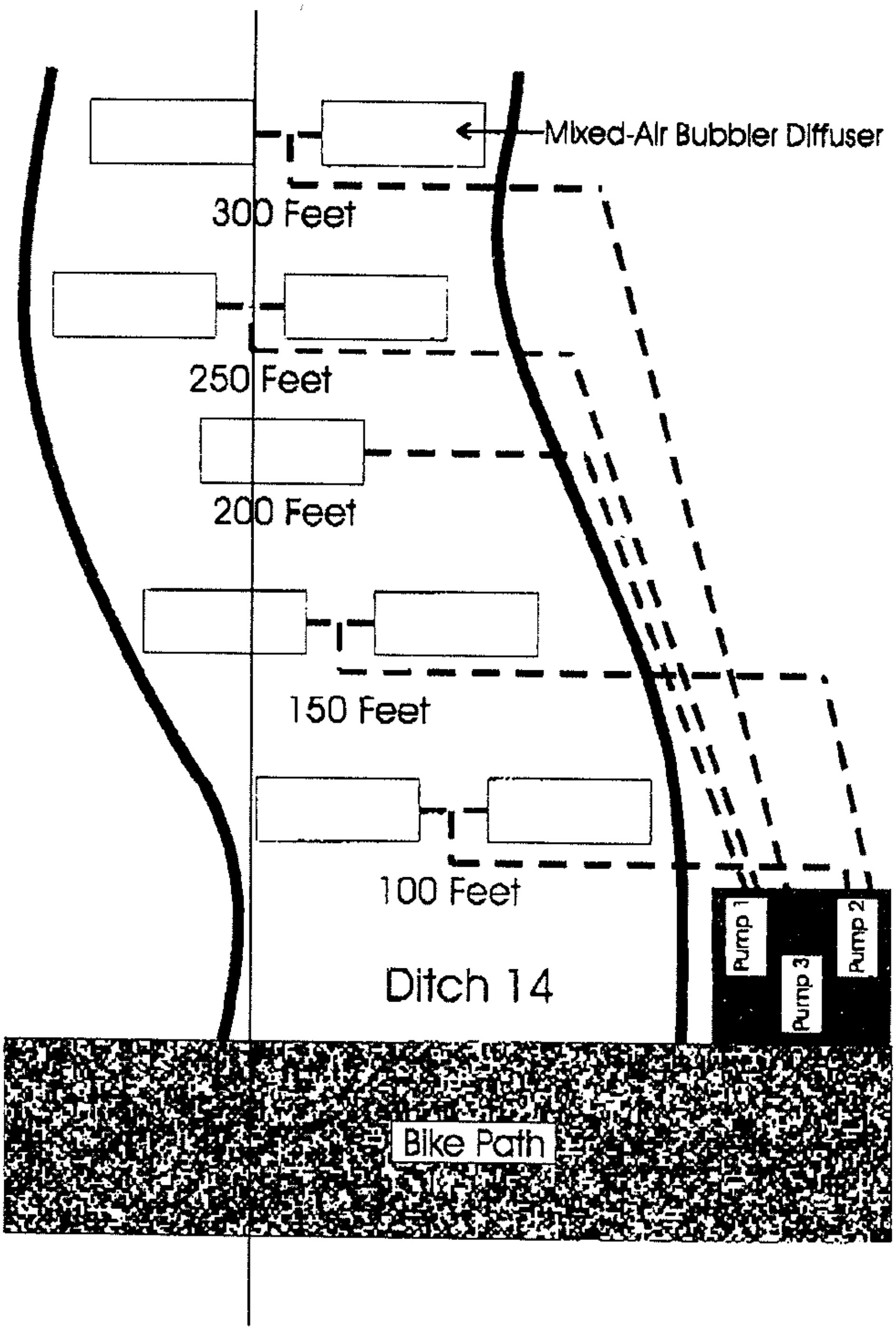


Figure 6. Configuration of diffuser installation. Air was supplied by three 1-hp compressors.

Results

The Ditch 14 aeration system began operation on June 20, 2000 and ran nearly continuously till the end of September 2000. 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.

Individual data points for two sample dates are shown in Table 1. Total iron concentrations were low on the two sample dates in 2000. Also dissolved oxygen was present at all sample dates at SC3A which is above the aeration system. We did not monitor dissolved oxygen (DO) on a diurnal basis.

Data summaries for stations SC3 (upstream) and SC4 (downstream) are shown in Tables 2 and 3. A summary of monthly flows and phosphorus loading since 1995 is shown for the upstream station (SC3) in Table 2 and downstream station (SC4) in Table 3. Low phosphorus loads from both SC3 and SC4 were recorded in the last 2 years (1999 and 2000). The alum application is responsible for some of the reduction, but flow weighted loads were lower in 2000 than 1999 at SC4.

Table 1. Results for several water chemistry parameters. SC3A is upstream of the aeration system and SC4 is downstream.

	TOC (mg/l)	DOC (mg/l)	Total Iron (μg/l)	Dissolved Iron (μg/l)	Calcium (mg/l))	pH	TP (μg/l)	OP (μg/l)
7.20.00								
SC3A	7.1	6.95	100	--	58.0	7.86	--	--
SC3A-rep	7.3	6.95	120	--	59.0	--	--	--
SC4	7.6	7.50	190	--	58.0	8.00	--	--
SC4-rep	7.2	7.20	180	--	60.0	--	--	--
8.24.00								
SC3A	11.3	11.1	180	29	--	--	76	15
SC3A-rep	11.7	10.9	170	27	--	--	76	7
SC4	11.5	10.7	160	30	--	--	79	10
SC4-rep	11.6	10.2	180	32	--	--	76	15

Summer orthophosphorus concentrations at station SC4 for the last several years are graphed in Figures 7 and 8.

Table 2. Summary of monthly flows and phosphorus loads for SC3 for 1995-2000.

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

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

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

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

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

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

Table 3. 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

ORTHOPHOSPHORUS (pounds)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual
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

DISCHARGE (millions cubic feet)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual
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

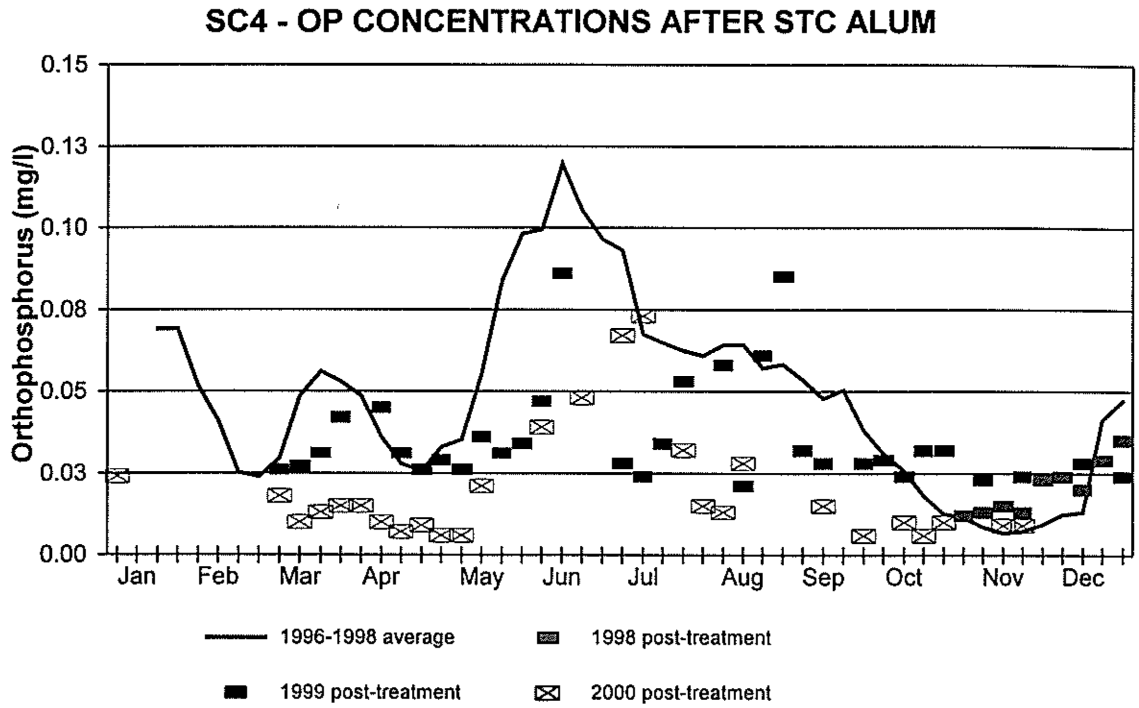
TOTAL PHOSPHORUS FLOW-WEIGHTED LOAD (pounds per million cubic feet)*

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual
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

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

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual
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

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



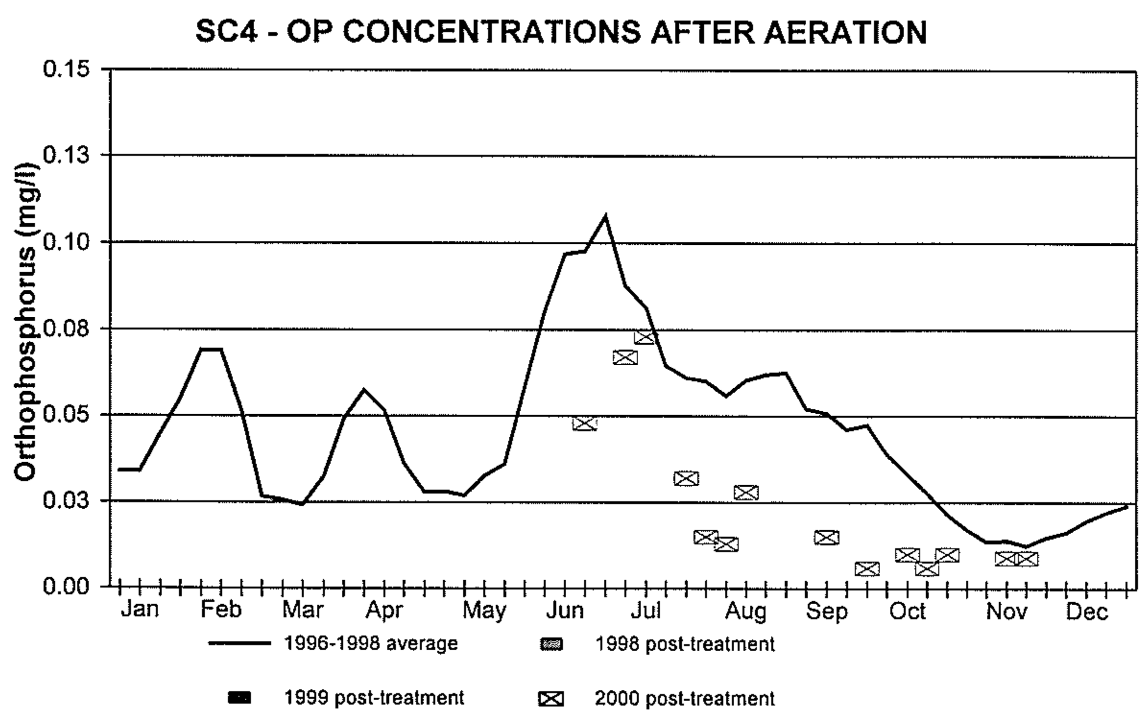


Figure 7. [top] OP concentrations for 1996 through 2000 at SC4. Alum was added to Lake St. Clair in October 1998.
Figure 8. [bottom] Average of OP concentrations for 1996-1998 are shown with the solid line and OP concentrations in 2000 are shown with a square.

Muskrat and Sallie Lakes: The overall objective of water quality improvements in the Lake Sallie watershed is to improve water quality in Lake Sallie. If water quality improvements in both Muskrat and Sallie are occurring they are subtle. Water transparency in Muskrat Lake appears to be better in 2000 compared to 1998 (Table 4). Also Lake Sallie had slightly improved water transparency in 2000 compared to a 5-year average from 1995-1999 (Figure 9).

Table 4. Muskrat Lake water quality for the summer growing season (June -August).

	1998	1999	2000
Secchi disc (ft)	8.8	8.4	11
Total phosphorus (ppb)	56	34	31
Orthophosphorus (ppb)	23	10	15
Depth (ft) where DO < 2.0 mg/l	9	13	14

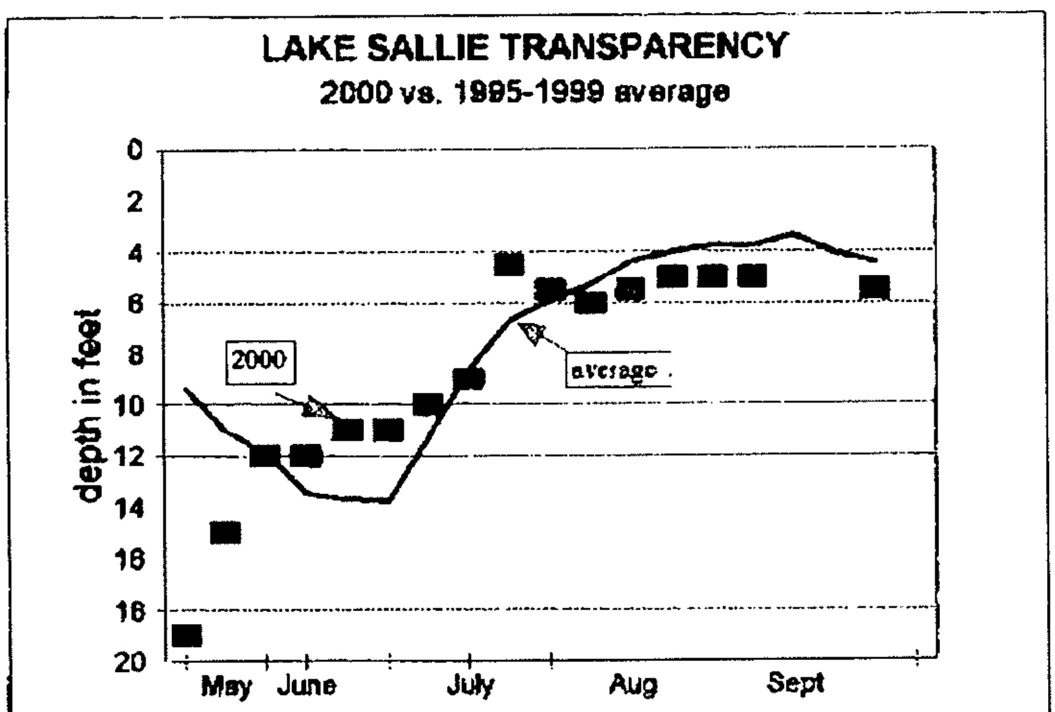


Figure 9. Lake Sallie from 1995 through 2000.

Observations and Comments on the Ditch 14 Aeration Project for 2000

- The 2000 summer may have been atypical. The lowest nutrient loads recorded since records have been kept were recorded in 2000.

- Ditch aeration may not have been efficient because there was DO present in the ditch water and dissolved iron and orthophosphorus were at low levels.

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

- pH may be above 7 and even 8 in the ditch, but is not a factor. We are not as interested in iron-phosphate co-precipitation which is sensitive to pH as we are in iron-phosphate adsorption processes (see charts on the next two pages) Iron is in the solid form over a broad pH range. Redox is the more critical factor. Nighttime dynamics may be a big influence in phosphorus movement, but we don't have monitoring for that period.

- 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 may have resulted in lower nutrient loads, and 6) aeration system in Ditch 14 lowering bio-avaible phosphorus.

- Lake Sallie was slightly better in 2000. 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. With one pathway, soluble iron co-precipitates with phosphate, which inactivates phosphorus. This occurs under a narrow pH range and relatively high concentration of phosphate (over 100 ppb) is needed (Figure 10). This is considered to be the secondary phosphate removal mechanism. The primary removal mechanism is an adsorption process.

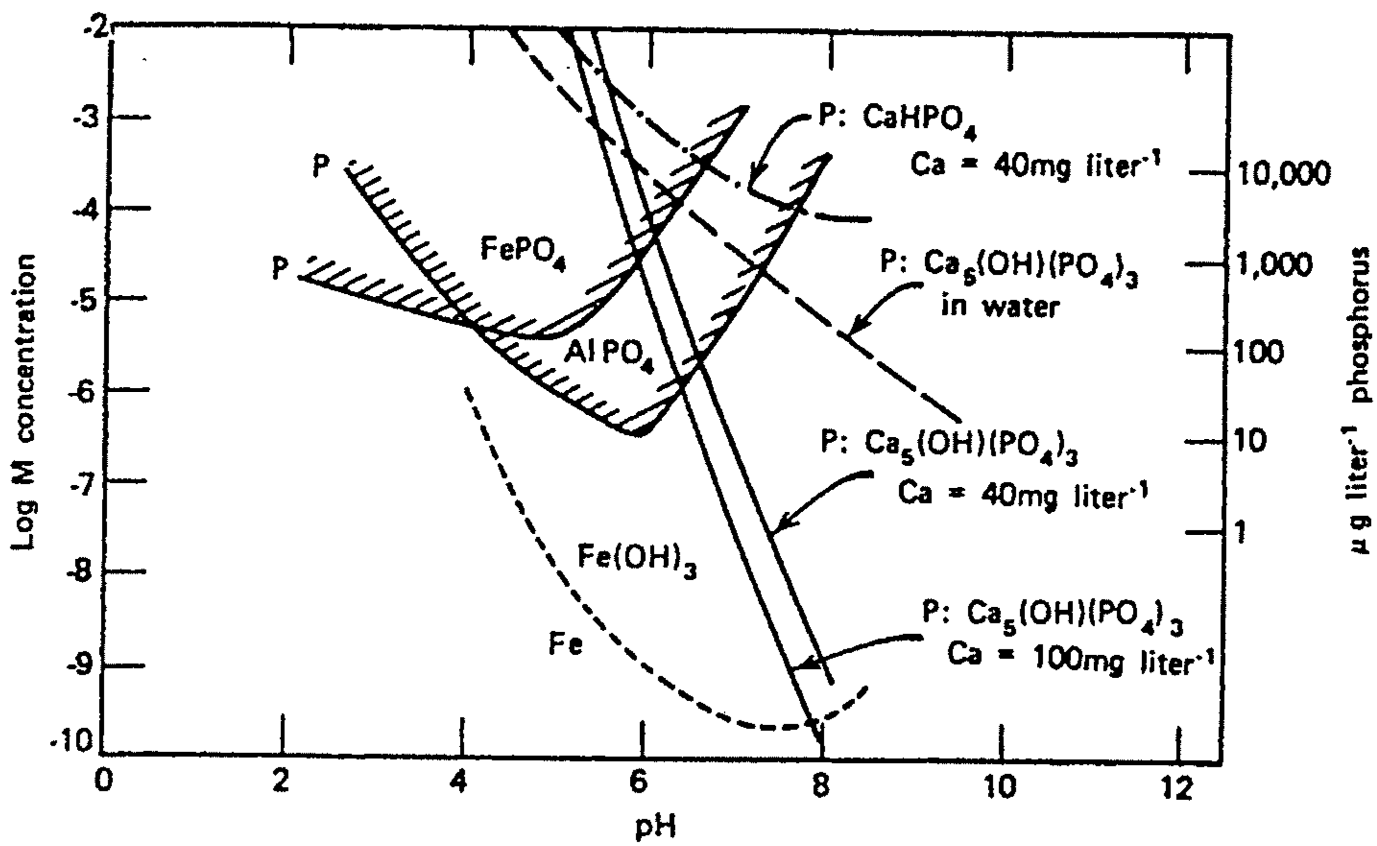


Figure 10. Solubility of metal phosphorus as a function of pH diagram from Nustad, R. 2000. Use of Aeration to Reduce Orthophosphate Concentrations in Ditch 14. Submitted to PRWD, May 2000.

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 could help determine is phosphate if being inactivated.

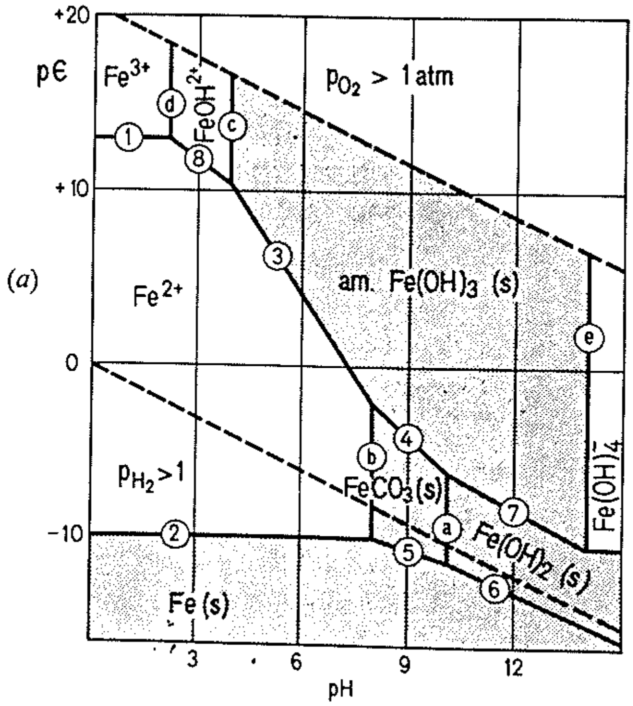


Figure 11. pε-pH diagrams for the Fe, CO_2 and H_2O systems (25°C). (a) Solid phases considered: amorphous Fe $(OH)_3$, $FeCO_3$ (siderite), Fe, $C_T = 10^{-3}$ M. (From: Stumm and Morgan, 1981. Aquatic Chemistry. Academic Press)

Conclusions of the Ditch Aeration System

From a thermodynamic and kinetic perspective, dissolved iron should precipitate in the ditch based on contact time. In addition, 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 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 show orthophosphorus concentrations at SC4 are below the average of the years 1996, 1997, and 1998 (Figures 7 and 8). Most of the decrease is attributed to the alum treatment in Lake St. Clair in October 1998. However, OP values are even lower at SC4 in 2000 compared to 1999 from July through October (Figure 7). The 2000 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. There appears to be a weak correlation between aeration contact time and the OP flow weighted load (Table 3). As contact time increases, the OP flow weighted load decreased (Figure 8 and Table 3).

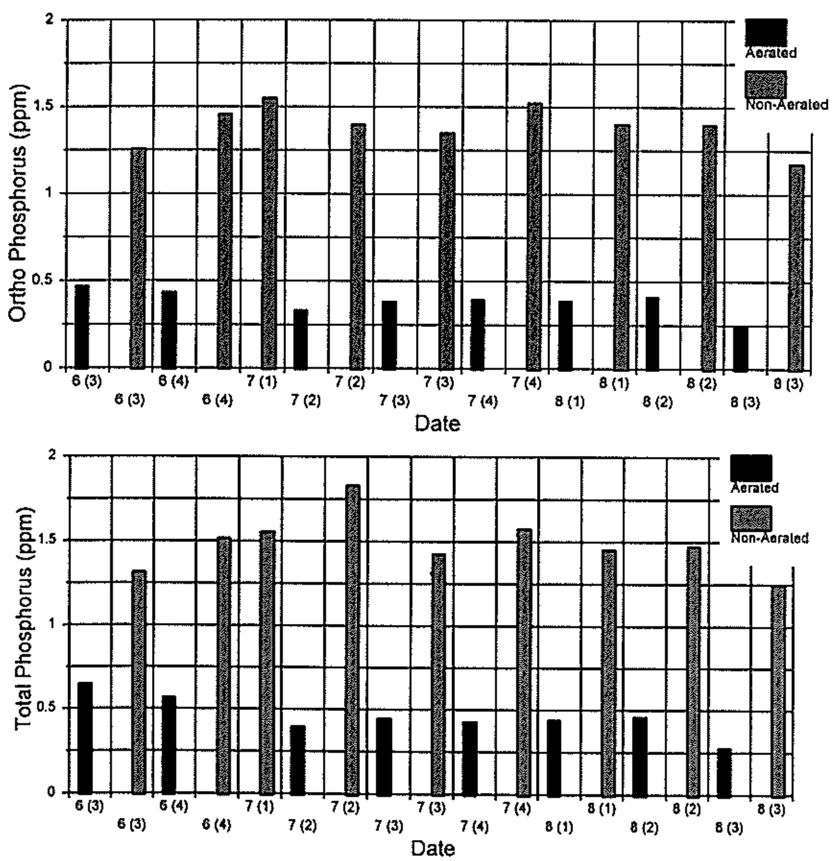


Figure 12. Comparison of aerated to unaerated groundwater results from a ditched wetland in the Detroit Lakes area. Results showed that aeration could reduce TP and OP concentrations in groundwater. Aerated results represent the mean of 10 wells and the unaerated results are the mean of 3 wells for each 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 2001

I would recommend another summer of using the aeration system, but employ some monitoring changes.

- Consider adding a 100-foot extension to the aeration system to increase the length of the aeration system to about 350 feet which would increase contact time.
- Obtain nighttime measurements above and below the aeration system and measure for DO, pH, redox, T Fe, Diss Fe, TP, and OP. Ten sample dates after the course of the summer would be helpful.
- Conduct algal bioassays in June, July, and August on water collected above and below the aeration system. Collect water during the nighttime period. Results would give an indication if bioavailable phosphorus was being activated by the aeration system. We would predict there would be more algal growth in the upstream water than in the downstream water.
- Use iron-coated paper strips to test for bioavailable phosphorus. Iron coated paper has been used to evaluate bioavailable phosphorus in rural runoff settings. Steve McComas has experience with this technique from a previous project (McComas, S. 1994. Diamond Lake Management Plan, Kandiyohi County).
- Set-up settling tests to characterize what is settling out of solution after the ditch water is aerated. This will give some insight to the material that could settle out in Muskrat Lake or Lake Sallie. The settleable material should be analyzed for bioavailable phosphorus.

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" really means what are other options that could accomplish the Watershed District's objectives. Several options that address nutrient reductions in the Ditch 14 wetland are described in Table 5.

Table 5. Options to consider for addressing Ditch 14 wetland phosphorus loading if ditch aeration turns out to be ineffective.

Options	Comment	Costs
1. 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
2. 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)
3. 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)
4. Lower water levels in the wetland complex.	Additional ditching in the wetland would be needed as well as diverting stormwater inflows. In a worst case, a dam would be installed at SC4 and water pumped into the Pelican River.	$30,000 (does not include stormwater diversion or pumping costs)
5. 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)
6. 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
7. 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

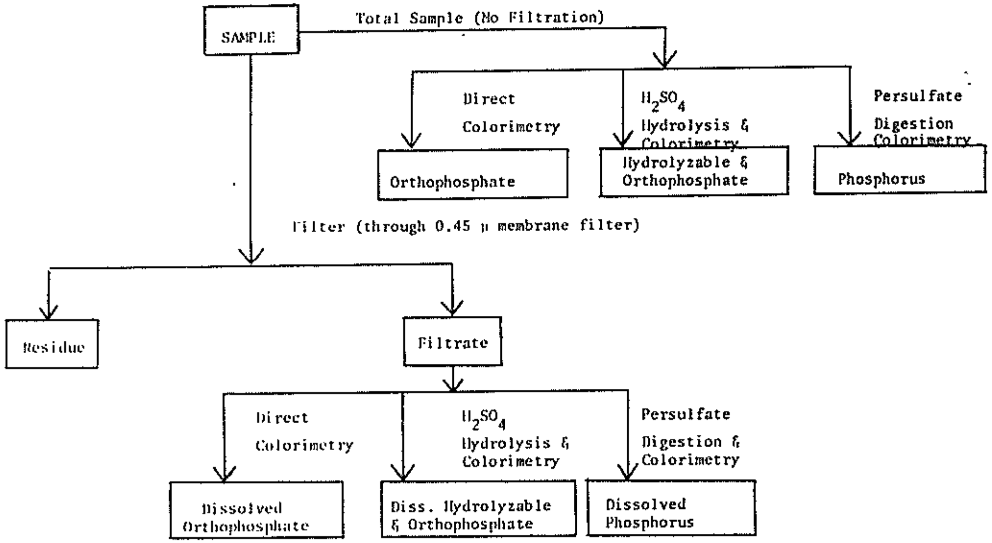


FIGURE 1. ANALYTICAL SCHEME FOR DIFFERENTIATION OF PHOSPHORUS FORMS

EPA 365.1

EPA Method 365.1

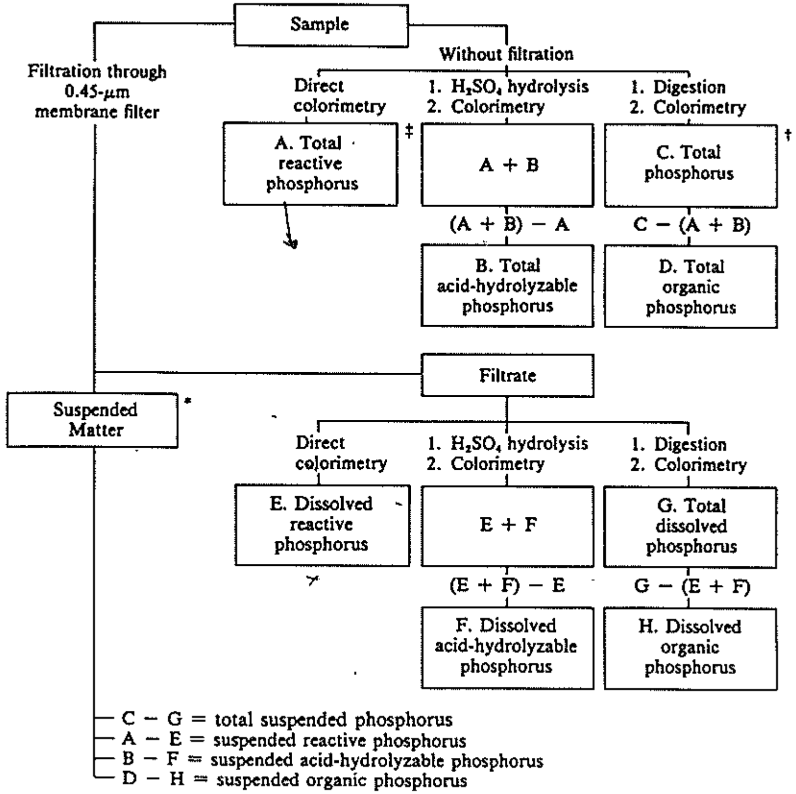


Figure 424:1. Steps for analysis of phosphate fractions.

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