OSGOOD CONSULTING

Lake Mitchell / Firesteel Creek Water Quality Improvement Project

Final Progress Report on the 2003-2005 Alum Demonstration Project

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INTRODUCTION

Lake Mitchell has been plagued with severe blue-green algae problems for a long time. To address this problem, the City of Mitchell conducted a diagnostic-feasibility study (Stueven and Scholtes 1997). This study recommended a comprehensive watershed restoration program, which is being implemented by the Davison Conservation District, through a '319 grant' from the South Dakota Department of Environment and Natural Resources. Early in that ten-year program, it became apparent that significant improvements in Lake Mitchell's water quality would not occur for a long time. Thus, the City of Mitchell retained Dick Osgood to evaluate and recommend management alternatives that would mitigate the algae nuisances in the short-term. That study (Osgood and Nürnberg 2001; Nürnberg and Osgood 2001) recommended annual alum applications.

The City of Mitchell, working with the Davison Conservation District, applied for and received an amendment to the 319 grant which provided supplemental funding to implement the alum treatments. Specifically, this project involved three annual alum applications, the partial recommended overall dose, and evaluated the interim results to provide recommendations for ongoing alum applications to Lake Mitchell. This document reports the results of the three year (2003, 2004 & 2005) alum demonstration project and recommends future treatment options.

PROJECT BACKGROUND

Lake Mitchell was created in 1928 by damming Firesteel Creek. Firesteel Creek drains a very large agricultural watershed and provides practically all of the water supply to Lake Mitchell. The lake has experienced water quality problems for a long time, probably since it was created. Efforts to mitigate water quality concerns have been more recent.

The alum demonstration project, the subject of this report, has occurred in a larger context of the overall management of Lake Mitchell's water quality.

A. Firesteel Creek/Lake Mitchell Water Quality Study

The South Dakota Department of Water and Natural Resources conducted a study of Firesteel Creek and Lake Mitchell during 1981 – 1983 (SDDWNS 1985). This study noted 'large populations of algae' and classified the lake as 'hypereutrophic.' The study found 'dangerously' high loads of phosphorus and nitrogen entering the lake via Firesteel Creek, as well as excessive fecal coliform levels. The study recommended reducing nutrient loading to the lake with Best Management Practices (BMPs), including fertilizer management, conservation tillage, proper grazing use, feedlot waste management systems, and vegetative barriers strips. It is not know whether or to what extent watershed BMPs were implemented at that time.

Following the implementation of the recommended watershed BMPs, the report recommended selective dredging in the lake as well as chemical phosphorus flocculation (alum applied every one to three years) in Lake Mitchell.

B. Diagnostic-Feasibility Study

A Phase I diagnostic-Feasibility Study, prepared by the South Dakota Watershed Protection Program, was conducted from 1993 – 1995 (Stueven & Scholtes 1997). The objectives of the study were to:

- Evaluate and quantify nonpoint source (NPS) yields from each subwatershed and determine the net loading (of pollution) to Lake Mitchell;
- Define critical NPS cells within each subwatershed (elevated sediment, nitrogen, phosphorus); and
- Prioritize and rank each concentrated feeding area and quantify the nutrient loading from each feeding area.

The study found:

- Overall sediment loading to Lake Mitchell was low, and result in one foot of sediment accumulation in the lake every 61 years;

- Nutrient loadings to Lake Mitchell were high – 166 tons of nitrogen and 63 tons of phosphorus annually.

- Lake Mitchell was highly enriched with phosphorus, at least ten times the level needed to support algae blooms.

- At least 116 animal feeding operation contributed to excess phosphorus loading to the lake.

The study recommended the implementation of BMPs, specifically targeted to the priority animal feeding areas, the diversion of three storm sewer outlets through settling basins, and several other restoration alternatives.

A ten-year Lake Mitchell / Firesteel Creek Watershed Water Quality Improvement Project, designed to implement recommendations of the diagnostic-feasibility study, is currently underway.

C. Alum Evaluation & Recommendations

In the midst of the Lake Mitchell / Firesteel Creek Watershed Water Quality Improvement Project, the City of Mitchell sponsored a study to evaluate alum applications to Lake Mitchell to address lake quality improvements in the short-term (Osgood & Nürnberg 2002; Nürnberg & Osgood 2002). This study was to:

- Evaluate lake and watershed conditions;
- Develop appropriate water quality goal;
- Conduct field studies;
- Develop a water quality model; and
- Design an alum treatment system implementation plan.

Based on this study, alum was recommended as the only feasible short-term solution to mitigate nuisance blue-green algae blooms in Lake Mitchell. Specifically, a three-phase alum demonstration project was recommended:

Phase One The diagnostic evaluation (Osgood & Nürnberg 2002; Nürnberg & Osgood 2002)

Phase Two Initial project implementation (the three-year demonstration, this project)

Phase Three Ongoing operation

The three-year alum demonstration project (Phase Two) was designed to address the dual needs of a) providing successive, partial sediment alum doses and b) demonstrating the effectiveness of alum as a water column phosphorus control measure. This demonstration was to be used to refine the ongoing alum treatments (Phase Three).

D. This Project

This report summarizes the three annual whole-lake alum applications to Lake Mitchell, evaluates their effects and makes recommendations for ongoing alum applications in the larger context of the watershed management clean up efforts.

E. Future Projects

It has been intended that the three-year alum demonstration project would set the stage for the ongoing alum treatments. This report provides the rationale and recommendations to consider for future water quality projects on Lake Mitchell.

RESULTS

A. Alum Applications

Liquid alum was transported to Lake Mitchell in tanker trucks, each carrying 4,300 gallons. Upon arrival, the alum product was offloaded onto the Sweetwater alum application barge. The capacity of the barge was half a tanker load, or 2,150 gallons in 2003 and 2004; but the barge was modified in 2005 to increase its capacity by 50%. Once filled, the barge applied the alum along rows. The delivered alum was metered to apply a dose based on lake water volume (2003) and a uniform dose by water surface (2004 & 2005). The barge was guided by a GPS navigation system which allowed for precise delivery across the lake surface.

The application schedule was as follows:

Year	Date	Gallons of Alum	Total Gallons of Alum
2003	June 9	12,900	150,000
	June 10	34,400	
	June 11	34,400	
	June 12	34,400	
	June 13	33,900	
2004	May 3	43,207	120,787
	May 4	51,708	
	May 5	25,872	
2005	May 23	34,188	128,387*
	June 21	38,325	
	June 22	30,261	
	June 23	25,613	

* About 8,900 gallons of additional alum, over the planned dose of 120,000 gallons, were applied due to the interruption of the application. For water and sediment dose calculations in this report, a total of 120,000 gallons is used.

B. Bathymetric Survey

A bathymetric survey (depth contours) was conducted as an element of this demonstration project. The full details were reported in the 2003 project report. This was important for properly determining alum doses and application rates. The results are summarized below:

Surface Area:	29,550,000 ft^2 (678.4 acres or 274.5 hectares)
Volume:	388,834,000 ft^3 (2,908,000,000 gallons or 8,927 acre-feet)
Mean depth:	13.2 feet (4.0 meters)

C. Sediment Analysis

Sediment analyses were conducted in August 2004, following the second annual alum application. These analyses were designed to evaluate the impact of alum additions on immobilizing sediment phosphorus in Lake Mitchell. At that time, the City wanted to know a) if the alum additions were working and b) if so, could the full dose be applied to accelerate treatment program and see improvements. The results and evaluation were reported in the 2004 project report.

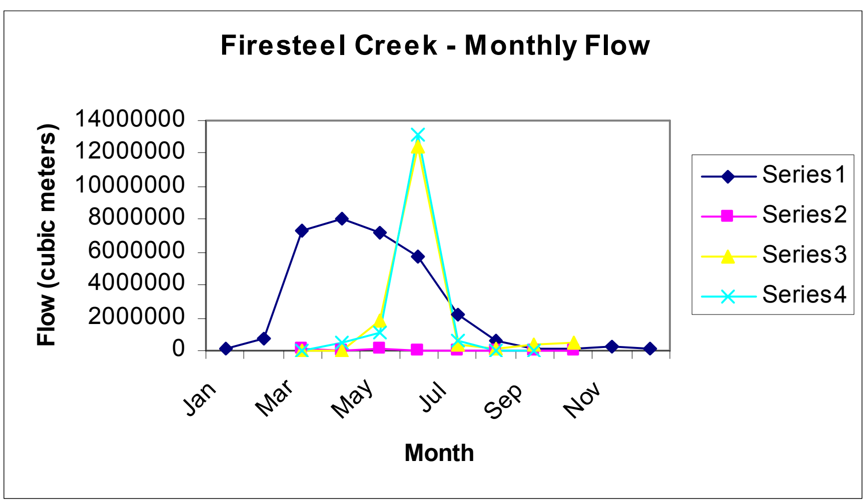
Following the sediment analysis, recommendations were made to the City in late-2004 regarding the needed alum dose to complete the treatment program for immobilizing sediment phosphorus. The City decided at that time to continue with the planned treatments and complete the three-year demonstration project. This demonstration project includes three annual alum applications as part of a five-year regime.

D. Water and Phosphorus Inputs

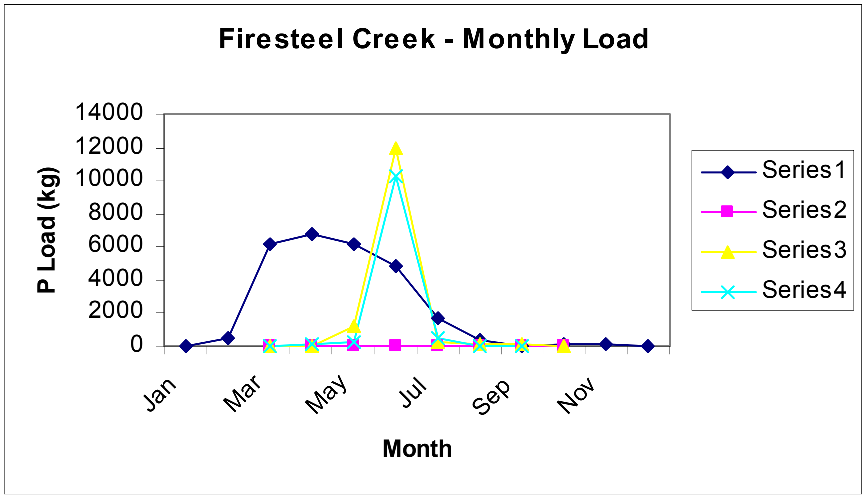
1. Runoff

The 2003 water year (October 2002 through September 2003) was extremely dry; 2004 and 2005 were also dry, but very wet during the summer. The annual water and phosphorus loads from Firesteel Creek compare to the long-term average (from Table 4-1 in Nürnberg and Osgood 2002):

	1956-2001 Average	2003	2004	2005
Flow (10^6 m^3)	32.5	0.2	15.6	16.4
TP Load (10^3 kg)	26.8	<0.1	13.6	11.3



Monthly water inflows. Series 1 is the 1956-2001 average (from Nürnberg & Osgood 2002), Series 2 is 2003, series 3 is 2004 and series 5 is 2005.



Monthly phosphorus inflows. Series 1 is the 1956-2001 average (from Nürnberg & Osgood 2002), Series 2 is 2003, series 3 is 2004 and series 5 is 2005.

Water and phosphorus from all other surface sources were negligible.

2. Pumping from the James River

Water from the James River was pumped into Lake Mitchell during two of the project years. The amounts of water and phosphorus that entered Lake Mitchell were:

	2003	2004	2005
Flow (10^6 m^3)	2.0	1.9	0
TP Load (10^3 kg)	549	543	0

3. Internal Phosphorus

Internal phosphorus supplies and loading rates were evaluated in this demonstration project. The supply of internal phosphorus refers to the amount of phosphorus in the lake sediments. This was measured directly in the diagnostic study in 2001(Nürnberg and Osgood 2002) and during this study in 2004. Based on these analyses, the internal phosphorus loading rate can be estimated as follows (Nürnberg 1988):

	Estimated P Release Rates ($mg/m^2/day$)
2001	11.4
2004	7.2

E. Lake Monitoring

Water quality samples were collected from three sampling sites in 2003, 2004 and 2005. These were sites 12A, 12B and 13A from the 2001 study (Figure 1).

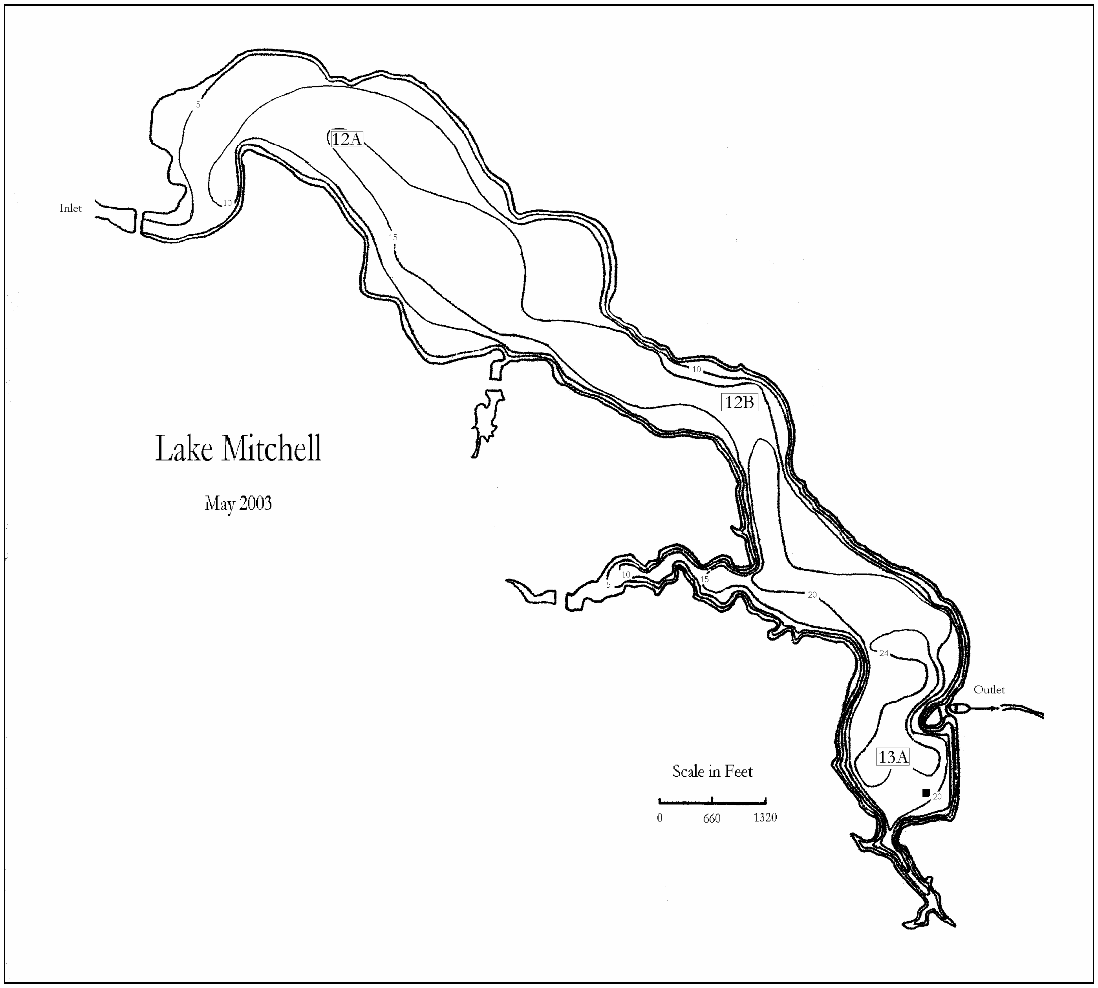
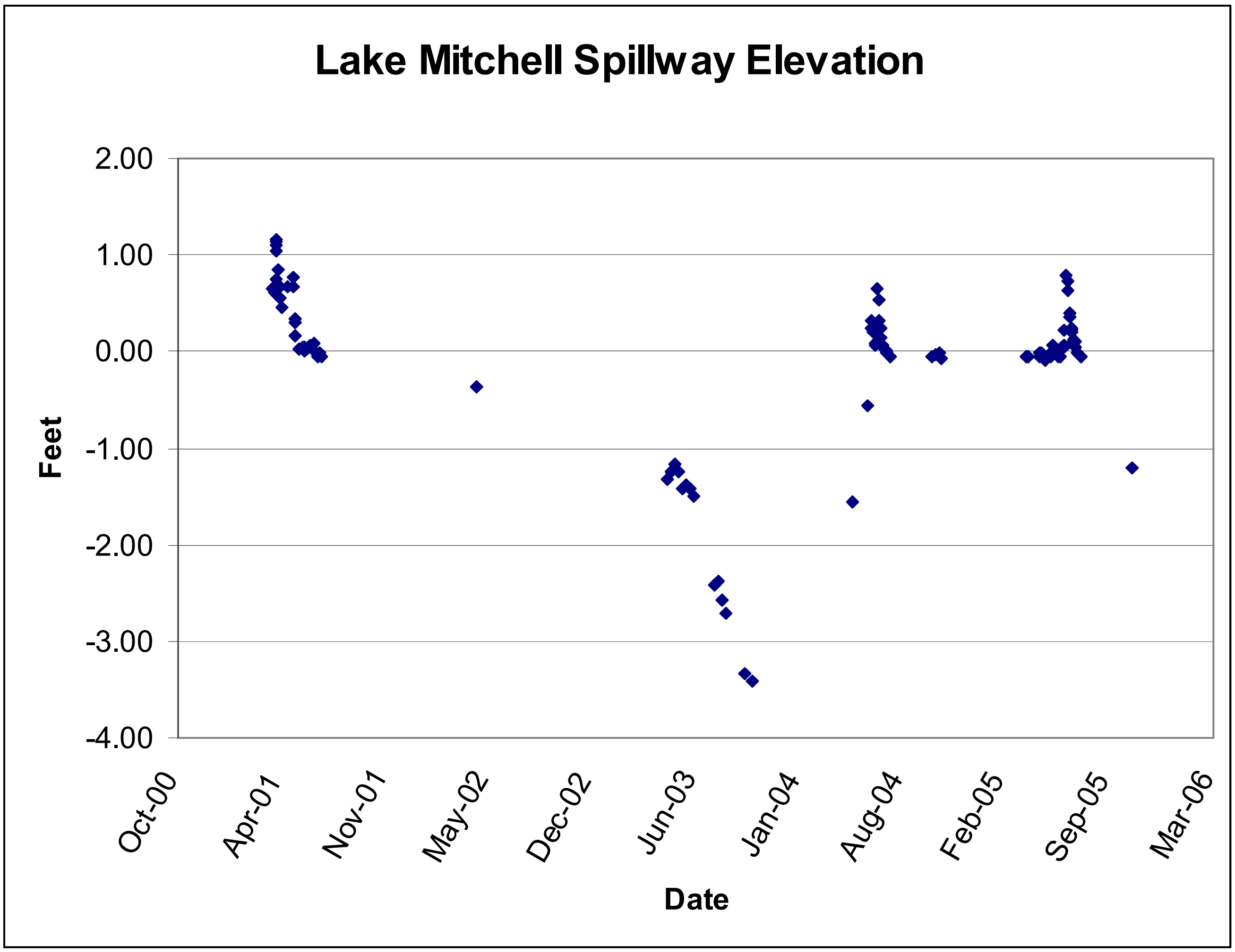


Figure 1. 2003, 2004 & 2005 Water Quality Sampling Sites

a. Lake Level

The lake's elevation varied throughout the demonstration project. The summer of 2003 was very low and the summers of 2004 and 2005, the lake as at or near the spillway elevation.

	Summer Ranges
2003	- 1.3 to - 3.3 feet
2004	- 0.5 to + 1.7 feet
2005	- 0.1 to + 0.8 feet



b. Phosphorus

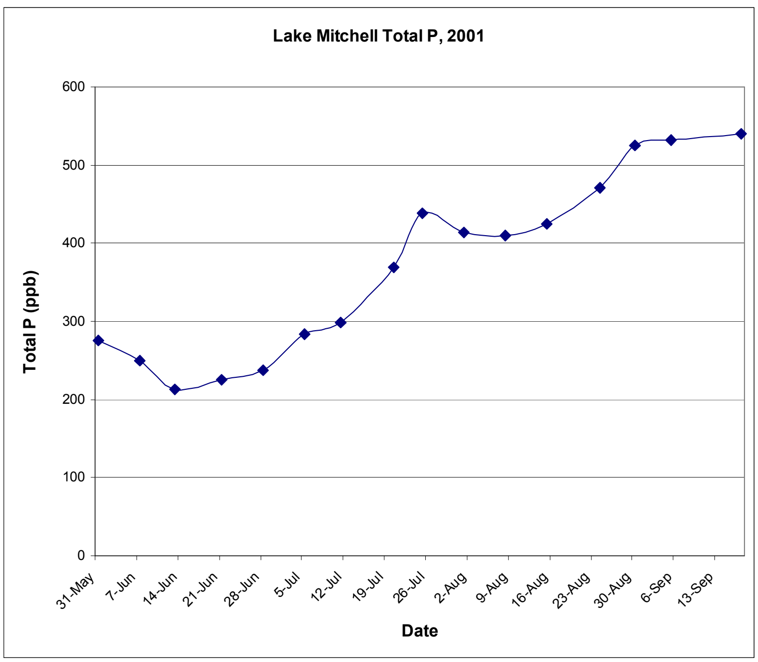
Phosphorus concentration was measured from the surface of the lake. Because Lake Mitchell is well mixed, surface samples represent a good approximation of water column phosphorus content.

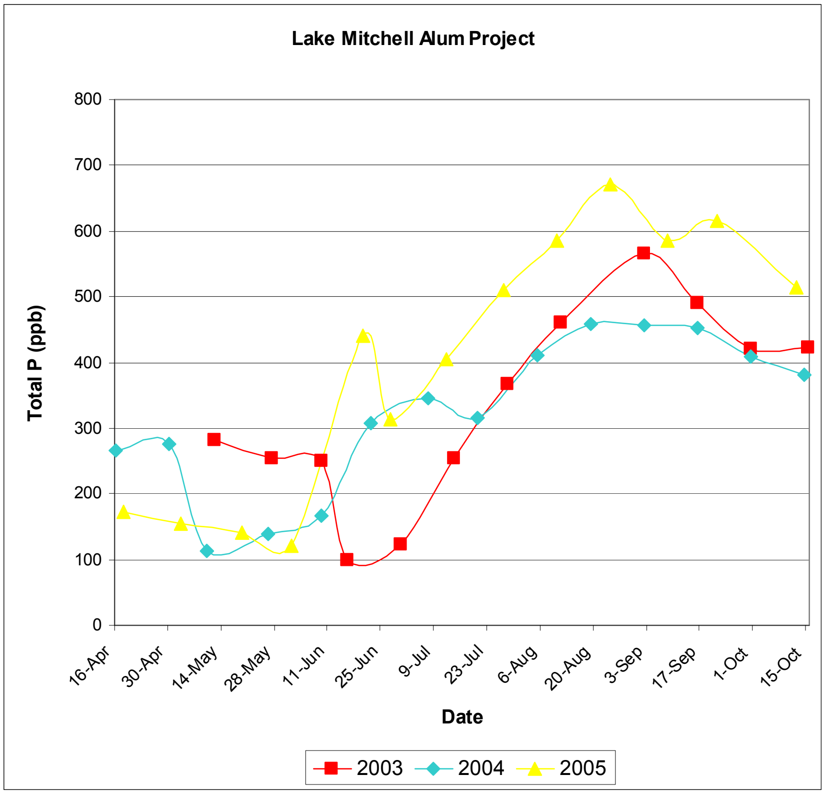
Lake phosphorus concentrations were reduced following the alum applications:

Year	Lake P, before	Lake P, after
2003	250 ppb	98 ppb
2004	276 ppb	114 ppb
2005	229 ppb	150 ppb*

* The 2005 alum application occurred in two parts and there were significant inflows of phosphorus during that period.

Lake phosphorus concentrations are shown in the figures below.





The lake condition is best represented by the summer average phosphorus concentration. The June-September average lake phosphorus concentrations are shown below, in comparison with 2001:

Year	Summer TP
2001	376 ppb
2003	324 ppb
2004	325 ppb
2005	393 ppb

The summer lake phosphorus concentration is the product of various inputs and losses. These are evaluated in the analysis section below.

c. Algae

Algae have been measured in several ways throughout this project. Chlorophyll is a green pigment found in all algae and its measure indicates the overall level of algae in the lake. The timing and level of maximum chlorophyll is also evaluated as an indicator the algal nuisance levels attained during the summer. Finally, phytoplankton (meaning all algae species) were enumerated from preserved samples. Individual algae species were counted.

1. Chlorophyll

Algae levels in Lake Mitchell is highly variable – both within the lake and within the summer season. For example, it is common to measure chlorophyll values spanning two orders of magnitude (100-fold difference) at various sites in the lake on the same day as well as over the summer period. For this reason, it is difficult to present the data in ways that are easy to discern trends, if present.

Lake Mitchell is dominated by the blue-green algae, *Aphanizomenon*, which makes chlorophyll a poor measure of lake quality because this species relates to phosphorus differently than most other algae. For this reason, we recommended not relying on chlorophyll as a measure of lake condition in Lake Mitchell (Nürnberg & Osgood 2002).

Below is a summary of July-August average (and seasonal range) chlorophyll in Lake Mitchell:

Average Chlorophyll	**12A**	**12B**	**13A**
2001	**37 ppb** (3-72 ppb)	--	--
2003	**126 ppb** (2-194 ppb)	**54 ppb** (1-112 ppb)	**64 ppb** (1-157 ppb)
2004	**57 ppb** (4-119 ppb)	**26 ppb** (0-87 ppb)	**16 ppb** (0-47 ppb)
2005	**16 ppb** (1-63 ppb)	**110 ppb** (1-298 ppb)	**38 ppb** (2-109 ppb)

2. Maximum Chlorophyll

As with summer average chlorophyll, maximum chlorophyll is variable within the lake and from year-to-year. Below is a summary of maximum chlorophyll (from June – August):

Maximum Chlorophyll	**12A**	**12B**	**13A**
2001	**72 ppb** (11 July)	--	--
2003	**189 ppb** (14 July)	**95 ppb** (30 June)	**157 ppb** (28 July)
2004	**119 ppb** (20 July)	**58 ppb** (19 August)	**28 ppb** (19 August)

2005	**63 ppb** (20 June)	**298 ppb** (12 July)	**109 ppb** (27 July)

3. Phytoplankton

Aphanizomenon, has been the dominant algal species in Lake Mitchell during the summer. The table below summarizes the predominance of blue-green algae and *Aphanizomenon*, also a blue-green, in relation to all other algae in the lake. There was a shift in the mid-summer dominant – from *Aphanizomenon* to *Microcystis* - beginning August 10, 2005.

		Blue-Green Algae (% of all algae)	*Aphanizomenon* (% of all algae)
2003	27 May	14/0/0	0/0/0
	9 June	43/73/47	33/59/40
	16 June	76/81/32	54/61/12
	14 July	99/99/94	99/99/89
	18 Aug	99/98/68	98/90/16
2004	26 May	0/0/0	0/0/0
	9 June	71/0/93	22/0/59
	22 June	73/59/97	58/30/95
	7 July	98/92/92	96/93/91
	20 July	98/53/17	98/46/7
	5 August	56/93/88	30/86/86
	19 August	94/97/90	84/81/75
	2 September	77/46/35	69/28/17
	16 September	92/88/92	89/83/91
	30 September	94/82/51	94/81/47
	14 October	84/95/93	80/95/91
2005	18 April	2/0/0	1/0/0
	3 May	0/0/40	0/0/0
	19 May	10/55/0	0/51/0
	1 June	90/95/49	89/95/46
	20 June	98/86/58	94/70/15
	27 June	95/92/93	84/88/88
	12 July	98/99/97	95/97/91
	27 July	97/99/99	80/91/92
	10 August	94/91/89	6/8/5
	24 August	92/60/50	55/47/3
	8 September	95/81/55	79/66/71
	21 September	91/95/28	71/89/70
	12 October	98/93/85	98/90/70

* Numbers are percentages from sites 12A/12B/13A.

d. Zooplankton

Zooplankton were collected and enumerated only in 2003. The results are reported in the 2003 project report.

e. Secchi Disk

The lake condition is best represented by the summer average Secchi disk transparency, represented below as the July-August average, in comparison with 2001:

Year	Site 12A	Site 12B	Site 13A
2001	2.7 feet	5.0 feet	6.7 feet
2003	2.2 feet	4.8 feet	10 feet
2004	3.2 feet	5.4 feet	6.4 feet
2005	2.3 feet	3.0 feet	4.6 feet

ANALYSIS

A. Watershed Inputs

The major surface water inlet to Lake Mitchell is Firesteel Creek, providing 99% of the water and phosphorus inputs to the lake (except in very dry years when water is pumped in from the James River). The patterns of these inputs were evaluated in the diagnostic studies (Osgood & Nürnberg 2002; Nürnberg & Osgood 2002). The table below summarizes historical patterns and those measured during the diagnostic study (2001) and the demonstration project (2003-2005):

	- - Percentiles[1] - -			1991-				
	10	50	90	2001[2]	2001	2003	2004	2005
Annual Water Inputs (water year, 10^6 m^3)								
- Firesteel Creek	21.0	114	275			0.31	15.5	16.4
- Pumping from the James River						2.0	1.0	--
TOTAL	**21.0**	**114**	**275**	**75.6**	**120**	**2.31**	**19.4**	**16.4**
Annual Phosphorus Inputs (water year, 10^3 kg)								
- Firesteel Creek	0.7	18.5	101	53.5	86.2	0.1	13.6	11.3
- Pumping from the James River					--	0.5	0.5	--
TOTAL	**0.7**	**18.5**	**101**	**53.5**	**86.2**	**0.6**	**14.1**	**11.3**

1. From Osgood & Nürnberg (2002).
2. From Nürnberg & Osgood (2002).

There are several notable observations from these data:

1. 2001 was near-normal with respect to the amount of runoff, its phosphorus content and the timing of the inputs during the year.

2. 2003 was extremely dry, substantially drier than the 10th percentile. The phosphorus inputs from Firesteel Creel were similarly low, and the addition of pumped water from the James River was the largest external phosphorus supply to the lake.

3. 2004 and 2005 had near-normal amounts of phosphorus inputs on an annual basis; however the vast majority of these inputs occurred during July and August. Indeed, the phosphorus inputs during July and August represented 90% and 96% of the total annual inputs during 2004 and 2005, respectively.

B. Lake Condition

1. Water quality

The water quality of Lake Mitchell has not changed throughout the demonstration project. There have been short-term improvements in phosphorus concentration immediately following the alum applications, but lake phosphorus concentrations increased due to the fact that internal inputs have not been fully abated or that external inputs occurred during the summer. Because the lake's phosphorus concentration remained high, the lake's algae remained dominated by blue-greens and the lake's water clarity remained substantially unchanged.

Because the full alum dose has not yet been added to the lake, the fact the lake's water quality remains poor is expected. Significant water quality improvements are not expected until the lake's target phosphorus concentration of 90 ppb is reached (Osgood & Nürnberg 2002).

2. Sediment Phosphorus and Internal Phosphorus Loading

Sediment phosphorus was measured in 2001 and in 2004 (following the 2004 alum application). Based on these analyses, internal phosphorus loading rates were estimated (see results). In addition, the mass of internally supplied phosphorus was determined in 2001 as 4,066 kg.

The diminished sediment phosphorus is the result of the alum additions. It is reasonable to estimate the diminished internal phosphorus loading rates in proportion to the amount of alum added, and therefore the amount of sediment phosphorus immobilized. Internal phosphorus loading rates and amounts are estimated as follows:

	Estimated P Rate ($mg/m^2/day$)	Estimated P Load (kg/summer)
2001	11.4	4,066
2003	9.1	3,246
2004	7.2	2,568
2005	5.3	1,891

C. Modeling

Using results from this study and applying the model developed in Nürnberg & Osgood (2002), it is possible to evaluate the impacts of the alum applications in the context of variable loading conditions. The three years of the demonstrations have been extreme in several ways, which challenges this evaluation. It was extremely dry in 2003, so dry that the input parameters are outside the range of the model. The years 2004 and 2005 were near-normal overall, but substantial inflows occurred in mid-summer, a condition not encompassed in the modeling analysis of Nürnberg & Osgood (2002). As a result of these extremely unusual conditions, I have had to make modifications or assumptions in the modeling evaluations.

The lake phosphorus model considers internal and external phosphorus inputs to Lake Mitchell and estimates the lake's phosphorus concentration, expressed as the summertime average. I have listed the measured summertime (June through September) average phosphorus concentration and compared that with the model evaluation to help explain the observed results.

	2001	2003	2004	2005
Observed Lake P (ppb)	376	324	325	393
Model Estimate, original (ppb)	466	n/a[1]	226	185
Model Estimate, modified[2] (ppb)	466	n/a	401	371

1. The model could not be used due to 2003 being extremely dry.
2. The annual external P inputs that occurred during the summer were added back into the internal loading term in the model as a way to adjust for the unusual situation where the majority of the external input occurred in mid-summer.

The results above show:

- The measured lake phosphorus concentration remained relatively constant throughout the demonstration project.

- In 2003, lake phosphorus concentration was not reduced because internal phosphorus inputs had not been sufficiently mitigated (see also the 2003 progress report).

- The original model, the model developed in the diagnostic study (Nürnberg & Osgood 2002), estimates that lake phosphorus concentration decreases throughout the demonstration project period. However, the original model was developed using historic data where the majority of the external phosphorus inputs occurred prior to summer. Thus, the original model also indicates that in a more normal hydrologic year, the lake phosphorus would have been reduced.

- The modified model adjusted for the fact that 90 and 96% of the external phosphorus inputs entered Lake Mitchell in mid-summer in 2004 and 2005, respectively. When this adjustment was made, the model more accurately estimated the observed condition in Lake Mitchell.

D. Alum Demonstration

The three annual alum applications that occurred during this demonstration project were designed to accomplish a two-fold objective: to reduce internal phosphorus and to mitigate the annual external inputs to provide seasonal relief. This application strategy is called for because of the extreme conditions that occur in Lake Mitchell (Osgood & Nürnberg 2002).

1. Sediment Treatment

The annual alum applications were applied over the lake surface to provide a bottom blanket of alum floc. As the alum is applied, it strips phosphorus from the water, which is why the lake phosphorus concentration decreased immediately following each application. The 'unused' alum that settles to the lake sediments, forms aluminum-phosphorus bonds, which permanently immobilizes sediment phosphorus, thereby reducing internal phosphorus loading. The results presented above show that sediment phosphorus was immobilized and internal phosphorus loading rates have been reduced.

As called for in the diagnostic study (Osgood & Nürnberg 2002), the first three alum applications have only provided a portion of the required dose. As a result of the evaluation throughout this demonstration, which have included field measurements, modeling and a sediment study, the original sediment dose can be refined. I estimate the alum dose needed to immobilize the remaining sediment phosphorus to be (see appendix A):

Single application (2006)	256,000 to 441,000 gallons
Split application (2006 & 2007)	146,500 to 250,000 gallons per year

This estimate is applicable if the alum applications occur in 2006 (single application) or in 2006 and 2007 (split application). These doses would need to be increased if the applications are delayed.

2. Water Column Treatment

Ongoing alum applications will be necessary to meet Lake Mitchell's water quality goals, until substantial reductions in watershed phosphorus loading are realized.

Level of Watershed Loading Reduction to Meet Lake Water Quality Goal

Nürnberg & Osgood (2002) found that Lake Mitchell's water quality goal would not be met with a 50% reduction in watershed phosphorus loading, even after internal phosphorus loading had been controlled. When assuming internal phosphorus loading is totally controlled (= 0), the model from Nürnberg & Osgood (2002) shows that a 80% reduction in watershed phosphorus loading must occur before the 90 ppb lake phosphorus goal is accomplished.

The 80% reduction in watershed phosphorus loading should be used as a target, along with an assurance that internal phosphorus inputs being controlled, before considering whether ongoing alum applications should be discontinued.

Continuous Alum Application

As noted above, ongoing alum applications will be necessary to accomplish water quality improvements in Lake Mitchell. Some method of continuous application is needed to compensate for the excess phosphorus that enters the lake each year.

The demonstrations have addressed this need, in part, through annual, whole-lake applications. This method made sense because these were designed with the dual purpose of stripping phosphorus from the water and immobilizing phosphorus in the lake sediments. As the projects moves into Phase III, a different method for continuous application is appropriate.

A continuous application system is designed to add alum on demand based on the amounts of phosphorus entering the lake. Because these amounts vary greatly from year-to-year as well as seasonally, the system must have the capacity to meet these demands. The system is comprised of a primary shore station that includes a reservoir to hold the liquid alum, and a distribution system that includes an air compressor and liquid alum pump. The alum is distributed to multiple points in the lake through microfloc generators. These generators 'spray' the alum into the water where it strips phosphorus from the water and, as it settles, adds to the bottom barrier of alum. The rate of alum application is adjusted to meet the known demand.

I have estimated the required annual alum dose (gallons), based on a range of flow conditions (see Appendix D) as follows:

Flow	at least	up to
10%	0	0
25%	34,800	69,600
50%	155,500	311,000
75%	382,900	765,800
90%	352,300	704,500

E. Conclusions

The three year alum demonstration project has quantitatively illustrated the magnitude of the problem confronting the management of Lake Mitchell. Water quality goals, meaning real improvements in water quality, will not be accomplished until both of the following objectives are met:

- Substantial control of internal phosphorus loading, and
- An 80% reduction in watershed phosphorus loading

The three annual alum applications have accomplished a significant reduction in internal phosphorus loading. The remaining dose needed to finish this task has been estimated.

The watershed improvements accomplished to date, have not yet accomplished the required phosphorus reductions. Until this happens, continuous alum applications will need to occur to accomplish the water quality goal. The required annual dose for this task has been estimated.

RECOMMENDATIONS

The alum demonstration project on Lake Mitchell addressed this problem statement (Osgood and Nürnberg 2002):

> *Excessive algae growth causes unpleasant tastes and odors in the City's drinking water and detracts from the lake's aesthetic qualities. The lake's poor water quality poses minimal public health concerns, because raw water is treated before it is distributes for drinking water. Algae problems in Lake Mitchell are longstanding, and there is evidence that lake phosphorus, which could make algae blooms worse, is increasing over the past decade.*

Based on the diagnostic studies as well as the results from this demonstration, these problems remain, although the tastes and odors in the City's drinking water have been mitigated to some extent after the City connected to the Dakota Rural Water system, which supplements the City's water supply with treated water.

The alum demonstration project was designed to evaluate whether alum could be used to lower Lake Mitchell's phosphorus concentration to 90 ppb, as an interim goal. While this phosphorus level in Lake Mitchell has not yet been attained, it remains an appropriate target.

The management alternatives and recommendations discussed below consider a lake phosphorus concentration goal of 90 ppb.

A. Future Management Alternatives

Ongoing watershed and lake management will be required in both the short- and long-term to realize water quality improvements in Lake Mitchell. Here, I review the most reasonable management approaches that can be considered.

1. Ongoing Watershed Management

Because the ultimate source of phosphorus to Lake Mitchell is its tributary watershed, this source must be addressed. However, this is a very large problem that will require a very large investment of time and resources to get on top of this problem.

The original goal for the Firesteel Creek management project was a phosphorus reduction of 50%. Here, I have estimated that an 80% reduction is needed.

It has been estimated that, after seven years, less 10% of the watershed phosphorus load has been mitigated. Clearly, there is much more work to do.

I have not critically evaluated additional or alternative approaches to reach the watershed goal as part of this project. However, I recommend that additional, more aggressive approaches and investments be evaluated and considered, because it appears the current strategy, while substantially proceeding as programmed, is inadequate. Additional or more aggressive approaches to be evaluated might include:

- Greater financial investments
- Water diversions
- Mandatory controls

It is time to re-think the overall scope of the watershed project.

2. In-Lake Alternatives

Osgood and Nürnberg (2002) considered a full range of lake management alternatives. The best available technologies and approaches were evaluated in 17 categories, and every one of them was found to be either not feasible or not effective (or both) – except alum (see below).

Because the water quality problems in Lake Mitchell are serious and there mitigation is difficult, there has been a high degree of urgency to address these problems. As well, because the three year alum demonstration project has yet to accomplish observable water quality improvements, there has been an understandable frustration within the community. One of the outcomes of this frustration has been to consider or re-consider alternative management approaches. I will comment briefly on these options below.

<u>Copper sulfate</u>

Copper sulfate is an algaecide that is reasonable effective at killing the kind of algae in Lake Mitchell. Its advantages include a known mode of action with predictable results. Its disadvantages include research that shows the algae develop a genetic resistance to the copper sulfate, the buildup of copper in the lake sediments and its high cost. I have estimated the initial copper sulfate treatments would cost $300,000 to $1,400,000 per year. I do not recommend using copper sulfate.

<u>Circulation</u>

Circulation refers to the process of artificially inducing water circulation to move algae out of the illumination they need to grow or to keep buoyant algae from accumulating on the lake surface. Sometimes circulation is also combined with aeration, but this is usually misunderstood, as air bubbles can be used to create the circulation, not add air or oxygen to the water. In the case of Lake Mitchell, these differences are not important because the lake is extremely well mixed and aerated naturally as a result of wind and wave action. Thus, artificial circulation or aeration will not be an effective treatment.

<u>Corn meal and barley straw</u>

Corn meal and barley straw have been used experimentally in ponds to accomplish algae control in some cases. The mode of actions appears to be a result of adding substances to the water which allow bacteria to compete with algae for phosphorus – or simply, to give bacteria an advantage over algae. While there is a credible theoretical basis for these treatments, they are highly experimental at this time. Also, the few cases where they have been tried, have been limited to ponds or very small lakes. I do not recommend the consideration of corn meal or barley straw at this time.

3. Continued Alum Applications

This project has been designed to evaluate and set the stage for continuous alum applications to mitigate excessive algae in Lake Mitchell. Specific recommendations are included below.

4. Do Nothing

Doing nothing is always an alternative. Given the extreme and excessive nature of the problems confronting Lake Mitchell, this is a rational alternative.

B. Recommended Management Actions

1. Alum

Alum applications are required to a) complete the sediment treatment and b) to offset the continuous phosphorus inflows. In the three-year demonstration project, alum was applied as a bulk application on an annual basis. To make the transition into Phase III, the ongoing application, it makes sense to shift to a continuous system. A continuous low-dose system is able to meter the needed alum dose at the times and locations where it is most effective and adjust for highly variable seasonal and annual inputs. The continuous injection system will accomplish both objectives and, after the initial investment, be less costly to operate.

Capital Costs

The costs for purchasing and installing a low dose alum injection system will be approximately $400,000. This estimate includes all materials and installation. Additional costs for providing buildings or housing as well as electrical hookup are not included in this estimate.

Operation and Maintenance Costs

I recommend both the sediment and annual alum be applied using the continuous injection system. The delivered alum costs have been estimated at a rate of $0.80/gallon.

Sediment Alum – Using the estimated alum doses presented above, the estimated cost is:

Dose applied in 2006	$250,000 to $352,000
Dose split in 2006 & 2007	$117,000 to $200,000 per year

Annual Alum – Using the estimated ranges from above, the estimate annual cost is

$249,000 (range $0 to $613,000) per year

System Maintenance – The approximate annual maintenance costs are approximately $1,000.

Monitoring – Ongoing monitoring is needed to evaluate the system's performance. The estimated costs, excluding staff, are estimated to be $5,000.

2. Watershed

Because the costs for the ongoing management of Lake Mitchell's water quality are high, every possible effort to control watershed phosphorus must be considered. While it is beyond the scope of this project to evaluate additional watershed projects, I recommend a more aggressive implementation schedule, greater investments and high flow diversions. All of these, if feasible and effective, will reduce the costs of the annual alum applications.

3. Lake Manager

Because the ongoing management of Lake Mitchell is necessarily a long-term commitment, a full time lake manager will be required to oversee the watershed implementation, the operation of the alum system and the lake and watershed monitoring.

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APPENDIX A

ESTIMATED REMAINING SEDIMENT ALUM DOSE

The estimated remaining sediment alum dose is based on the August 2004 sediment analysis and takes into account the 2005 alum application.

Sediment Dose Based on 2004 Sediment Analysis

a. From the method reported in the 2004 progress report, 339,000 gallons.

b. Using the mobile P method (more conservative):

From the sediment results reported in the 2004 progress report, mobile P is:

Sediment depth	Mobile P	Al:P ratio	Alum Dose
0 to 4 cm	2.75 g/m^2	100:1	275 g/m^2
0 to 10 cm	6.29 g/m^2	11:1	69.2 g/m^2

The higher dose is the most conservative estimate. The lower dose is representative of a greater sediment depth as well as being more consistent with the method used in step a, thus is used in this analysis.

The alum is to be applied over the sediment area in Lake Mitchell where there is excess mobile phosphorus. Based on the sediment sample analysis, that represents to 12-foot contour. Thus, applying the alum dose to sediments in water depths 12-feet deep and greater:

69.2 g/m^2 x 396.5 acres (1,600,000 m^2)	= 110,000,000 g Al
at 1,000 g/kg	= 110,000 kg Al
at 0.22 kg Al / gallon alum	= 500,000 gallons alum

Estimate of Water Demand

The lake phosphorus concentration in the springtime is about 250 mg/m^3. When this is applied over the lake volume (11 x 10^6 m^3) it represents 2,700 kg P in the lake water. Based on Al:P ratios of either 3:1 or 5:1, this represents 37,000 to 61,000 gallons of alum, which is an estimate of the water demand. Applying this demand to the range of estimated alum doses in steps a and b (above):

Remaining alum dose range:

339,000 gallons + 37,000 gallons = 376,000 gallons
500,000 gallons + 61,000 gallons = 561,000 gallons

Adjustment for 2005 Alum Application

The dose range presented above should be adjusted by the alum added in 2005 to result in an estimate of the remaining alum dose to be applied in 2006. In 2005, 120,000 gallons of alum were applied to Lake Mitchell, thus the range of remaining dose is estimated as:

376,000 gallons – 120,000 gallons = 256,000 gallons
561,000 gallons – 120,000 gallons = 441,000 gallons

Because the original plan called for splitting the sediment does into five annual applications, I have estimated the remaining dose split over 2006 and 2007. Because the dose is split, adjustments must again be made for another annual water demand, thus the remaining dose is increased overall:

Total dose range:

256,000 gallons + 37,000 gallons = 293,000 gallons (146,500 gallons per year)
441,000 gallons + 61,000 gallons = 502,000 gallons (251,000 gallons per year)

APPENDIX B

ESTIMATED CONTINUOUS ALUM DOSE

The estimated alum dose for a continuous application is based on the net annual phosphorus inputs (inflows – outflows) from Firesteel Creek, with adjustments for available phosphorus and a range of alum removal efficiencies.

Net annul phosphorus inputs were calculated from 1979 – 2001 data in Appendix G from Nürnberg and Osgood. (2002). These years were used because outflow volumes were measured and therefore outflow phosphorus could be estimated. After the net annual phosphorus was calculated, these data were ranked by percentiles:

Percentile	kg P / year
10%	0
25%	1,532
50%	9,776
75%	46,800
90%	62,000

The immobile or unavailable phosphorus fraction was estimated to discount the loads from above. This is appropriate because the mineral fraction of the phosphorus load is not considered biologically available of reactive. Based on the TP/TDP fractions from the inflow data collected throughout the Firesteel Creek project (1999 – 2005), which varied according to flow, the following adjustments were estimated:

Percentile	Adjustment
10%	0%
25%	0%
50%	30%
75%	64%
90%	75%

These adjustments were applied to the net annual loads from above:

Percentile	kg P / year
10%	0
25%	1,532
50%	6,843
75%	16,848
90%	15,500

Finally, to estimate the amount of alum needed to immobilize these phosphorus inputs, I used the rations 5:1 and 10:1, which encompasses the most commonly used ranges (Osgood et. Al 2005). The amount of liquid alum (gallons) is presented by using the conversion of 0.22 kg Al/gallon:

Percentile	5:1	10:1
10%	0	0
25%	34,800	69,600
50%	155,500	311,000
75%	382,900	765,800
90%	352,300	704,500