SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

WATERSHED PROJECT FINAL REPORT

Firesteel Creek / Lake Mitchell Watershed Project – Segment 1

Sponsor

Davison Conservation District

David Kringen

December 2008

This project was conducted in cooperation with the State of South Dakota and the United States Environmental Protection Agency, Region 8

Grant # C-998185-98, C-998185-99, and C-998185-02

EXECUTIVE SUMMARY

FIRESTEEL CREEK / LAKE MITCHELL WATERSHED PROJECT

PROJECT START DATE: April 1998 PROJECT COMPLETION DATE: September 2008

FUNDING: TOTAL BUDGET

	INITIAL	AMENDED	ACCRUED MATCH
EPA GRANT (C-998185-98)	$113,150	$125,650	$83,766
EPA GRANT (C-998185-99/02)	$738,000	$1,078,500	$719,000
TOTAL EPA GRANT	$851,150	$1,204,150	$802,766

GRANT AMENDMENTS: 6
BUDGET REVISIONS: 1 (August 2005)

The goal of the Firesteel Creek/Lake Mitchell Watershed Project – Segment 1 was:

> Reduce the nutrient (phosphorus) and sediment loading into Lake Mitchell by 50 percent by the year 2015 in order to restore water quality to a level that supports its priority use as a domestic water supply, and other multiple uses.

The Davision Conservation District sponsored the implementation project with partnership from the City of Mitchell, Aurora, and Jerauld Conservation Districts. The initial project grant was effective April 7, 1998. With amendments and additional funding, the project continued until September 30, 2008. The objectives of this project segment (summarized) were:

1. Reduce phosphorus loadings to Firesteel Creek by approximately 30 to 35 percent through the application of Best Management Practices (BMPs).
2. Reduce sediment and nutrient loadings to Firesteel Creek by 10 to 15 percent through the application of BMPs.
3. Through the application of alum (aluminum sulfate) to Lake Mitchell, reduce in-lake phosphorus concentrations to 90 ppb in order to reach a 50 percent summer bloom frequency.
4. Implement a water quality monitoring program to document effectiveness of alum applications on Lake Mitchell.
5. Implement an information and education program on project goals and objectives, animal waste management, and grazing and riparian management.
6. Assess, track and report the progress made through implementation of BMPs toward attaining the project goal.

The project resulted from contacts between city officials and the South Dakota Department of Environment and Natural Resources (SDDENR) in 1992 about declining Lake Mitchell water quality. The primary concerns were near continuous taste and odor issues residents experienced with their drinking water and excessive annual algal blooms. During 1993, the Firesteel Creek/ Lake Mitchell Water Quality Assessment (Phase I) was initiated to identify, prioritize, and present alternatives to correct identified nonpoint source (NPS) pollution sources in the watershed. The study came about as a result of South Dakota's NPS management program for 303(d) listed waterbodies to address total maximum daily load (TMDL) issues. The initial listing occurred "pre -1998" as a special approval; where the waterbody had sufficient data to write a TMDL before the first 303(d) impaired waterbody list (now included in the "The South Dakota Integrated Report for Surface Water Quality Assessment") was published. Components of the assessment study consisted of in-lake and tributary water quality monitoring, algae sampling, storm sewer monitoring, and use assessment using the Agricultural Nonpoint Source (AGNPS) computer model.

Analysis of the watershed results indicated that the most likely sources of the nutrient loading were animal feeding operations (AFOs) and/or intense summer long grazing. AFOs were estimated to contribute 51 percent of the soluble phosphorus (P) load in the watershed. The AGNPS reduction response model estimated that a 50 percent reduction in P inputs would reduce in-lake phosphorus by 17 percent and decrease chlorophyll *a* concentrations sufficient to reduce the TSI for chlorophyll *a* to a mesotrophic level (Phase I Final Report).

The Firesteel Creek Watershed Project is the result of recommendations made by the diagnostic/feasibility study. Funding for project activities was made possible, in part, by grants awarded by the United States Environmental Protection Agency to the South Dakota Department of Environment and Natural Resources. In April 1998, a $113,150 EPA 319 grant was awarded to the Firesteel/Lake Mitchell Watershed Project to initiate activities selected to reduce nutrient loading to Lake Mitchell. The amount was increased by $12,500 in September 1998 to assist in the ground-based removal of approximately 18 inches of sediment, or 3000 cubic yards, from the bottom of Plankinton Pond in Plankinton, SD after an oil spill occurrence near the pond in August 1998. A $738,000 extension grant was awarded in March 1999 to continue the implementation work begun a year earlier. A $340,500 amendment to the extension grant was approved in 2003 to fund a three-year alum demonstration project meant to supplement watershed activities and reduce in-lake P concentrations to decrease algal bloom frequency.

It is estimated that a 9 - 10% phosphorus reduction was realized from project activities implemented through September 2008. This load reduction was accomplished by focusing primarily on improvements to priority feeding operations along the main branches of Firesteel Creek. Alum applications began in 2003 and ended in 2006. Although there was anecdotal evidence from lake residents that alum treatments were having a positive impact on the condition of the lake, water quality monitoring provided little indication that treatments were working as intended. Based on the information available and public input, a decision was made by the City of Mitchell to discontinue alum applications in 2007 because of the uncertainty about its effectiveness and expense. Sediment removal and disposal from the Plankinton Pond began in August 1998 and was completed in an environmentally acceptable manner with approval by the State of South Dakota by September 1998.

ACKNOWLEDGEMENTS

The Firesteel Lake Mitchell Project would like to thank all those involved with this segment of the implementation of practices recommended from the 1993 Firesteel Creek/ Lake Mitchell Water Quality Assessment (Phase I). The efforts of all those involved from the following organizations are greatly appreciated and have been essential to the success of this project.

Davison Conservation District

Aurora Conservation District

Jerauld Conservation District

City of Mitchell

Local area farmers, ranchers, and landowners

United States Environmental Protection Agency (EPA)

South Dakota Department of Environment and Natural Resources (DENR)

United States Department of Agriculture Natural Resources Conservation Service (NRCS)

Lower James Resource Conservation & Development Council

Lake Mitchell Development Committee

Firesteel/Lake Mitchell Improvement Association, Inc.

United States Department of Agriculture Farm Service Agency (FSA)

United States Department of the Interior U.S. Geological Survey (USGS)

United States Department of the Interior U.S. Fish and Wildlife Service (FWS)

Walmart Corporation

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INTRODUCTION

Lake Mitchell is a man-made reservoir located on Firesteel Creek in the James River Basin geological subdivision of the glaciated Central Lowland Province in southeastern South Dakota (HU 10160011 + 100). Lake Mitchell has served as the sole source of drinking water for the city of Mitchell since 1928 and the Davison Rural Water System since 1985. The lake is also a hub for recreational activity for area residents. The approximately 351,000 acre Firesteel Creek watershed is located in Davison, Aurora, and Jerauld counties (Figure 1). Landuse in the watershed reflects the diversified agriculture of the region; with 42 percent of the land classified as rangeland, 36 percent cropland, 17 percent pastureland, and 5 percent other.

Firesteel Creek is divided into two main tributaries. The east fork begins north of Wessington Springs and travels south until it reaches the confluence of the west fork. The west fork begins in the Wessington Springs Hills northwest of Plankinton and travels east until it reaches the confluence with the east fork in Blendon Township in northwest Davison Country. Firesteel Creek, from the lake to the confluence of the east and west forks, is designated as a permanent warm water fishery with limited contact recreational usage. The east fork from the east-west confluence to state highway 34 is assigned the water quality standards for a semipermanent fishery and limited contact recreation. The beneficial uses designated for the west fork from the east-west confluence to Lake Wilmarth is a marginal warmwater fishery with limited contact recreation (Figure 2). Table 1 lists the water quality parameters and limits assigned for the designations indicated.

Table 1. South Dakota water quality standards for specific stream segments.

Designation	Parameter	Limits
Permanent warmwater fishery and limited contact recreation	unionized ammonia	< 0.04 mg/L
	dissolved oxygen	> 5.0
	pH	> 6.5 and < 9.0 su
	suspended solids	< 90 mg/L
	temperature	< 26.67° C
	fecal coliform*	< 2000 / 100 ml
	alkalinity	< 750 mg/L
	nitrates	< 50 mg/L
Semipermanent warmwater fishery and limited contact recreation	unionized ammonia	< 0.04 mg/L
	dissolved oxygen	> 5.0
	pH	> 6.5 and < 9.0 su
	suspended solids	< 90 mg/L
	temperature	< 32.22° C
	fecal coliform*	< 2000 / 100 ml
	alkalinity	< 750 mg/L
	nitrates	< 50 mg/L
Marginal warmwater fishery and limited contact recreation	unionized ammonia	< 0.05 mg/L
	dissolved oxygen	> 4.0
	pH	> 6.0 and < 9.0 su
	suspended solids	< 150 mg/L
	temperature	< 32.22° C
	fecal coliform*	< 2000 / 100 ml
	alkalinity	< 750 mg/L
	nitrates	< 50 mg/L

*grab sample

During 1992, city officials contacted the South Dakota Department of Environment and Natural Resources (SDDENR) because of concerns regarding declining water quality. The primary concerns were the taste and odor issues residents continually experienced with their drinking water and excessive annual algal blooms. During 1993, the Firesteel Creek/ Lake Mitchell Water Quality Assessment (Phase I) was initiated to identify, prioritize, and present alternatives to correct identified nonpoint source (NPS) pollution sources in the watershed. The study came about as a result of South Dakota's NPS management program for 303(d) listed waterbodies to address TMDL issues. The initial listing occurred "pre-1998" as a special approval; where the waterbody had sufficient data to write a TMDL before the first 303(d) list was published. Components of the assessment study consisted of in-lake and tributary water quality monitoring, algae sampling, storm sewer monitoring, and land use assessment using the Agricultural Nonpoint Source (AGNPS) computer model, version 5.0. The study was scheduled to last two years but was extended into 1995 because of lack of flow in the tributaries and the resulting limited number of samples collected.

Figure 1. Firesteel Creek Watershed.

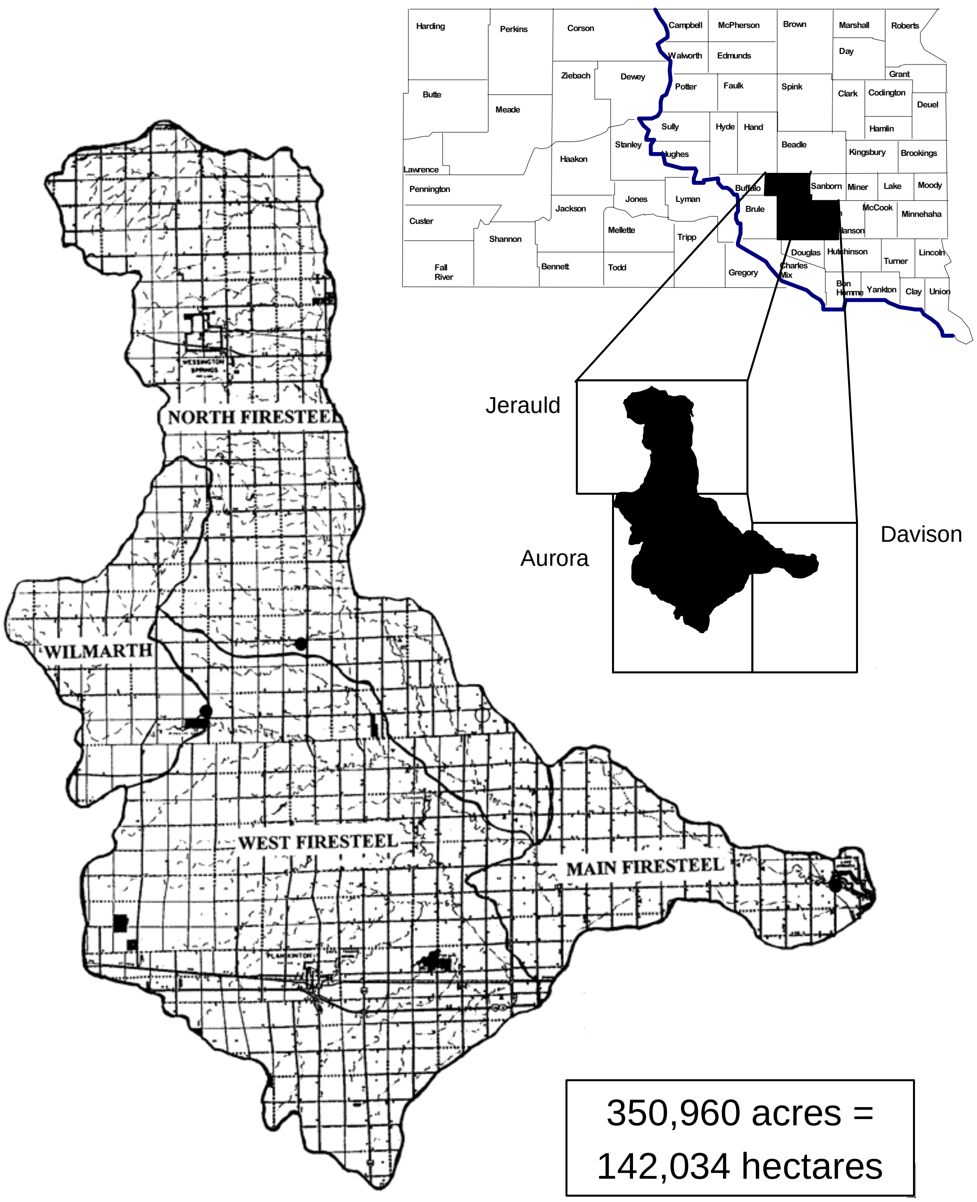
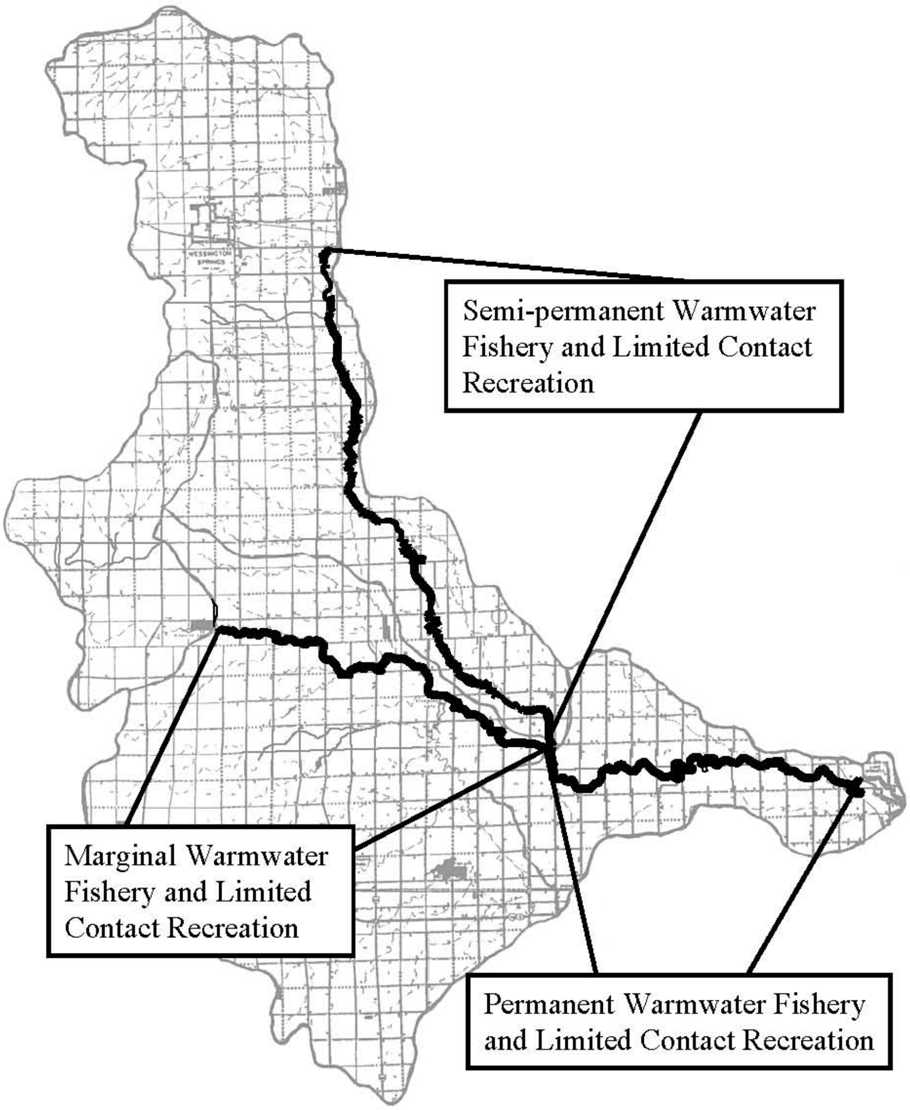


Figure 2. Firesteel Creek beneficial use locations.



Assessment project water quality sample results and computer modeling indicated that although the sediment loading was low compared to other eastern South Dakota watersheds, nutrient (phosphorus) concentrations were high. Analysis of the results indicated that the most likely sources of the nutrient loading were animal feeding operations (AFOs) and/or intense summer long grazing. The impact of grazing was difficult to quantify. AFOs were estimated to contribute 51 percent of the soluble phosphorus (P) load the watershed. The AGNPS reduction response model estimated that a 50 percent reduction in P inputs would reduce in-lake phosphorus by 17 percent and decrease chlorophyll *a* concentrations sufficient to reduce the TSI for chlorophyll *a* to a mesotrophic level (Phase I Final Report).

It was recommended that AFOs with an AGNPS non-corrected rating of > 30 or a distance corrected rating > 20 be targeted for treatment. Of the 241 animal feeding operations assessed, 116 were identified as having a non-corrected AGNPS ranking > 30; 155 feeding operations a distance corrected AGNPS ranking of > 20 (Table 2.). Computer simulations indicated that if the potential runoff from the 37 feedlots with a non-distance ranking of > 50 were addressed; the soluble P concentrations delivered to Lake Mitchell would be reduced by approximately 37 percent.

Table 2. AGNPS rating for animal feeding operations (AFOs).

Rating	Non-distance corrected	Distance corrected
91 - 100	0	0
81 - 90	0	0
71 - 80	6	1
61 - 70	7	1
51 - 60	24	0
41 - 50	36	4
31 - 40	43	26
21 - 30	48	51
11 - 20	37	72
0 - 10	40	86
TOTALS	241	241

AGNPS rank 81 - 100 = extremely critical
AGNPS rank 61 - 80 = very critical
AGNPS rank 41 – 60 = critical
AGNPS rank 21 – 40 = possibly critical
AGNPS rank 0 – 20 = not critical

The Firesteel Creek Watershed Project is the result of recommendations made by the diagnostic/feasibility study. Funding for project activities was made possible, in part, by grants awarded by the United States Environmental Protection Agency to the South Dakota Department of Environment and Natural Resources. In April 1998, a $113,150 EPA 319 grant was awarded to the Firesteel/Lake Mitchell Watershed Project to initiate activities selected to reduce nutrient loading to Lake Mitchell. The amount was increased by $12,500 in September 1998 to assist in the ground-based removal of approximately 18 inches of sediment, or 3000 cubic yards, from the bottom of Plankinton Pond in Plankinton, SD after an oil spill occurrence near the pond in August 1998. Sediment removal and disposal from the Plankinton Pond began in August 1998 and was completed in an environmentally acceptable manner with approval by the State of South Dakota by September 1998. A $738,000 extension grant was awarded in March 1999 to continue the implementation work begun a year earlier. A $340,500 amendment to the extension grant was approved in 2003 to fund a three-year alum demonstration project meant to supplement watershed activities and reduce in-lake P concentrations to decrease algal bloom frequency.

PROJECT GOALS, OBJECTIVES, AND ACCOMPLISHMENTS

The goal of the implementation project is:

Reduce the nutrient (phosphorus) and sediment loading into Lake Mitchell by 50 percent by the year 2015 in order to restore water quality to a level that supports its priority use as a domestic water supply, and other multiple uses. Objectives to reach this goal include:

Objective 1. Reduce phosphorus loadings to Firesteel Creek by approximately 30 to 35 percent through the application of best management practices (BMPs).

Task 1. Provide assistance to farmers/ranchers in the planning, design, and installation/implementation of animal waste storage facilities (WSF) and nutrient management plans (NMP).

Accomplishment: During the 1998-2008 project period, 15 WSF were installed. The first facility installed within the watershed was constructed during late 1995/early 1996 after the watershed assessment was completed. Of the 15 systems installed, 13 were conventional systems designed with sediment basins and evaporation ponds to contain 100 percent of the feedlot runoff. The fourteenth was the relocation of a cow/calf operation away from Firesteel Creek approximately 600 feet with a clean water diversion around the new lot. A fifteenth system built during late 2007 was the relocation of an open-air beef operation to a hoop barn configuration with the manure storage contained under the roof. All systems were designed and certified by NRCS engineering staff.

Table 3. WSF installed and estimated nutrient load reductions.

No.	Type of Operation	Year Built	Animal Units	Days of Confinement	P Load Reduction (tons)
1	Beef	1996	1000	365	0.22
2	Beef	1999	1000	365	0.22
3	Beef	2000	1000	365	0.22
4	Beef	2000	1000	365	0.22
5	Beef	2001	1000	365	0.22
6	Beef	2001	1000	365	0.22
7	Beef	2002	700	270	0.15
8	Beef	2002	1000	365	0.22
9	Beef	2004	600	365	0.13
10	Beef	2005	1000	365	0.22
11	Beef	2005	990	365	0.21
12	Beef	2005	800	365	0.17
13	Beef	2006	999	365	0.24
14	Beef	2007	240	150	0.06
15	Beef	2007	150	270	0.03
TOTALS			12,479		2.75

P load reduction estimates from Annualized Agricultural Nonpoint Source (AnnAGNPS) model using a 25-year storm event.

Task 2. Reroute three City of Mitchell storm sewers that drain into Lake Mitchell to reduce storm drainage area by 75 percent.

Accomplishment: The 1997 Assessment Study Report recommended that three storm sewers be rerouted away from Lake Mitchell. The storm sewers were identified as contributing 4 percent of the phosphorus and 8 percent of the nitrogen and sediment load. By rerouting the storm sewers, the nutrients and sediment from this source would be eliminated.

During 1998, the City of Mitchell completed a major reroute of storm water sewer lines ($2 million State Revolving Fund Loan over 10 years) in conjunction with construction of the Mitchell Highway 37 bypass, effectively rerouting approximately 75 percent of the storm water that was entering Lake Mitchell as cited in the 1997 assessment report. Work was also completed during 2007 to replace and redirect a 24" drain tile constructed during the 1920's that had previously flowed straight to Lake Mitchell. The pipe was replaced with a new, larger storm sewer pipe and redirected to a tributary west of Lake Mitchell with a more controlled structure to act as a sediment settling basin as water velocity slows within the natural drainage above the lake.

P load reduction = (75%)(4% of P load)(63.3 ton annual P load estimate) = 1.90 ton

Objective 2. Reduce sediment and nutrient loadings to Firesteel Creek by 10 to 15 percent through the application of BMPs.

Task 3. Provide assistance to farmers/ranchers in the installation of BMPs that reduce nutrient loadings through the uptake of nutrients, reduction of nutrient transfer, and/or reduction of available nutrients for transport; and practices that reduce sediment transfer through application of land management systems that reduce soil erosion.

Accomplishment: A total of 12,483 acres of pastureland/rangeland were improved within the watershed during the project period through the application of cross fence and exclusion fence for pasture rotation and alternative water supplies (Table 4). Water systems using wells and pipelines were generally seen as more cost-effective and dependable than dugouts or pasture pumps.

Table 4. Other BMP milestones and accomplishments.

	Task	Target	Completed	P Load Reduction (tons/yr)
Grazing Management	Grazing systems	7000 acres	12,483	0.74
Grazing Management	- water systems	10 units	12	
Grazing Management	- pipeline	10 miles	13.5	
Grazing Management	- tanks	30 units	34	
Grazing Management	- fencing	25 miles	28.9	
Grazing Management	- pasture pumps	25 units	6	
Grazing Management	- small dams/dugouts	25 units	13	
Grazing Management	Marginal pastureland wetland buffer (CP30)	0 acres	332	0.05
Cropland Management	Trees	500 acres	800+	
Cropland Management	Filter strips (EPA, CP21, CP28)	500 acres	615	0.19
Cropland Management	Pasture plantings (EPA, EQIP, WHIP)	0 acres	479.5	0.11
Shoreline Stabilization	Shoreline stabilization	700 LF	825 LF	0.01
I & E	Range Map Investigation	1 unit	1 unit	
			TOTAL	1.10

P reduction estimates from STEPL: Spreadsheet Tool for the Estimation of Pollutant Load v. 4.0

The majority of improved pasture/rangeland acres were through the NRCS Environmental Quality Incentive Program (EQIP). Improved acres are reported using the term “prescribed grazing” which is generally defined as a rotational grazing system which ensures that livestock forage demand is balanced with forage supply, has planned periods of growing season rest within grazing units, and season-of-use is alternated between years.

Starting in May 2003, a new Continuous CRP practice began called the Marginal Pastureland Wetland Buffer, or CP30. Livestock are excluded from riparian areas adjacent to perennial or intermittent watercourses for the life of the contract. Like filter strips along cropground, the purpose is to improve and protect water quality by stabilizing streambanks and shorelines and reducing the amount of sediment and other pollutants (i.e. nutrients) in surface runoff. Three-hundred thirty two (332) acres were signed into the CCRP program during the project period.

In 2005, the Firesteel/Lake Mitchell Project was amended to fund a computer modeling effort by the USGS Center for Earth Resources Observation and Science (EROS) data center titled Rangeland Condition Estimates for South Dakota. The GIS maps generated by the data center give a long-term condition of rangelands throughout the state and will be used both on a local and state-wide scale. On a watershed scale, the maps may be useful in determining the approximate number of impaired rangeland acres prior to the application of implementation funds. On a state-wide level, the maps will be useful in locating reference watersheds and stream reaches. The EROS report is located in the Appendix C.

Objective 3. Implement an information and education program on project goals and objectives, animal waste management, and grazing and riparian management.

Task 4. Provide project information to watershed farmers/ranchers, watershed residents, and area citizens through: personnel contacts, on-farm visits, workshops, demonstration sites, tours, the news media, and direct mailings.

Accomplishment: During the project, different media outlets were used to disseminate information about the project goals, objectives, and accomplishments. The project was featured on the front page of the Sioux Falls Argus Leader during 2000 and was the subject of many Mitchell Daily Republic articles. A list of selected presentations given and tours conducted during the project follows. Examples of newsletters and newspaper articles can be seen in Appendix E.

<u>Presentations</u>

- Wessington Springs Farmshow, Wessington Springs, SD (Feb 2000)
- Exchange Club, Mitchell, SD (Apr 2000)
- SD Association of Environmental Professionals, Chamberlain, SD (Oct 2000)
- DWU Biology Club, Mitchell, SD, (Nov 2000, Sep 2003)
- Lion’s Club, Mitchell, SD (Dec 2000, Aug 2006)
- Mitchell City Council, Mitchell, SD (Apr 2001, Nov 2002, Nov 2003, Dec 2003, Feb 2004, Jan 2005, Jun 2005, Nov 2005, Dec 2005, Mar 2006)
- Wal-Mart Earthday Festival, Mitchell, SD (Apr 2001)
- SD Nonpoint Taskforce, Pierre, SD (Nov 2001, Nov 2006)
- Davison Conservation District Awards Banquet, Mitchell, SD (Jan 2002)

Tours

- TMDL meeting & watershed tour (Jul 1999)
- Mitchell City Council watershed tour (Jun 1999, Jul 2006)
- EPA/DENR watershed tour (Aug 2000, Jul 2003, Jun 2007)
- AWS tour for producers (Jul 2001)
- SD Weed Board lake tour (Sep 2003)
- Lower James RC&D watershed tour (Sep 2004)
- US Senate staff/SDACD watershed tour (Aug 2007)
- Statewide RC&D staff training tour (Sep 2007)

Other

- DakotaFest participant, Mitchell, SD (Aug 1999, 2000, 2001)
- James River Water Festival participant, Huron, SD (May 2001, 2002, 2003, 2005)
- DWU Science Fair participant, Mitchell, SD (Mar 2000, 2001, 2006, 2007)
- KORN (radio) interview (Jan 2002)
- KSFY (television) interview (Jun 2002, Jul 2005)
- KELO (television) interview (Jul 2002)
- KMIT (radio) interview (May 2003)

Other I & E activities included a free lawn soil testing program offered to lake residents during 2001 using a grant from the Wal-Mart Corporation. Of the 49 lawn samples taken, 31 of them (63 percent) had P concentrations at or above what the SDSU Fertilizer Recommendation Guide considers “very high” and 44 (90 percent) were at or above what is considered “high” (see Firesteel Creek News, June 2001 issue).

A professional-quality publication pertaining to the watershed project was made possible through a NRCS EQIP I & E grant. The 2005 publication highlighted efforts being made throughout the watershed and included sections on grassland management, manure management (both feedlot improvements and nutrient management planning), and lawn and turf management.

Objective 4. Implement a monitoring, reporting, and management program to coordinate project efforts and document progress towards project objectives.

Task 5. Monitor two water quality sites in Firesteel Creek above and below Lake Mitchell through water quality sampling and testing.

Accomplishment: Of the eight tributary locations chosen for collecting water quality and quantity information during watershed assessment, only one, Site 4, (Figure 3.) was continually monitored during this project. The site was, however, moved during Phase II to correspond with the location of a United States Geologic Survey (USGS) satellite data collection platform (DCP) site north of Mt. Vernon, SD. The DCP was used regularly for stage height information along with instantaneous and daily mean flows. The site was selected to avoid any backwater situations that may have occurred while still being representative of the water quality and quantity entering Lake Mitchell. During 2007, some limited water quality data was also collected at Site 5 on the east branch of Firesteel Creek above the east-west confluence and at Site 6 on the west branch.

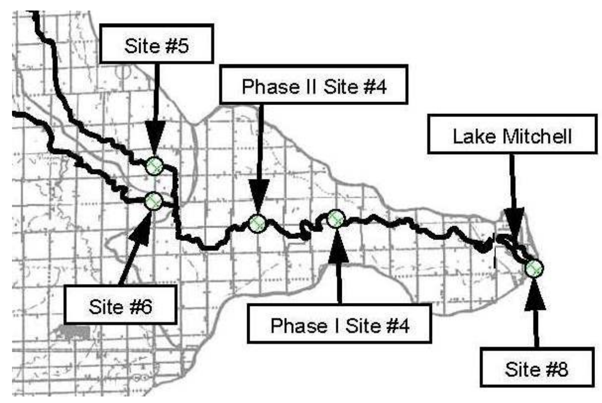
Hydrologic output data at Site 8 (below Lake Mitchell) was measured using a spillway staff gauge for flow readings. Outlet discharges were calculated using the weir equation:

Q = Length x Coefficient x Depth$^{1.5}$

if depth of water over spillway is < 1 foot, then coefficient is 2.8
if depth of water over spillway equals 1 – 2 feet, then coefficient is 3.0
if depth of water over spillway is > 2 feet, then coefficient is 3.1

length = 300 feet.

Figure 3. Location of Site 4, 5, 6, and 8.



Samples collected at each site were taken according to South Dakota's EPA approved *Standard Operating Procedures For Field Samplers* (Stueven et. al 2000). Water samples were then sent to the State Health Laboratory in Pierre, SD for analysis. Quality Assurance/Quality Control samples were collected in accordance to South Dakota's EPA approved *Clean Lakes Quality Assurance/Quality Control Plan* (Stueven et. al 2000). Raw data for Sites 4, 5, 6, and 8 can be seen in Appendix B. Water quality budgets have also been assembled for Sites 4 and 8 using information collected from the USGS satellite data collection platform and outlet discharges (see Appendix B).

Task 6. Document the improvement of ANMF by sampling above and below two (2) feeding areas before and after ANMF installation.

Accomplishment: One attempt of sampling above and below a feeding area was made in April 2001. Because of the distance of feeding locations and the difficulties involved in collecting a sample during the peak stage of a rain event without the use of automatic samplers, it was decided by DENR and project personnel instead to focus more on sampling above and below Lake Mitchell (Task 5). It was also felt that enough literature existed documenting the water quality benefits of installing an ANMF that more would be of little benefit.

Objective 5. Through the application of alum (aluminum sulfate) to Lake Mitchell, reduce in-lake phosphorus concentrations to 90 ppb in order to reach a 50 percent summer bloom frequency.

As efforts were initiated to reduce the phosphorus loading in the long-term, it was determined that Lake Mitchell would be slow to respond to watershed treatments because of the high in-lake P levels. In 2003, an amendment to the existing 319 grant was approved for a three-year alum demonstration project designed to supplement watershed activities and reduce existing in-lake P concentrations in order to decrease algae bloom frequency. The graph below was used to select a desired water quality condition with respect to algae blooms and the corresponding total P value.

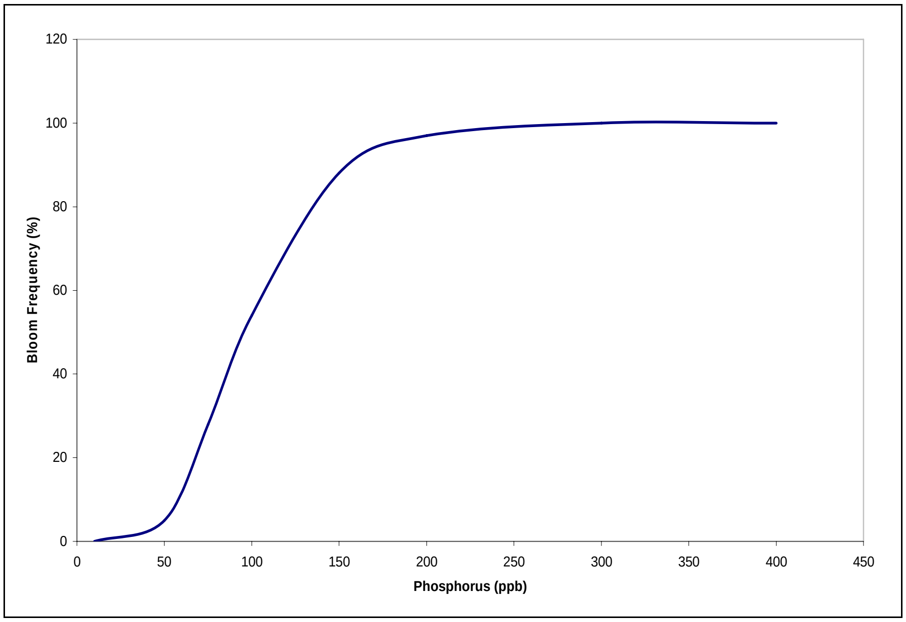


Figure 4. Algae bloom frequency vs. total phosphorus concentration.

Task 7. Apply aluminum sulfate (alum) to Lake Mitchell for three years to remove phosphorus from the water column and (secondarily) reduce internal P loading from lake sediment.

Accomplishment: Completed. Typical alum treatments are usually done as a one-time, whole-lake application sufficient to chemically seal the bottom sediments and retard P release. Under this scenario, it was estimated that 530,000 gallons of alum would need to be applied to Lake Mitchell. But because of concerns with respect to expense and accounting for average annual phosphorus inputs from upstream, it was decided instead to spread the application over a five year period to achieve the same result. Under this scenario, it was estimated that 656,000 gallons of alum would be needed. A final report by the project consultant documenting the applications during 2003, 2004, and 2005, along with recommendations for future treatments can be seen in Appendix D.

Alum applied to Lake Mitchell (in gallons)
2003 – 150,000
2004 – 120,000
2005 – 120,000
2006 – 111,000
Total – 501,000

A fourth application was completed during 2006 by the City of Mitchell, but treatments were discontinued in 2007 because of uncertainty about its effectiveness and expense.

Objective 6. Implement a water quality monitoring program to document effectiveness of alum applications on Lake Mitchell.

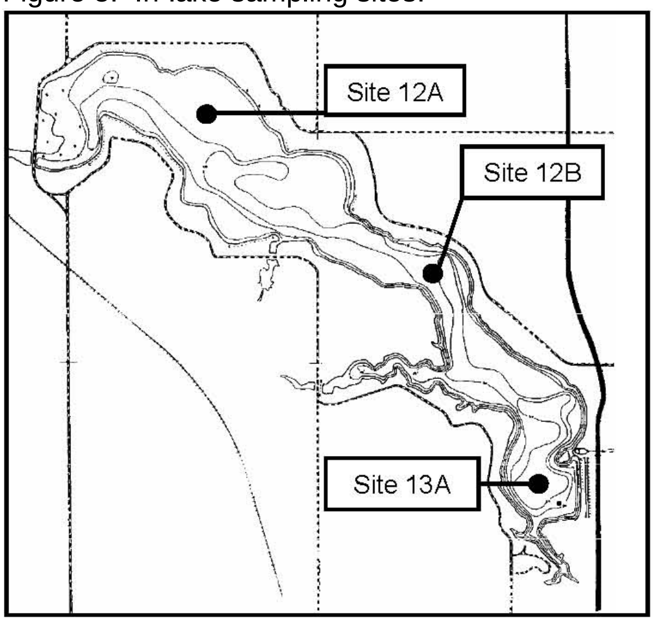
Task 8. Accurately detail Lake Mitchell bottom contours using depth soundings and position measurements.

Accomplishment: Completed May 2003. See Osgood Consulting Final Progress Report (January 2006) in Appendix D.

Task 9. Monitor 3 water quality sites through bi-weekly in-lake sampling and testing from April through October.

Accomplishment: Bi-weekly water quality parameters included total phosphorus concentrations, chlorophyll-a, dissolved oxygen/temperature profiles, and secchi depth readings. Testing was routinely conducted at three sampling sites (Figure 5) during the four years of alum application (2003 - 2006) and also during 2007 when no aluminum sulfate was added to the lake. Raw data monitoring results are located in Appendix B.

Figure 5. In-lake sampling sites.



During 2001, total phosphorus samples were taken on a regular basis to evaluate the condition of the lake and create a baseline for future treatment recommendations. Sampling showed that total P concentrations increased over the course of the growing season (Figure 6). It was thought that this gradual increase was primarily due to P release from lake sediments.

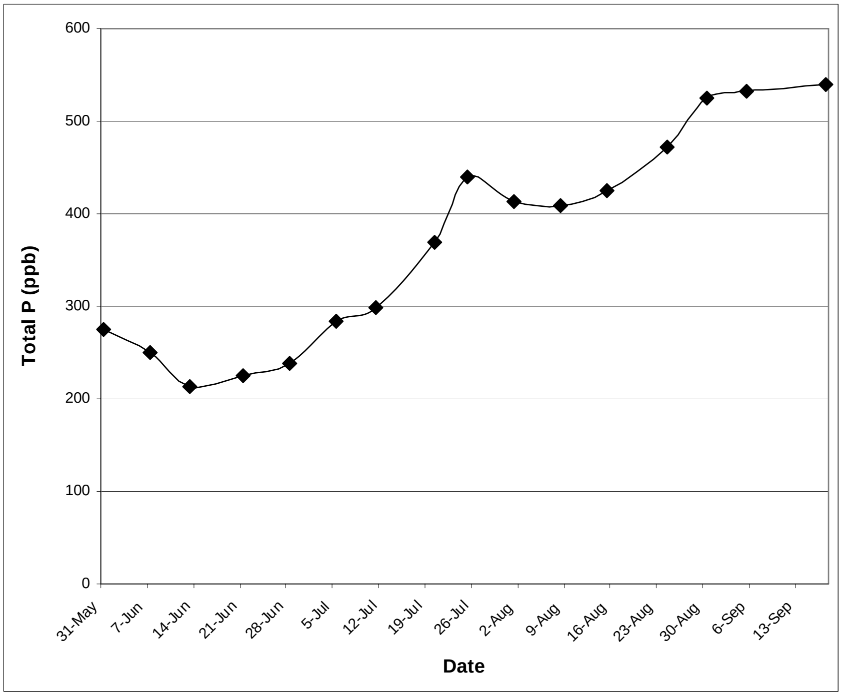


Figure 6. Lake Mitchell Total P concentrations, 2001.

Alum applications began in 2003. Whole-lake applications would generally take place after the peak spring runoff event had occurred but before a major algae bloom had begun; but was also dependent on contractor availability. Similar to 2001, P concentrations trended upwards each year after an initial drop immediately following a spring treatment (Figure 7).

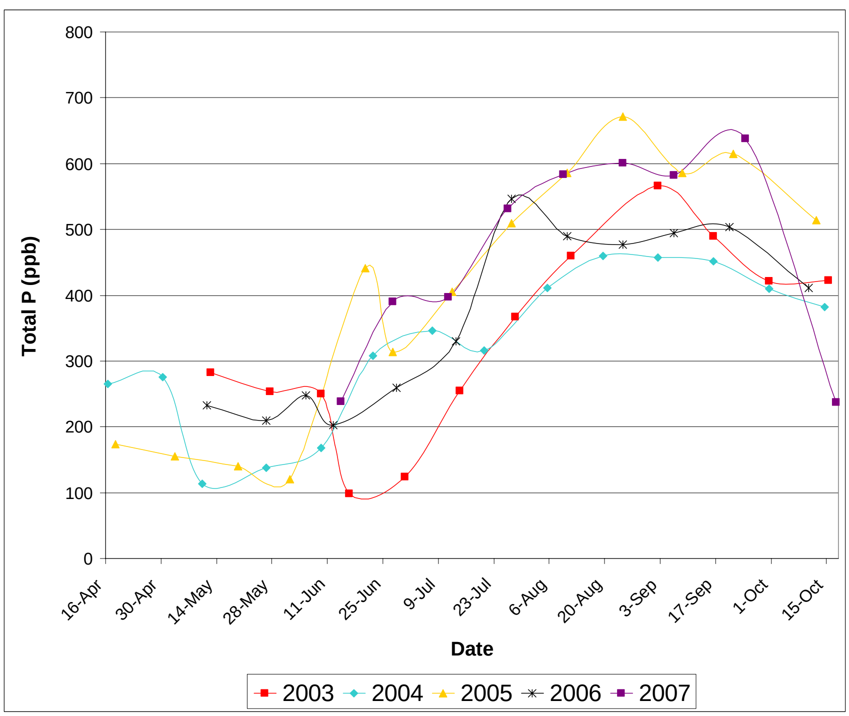


Figure 7. Lake Mitchell Total P concentrations, 2003 – 2007.

It was hoped that over successive years, phosphorus concentrations might begin to level off to a more manageable level but after four years of treatments, these reductions were not being realized. The effects of the alum program on algae control was also inconclusive (Figure 8).

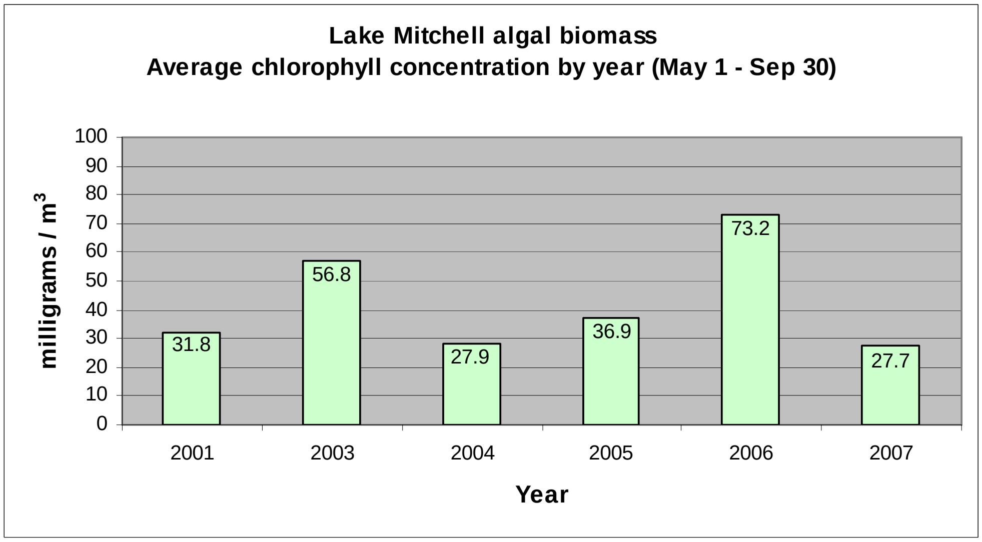


Figure 8. Algal biomass by year.

Despite the fact that water quality monitoring provided little indication that treatments were working as intended; there continued to be anecdotal evidence from lake residents that the alum was having a positive impact on the condition of the lake. Based on the information available and public input, a decision was made by the City of Mitchell to discontinue alum applications in February 2007.

Task 10. Sample and analyze sediment samples from 5 locations on Lake Mitchell before third alum treatment.

Accomplishment: Completed August 2004. See Osgood Consulting Final Progress Report (January 2006) in Appendix D.

Task 11. Monitor 3 water quality sites through monthly in-lake testing from April through October.

Accomplishment: Monthly water quality parameters included total aluminum and alkalinity. A water color test was developed during 2003 but the project consultant felt that the information gained was of little value. Therefore, this test was discontinued for the remainder of the monitoring program. Raw data can be seen in the Appendix B.

Objective 7. Implement a public information program on the effectiveness of the alum applications on Lake Mitchell.

Task 12. Information activities

Accomplishment: As part of the public information program, a Lake Mitchell Alum Treatment Fact Sheet was created in the spring of 2003 and placed at numerous businesses within the city to help explain the application process. The project consultant was also on-hand during the alum applications in the spring and gave regular updates to the city council over the course of the demonstration project which were, in turn; reported by the local newspaper and the different local radio stations.

Objective 8. Prepare final report

Task 13. Prepare a final report assessing the project successes and the effectiveness of BMP implementation in the watershed and alum applications in the lake.

Accomplishment: Completed 2008.

COORDINATION EFFORTS

The Davison Conservation District served as the main sponsor with the City of Mitchell and the Aurora and Jerauld Conservation Districts serving as co-sponsors of the watershed project. District staff for the Davison CD included the project coordinator, a district manager, and a district secretary supervised by a Board of Supervisors. The district coordinated project activities, reported on progress, vouched for grant funds and provided record keeping services. Coordination efforts with other agencies are described below.

STATE AGENCIES

South Dakota Department of Environment and Natural Resources, Clean Water Act Section 319 and Consolidated Water Facilities Construction Program (CWFCP). CWFCP grant used for the design and construction of animal waste management systems and shoreline stabilization projects associated with the Firesteel Creek watershed.

USDA

USDA Natural Resource Conservation Service (NRCS) and Farm Service Agency (FSA) for technical and financial assistance for BMP installation through Conservation Reserve Program (CRP) and the Environmental Quality Incentive Program (EQIP).

South Dakota Nutrient Management Team, Nutrient management planning and design assistance for animal waste management systems. Team funded through NRCS and the South Dakota Association of Conservation Districts (SDACD).

OTHER FEDERAL

US Environmental Protection Agency (EPA) Clean Water Act Section 319 grants awarded through SDDENR for project personnel, I & E activities, and BMP installation.

US Fish & Wildlife Service (FWS) financial assistance for grazing management practices implemented during project.

OTHER

City of Mitchell for technical and financial assistance towards watershed BMP installation, in-lake activities, and shoreline stabilization projects.

Lake Mitchell Development Committee - committee appointed by mayor designed to advise city staff and councils on issues pertaining to Lake Mitchell.

Firesteel/Lake Mitchell Improvement Association - a non-profit, lake resident-based group that contributed cash towards several I & E projects.

Landowners who participated by contributing in-kind and cash match through the installation of watershed BMPs.

ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

Some of the challenges faced were those occasionally encountered during the design and/or construction of animal waste management systems. For example, during construction of an AWS in 2000, a producer realized an access road for feeding was needed but had not been included in the design. A road using two 18" culverts was built between the lots and the sediment basins even though the system was originally designed for the lots to drain directly into the basins. The installation of the culverts interrupted this flow, and as a result, the producer has occasionally had issues with water ponding in his lots during heavy rain events. Although NRCS engineers have since studied the capacity of the existing culverts and have suggested alternatives, it is not known if the producer will take steps to alleviate the situation. Other challenges have come from trying to design a containment system to fit between a feedlot and the receiving waters when the producer is unable or unwilling to relocate. Couple that with some landowners that have changed their mind after final design was completed (whether it be a change in the design itself or walking away from the project all together); it can sometimes be challenging to get systems on the ground.

Alum applications began in 2003 and ended in 2006. Although there was anecdotal evidence from lake residents that alum treatments were having a positive impact on the condition of the lake, water quality monitoring provided little indication that treatments were working as intended. Based on the information available and public input, a decision was made by the City of Mitchell to discontinue alum applications in 2007 because of the uncertainty about its effectiveness and expense. The City determined that future load reductions would be better realized through "upstream" BMP implementation, so the money that was reserved for the 2007 alum treatment was shifted to a new riparian set-aside program which was initiated in 2008 (see Results and Future Recommendations).

RESULTS AND FUTURE ACTIVITY RECOMMENDATIONS

It is estimated that a 9 - 10% phosphorus reduction was realized from project activities implemented through September 2008. This load reduction was accomplished by focusing primarily on improvements to priority feeding operations along the main branches of Firesteel Creek. Animal waste system construction efforts will continue throughout the watershed during Segment 2, which began September 2007.

Along with AWS installation as a part of ongoing activities, a new program called the Firesteel Creek Riparian Area Management (RAM) program began in the spring of 2008 under the current segment of the watershed project. The program is designed to provide landowners an incentive to establish buffer strips along the main stems of Firesteel Creek in order to improve the water quality of Lake Mitchell. Landowners that are eligible are encouraged to enroll cropland or marginal pastureland immediately adjacent to Firesteel Creek into Continuous CRP. If desired, landowners can also enroll areas into the RAM program beyond the maximum allowable width that CRP offers. Fifteen-year lease agreements and/or 30-year or permanent conservation easements are available through the RAM program. The program has received funding from EPA 319, the City of Mitchell, the James River Water Development District, and the Lower James Resource Conservation & Development Council. Efforts to establish more buffers along Firesteel Creek above Lake Mitchell is expected to take on a more significant role in future restoration activities.

LITERATURE CITED

South Dakota Department of Environment and Natural Resources. 1997. Phase I Diagnostic Feasibility Study Final Report. Lake Mitchell / Firesteel Creek, Davison County, South Dakota. South Dakota Watershed Protection Program, Division of Financial and Technical Assistance.

Stueven, Eugene, Alan Wittmuss, and Robert L. Smith. 2000. Standard Operating Procedures for Field Samplers, Revision 4.0. State of South Dakota, Department of Environment and Natural Resources, Water Resource Assistance Program.

Walker, William W. 1996. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. Instruction Report W-96-2. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

APPENDIX A

EPA 319 Project Budgets

Firesteel Creek Watershed Project – original $113,150 start-up grant

ITEM	TOTAL COST	EPA 319	FEDERAL	STATE	LOCAL	PRODUCERS
PERSONNEL/SUPPORT						
Salary/Benefits						
Project Coord./Nat. Res. Specialist	$66,000	$66,000				
Benefits = 20% (3% salary increase/yr.)						
Engineer = 1/3 FTE/yr.	$40,000		$40,000			
Admin./Clerical = 1/3 FTE/yr.	$12,550	$3,150			$9,400	
Office Rent/Utilities ($150/month/person)	$8,000				$8,000	
Travel						
Mileage = 16,000 mi. @ $ 0.24/mi.	$3,840	$3,840				
Lodging/Per Diem = 6 days @ $ 70 ea.	$420				$420	
Phone						
Local = $200/yr x 2 yr.	$400				$400	
Long Distance = $300/yr x 2 yr.	$600				$600	
Equipment & Supplies						
Computer/Printer $500/yr. x 2 yr.	$1,000				$1,000	
Copier = $300/yr. X 2 yr.	$600				$600	
FAX = $25/yr x 2 yr.	$50				$50	
Supplies & Printing = $1000/yr x 2 yr.	$2,000				$2,000	
SUBTOTAL: PERSONNEL	**$135,460**	**$72,990**	**$40,000**	**$0**	**$22,470**	**$0**
OBJECTIVE 1: NUTRIENT REDUCING BMPs						
TASK 1: Animal Waste Systems/Nutr. Mgt.						
Ag Waste Sys. = 3 @ $50,000	$150,000	$24,495	$46,500	$17,505	$24,000	$37,500
Nutrient Mgt. Plans = 3 on 1200 ac. @ $5/ac.	$6,000					$6,000
TASK 2: Storm Water Sewer Reroute						
SRF Payment = $200,000/yr.	$400,000				$400,000	
TASK 3: Additional BMPs						
Seeding 200 ac. @ $50/ac.	$10,000		$7,500			$2,500
Tree Planting: 4 sites @ $2000/site	$8,000		$6,000			$2,000
Pasture Pumps: 5 @ $500 each	$2,500	$1,875				$625
Stockwater Ponds: 2 @ $3500 each	$7,000		$5,250			$1,750
Stockwater Pipeline: 2,500 LF @ $1.40/LF	$3,500		$2,625			$875
Livestock Tanks: 2 @ $1250 each	$2,500		$1,875			$625
Fencing: 5,000 LF @ $ .66/LF	$3,300		$2,475			$825
Stream Crossings: 1 @ $1500 each	$1,500	$1,125				$375
Planned Grazing Syst.: 1000 ac. @ $6/ac./2 yr.	$6,000	$4,500				$1,500
SUBTOTAL: OBJ. 1	**$600,300**	**$31,995**	**$72,225**	**$17,505**	**$424,000**	**$54,575**
OBJECTIVE 2: SEDIMENT REDUCING BMPs						
TASK 4: BMP Installation						
Seeding: 500 ac. @ $ 50/ac.	$25,000		$16,250	$2,500		$6,250
Tree Planting: 8 sites @ $2000/site	$16,000		$6,000	$2,000	$2,000	$6,000
Stockwater Ponds: 2 @ $3500 each	$7,000		$5,250			$1,750
Stockwater Pipeline: 2,500 LF @ $1.40/LF	$3,500		$2,625			$875
LIvestock Tanks: 1 @ $1250 each	$1,250		$938			$313
Fencing: 2,500 LF @ $ .66/LF	$1,650		$1,238			$413
Streambank Stab. (veg) 1 site @ $2500/site	$2,500		$1,875			$625
Conservation Tillage: 2000 ac. @ $15/ac.	$30,000			$5,000		$25,000
Sod Waterways: 1300 LF @ $1/LF	$1,300		$975			$325
Wetland Restoration: 40 ac. @ $50/ac.	$2,500		$1,875			$625
SUBTOTAL: OBJ. 2	**$90,700**	**$0**	**$37,025**	**$9,500**	**$2,000**	**$42,175**
OBJECTIVE 3: INFORMATION & EDUCATION						
TASK 5: Info. & Ed. Activities						
(Cost not shown are personnel costs						
already in the Personnel Budget)						
On-Farm visits: 200 @ $130 ea.						
Presentations: 5 @ $100 ea.						
Workshops: 2 @ $500 ea.	$1,000	$750			$250	
News Releases: 4 @ $50 ea.						
Newsletter Art.: 6 @ $50 ea.						
Inf. Mailings: 1000 @ $ 0.50 ea.						
SUBTOTAL: OBJ. 3	**$1,000**	**$750**	**$0**	**$0**	**$250**	**$0**
OBJECTIVE 4: MONITORING & EVALUATION						
TASK 6: Monitor Two Sites						
Sampling: 2 sites, 48 samples @ $110 ea.	$5,280	$5,280				
QA/QC on 10% of samples	$375	$375				
TASK 7: Monitor 2 Ag Waste Systems						
Sample 2 Systems: 16 samples @ $110 ea.	$1,760	$1,760				
TASK 8: Evaluation & Reporting						
Annual Reports: 2 @ $250 ea. (see pers. budget)						
BMPs/Progress Doc.: 6 days @ $128/day						
(part of pers. budget)						
SUBTOTAL: OBJ. 4	**$7,415**	**$7,415**	**$0**	**$0**	**$0**	**$0**
PROJECT TOTAL	**$834,875**	**$113,150**	**$149,250**	**$27,005**	**$448,720**	**$96,750**

Firesteel Creek Watershed Project – original $738,000 extension grant

ITEM	QTY	TOTAL COST	USDA CRP/EQIP	EPA 319	CWFCP	CONS. COMM.	CITY OF MITCHELL	NRCS	CONS. DIST.	LOCAL	OTHER
CONSERVATION ACTIVITIES											
Ag. Waste Systems	28	$1,282,000	$604,000	$194,000	$120,000	$20,000	$80,000			$254,000	$10,000
Clean Water Diversion	15	$39,000		$13,450		$4,000	$9,550			$10,000	$2,000
Water Systems	10	$78,000		$15,000		$4,000	$9,000			$50,000	
Pipelines	10 mi.	$101,900	$27,700	$10,000		$8,000	$6,200			$50,000	
Tanks	30	$24,000	$6,000	$2,000		$2,000	$2,000			$12,000	
Small dams / ponds / dugouts	25	$84,500		$5,000	$32,000	$8,250	$8,000			$31,250	
Pasture Pumps	25	$12,500		$2,250		$2,500	$1,500			$6,250	
Grazing Systems	7,000 ac.	$84,000		$22,000		$20,000				$42,000	
Cross Fencing	55 mi.	$192,400	$48,100	$13,150		$30,000	$5,000			$96,150	
Trees	500 ac.	$125,000	$62,500	$20,000		$10,000				$28,250	$4,250
Grass / Buffer Strips	500 ac.	$50,000	$12,500	$13,750		$13,000	$10,750				
Shoreline Stabilization	700 lf	$58,000		$10,000	$38,000	$4,000	$6,000				
SUBTOTAL		**$2,131,300**	**$760,800**	**$320,600**	**$190,000**	**$125,750**	**$138,000**	**$0**	**$0**	**$579,900**	**$16,250**
PERSONNEL / SUPPORT											
Project Coordinator		$310,000		$310,000							
Engineering / Tech. Assist.		$140,000		$56,000		$5,000	$10,000	$69,000			
Admin. / Clerical / Planning		$24,000		$12,000		$12,000					
Office Space		$32,000						$32,000			
Travel		$19,200		$12,000				$3,200	$4,000		
Phone / Long Distance		$3,000		$2,000				$1,000			
Office Supplies		$4,000		$2,000				$1,000	$1,000		
SUBTOTAL		**$532,200**	**$0**	**$394,000**	**$0**	**$17,000**	**$10,000**	**$106,200**	**$5,000**	**$0**	**$0**
INFORMATION & EDUCATION											
Newsletters		$4,000		$2,000		$2,000					
Informational Meetings		$1,400		$600		$600				$200	
Mailings		$1,600		$1,300		$300					
Pictures / Slides		$2,500		$1,500		$1,000					
Reports / Audit		$5,000		$3,000			$1,000		$1,000		
SUBTOTAL		**$14,500**	**$0**	**$8,400**	**$0**	**$3,900**	**$1,000**	**$0**	**$1,000**	**$200**	**$0**
MONITORING											
Monitor 2 Sites		$20,000		$12,000			$8,000				
Sample Ag. Waste Systems		$6,000		$3,000			$3,000				
SUBTOTAL		**$26,000**	**$0**	**$15,000**	**$0**	**$0**	**$11,000**	**$0**	**$0**	**$0**	**$0**
TOTAL		**$2,704,000**	**$760,800**	**$738,000**	**$190,000**	**$146,650**	**$160,000**	**$106,200**	**$6,000**	**$580,100**	**$16,250**

APPENDIX B

Water Quality Data

Site 4 Water Quality Raw Data, 1999 – 2007

Site	Date	Time	inst. flow (cfs)	daily flow (cfs)	air temp (C)	H_2O temp (C)	DO (mg/L)	pH	fecal coliform (per 100 ml)	E. coli (per 100 ml)	alkalinity-m (mg/L)	alkalinity-p (mg/L)	TS (mg/L)	SS (mg/L)	DS (mg/L)	TKN (mg/L)	nitrate (mg/L)	ammonia (mg/L)	total P (mg/L)	total diss P (mg/L)	% diss P
4	30-Mar-99	11:15 AM	18.0	17.0	15.6	10.6	12.4	8.52	52	NA	295	0	1978	55	1923	1.40	<0.1	0.15	0.204	0.066	32.4%
4	06-Apr-99	1:00 PM	21.0	21.0	15.6	9.2	13.8	NA	100	NA	286	0	1801	37	1764	1.15	0.2	<0.02	0.215	0.080	37.2%
4	13-Apr-99	9:15 AM	1150.0	1100.0	12.8	10.8	8.6	7.73	5,700	NA	120	0	800	120	680	1.80	1.2	0.11	0.572	0.338	59.1%
4	06-May-99	9:15 AM	1660.0	1760.0	10.0	11.2	8.4	7.72	11,000	NA	145	0	1038	320	718	2.45	1.4	0.13	0.898	0.121	13.5%
4	08-Jun-99	9:45 AM	NA	62.0	23.9	22.6	8.6	8.15	1,500	NA	282	8	1010	82	928	2.54	0.2	<0.02	0.715	0.457	63.9%
4	20-Jul-99	1:00 PM	32.0	31.0	26.7	27.1	10.4	8.20	900	NA	300	0	894	186	708	2.16	<0.1	0.02	0.911	0.528	58.0%
4	31-Aug-99	9:30 AM	6.5	6.2	21.1	22.8	7.2	8.20	2,900	NA	278	4	1148	96	1052	1.69	0.1	<0.02	0.442	0.162	36.7%
4	20-Apr-00	2:15 PM	2.7	2.3	12.8	14.0	7.2	8.32	60	NA	275	0	1640	42	1598	1.12	<0.1	<0.02	0.190	0.040	21.1%
4	25-May-00	9:40 AM	1.4	1.3	18.3	16.6	8.5	8.23	1,600	NA	310	0	2230	50	2180	1.65	<0.1	<0.02	0.242	0.056	23.1%
4	21-Jun-00	1:30 PM	0.4	0.4	25.0	20.7	9.9	8.36	17,000	NA	259	0	2388	68	2320	1.41	<0.1	<0.02	0.309	0.073	23.6%
4	08-Aug-00	8:45 AM	0.5	0.5	18.9	23.0	4.0	7.83	1,900	NA	162	0	1033	132	901	2.19	<0.1	0.07	0.497	0.032	6.4%
4	29-Mar-01	1:00 PM	NA	60.0	3.3	1.8	7.0	8.06	5	6.1	111	0	537	27	510	2.42	1.0	1.12	0.976	0.862	88.3%
4	03-Apr-01	11:45 AM	NA	650.0	3.3	0.8	11.1	8.05	50	66.9	77	0	437	152	285	2.09	0.7	0.89	0.948	0.567	59.8%
4(D)	03-Apr-01	-	-	-	-	-	-	-	50	101.7	76	0	439	152	287	2.14	0.7	0.92	0.908	0.592	-
4(B)	03-Apr-01	-	-	-	-	-	-	-	<10	<1	<6	0	<7	<1	-	<0.36	<0.1	<0.02	<0.002	0.002	-
4	09-Apr-01	8:30 AM	1460.0	1390.0	2.8	7.9	8.7	7.74	3,000	548.0	85	0	539	176	363	1.11	0.9	0.40	0.868	0.508	58.5%
4	12-Apr-01	12:00 PM	856.0	874.0	6.7	6.2	11.9	8.20	660	649.0	80	0	437	66	371	1.27	0.4	0.12	0.675	0.480	71.1%
4	24-Apr-01	8:15 AM	2140.0	2320.0	4.4	6.4	9.8	7.95	21,000	>2420	89	0	630	300	330	1.07	0.8	0.18	1.080	0.539	49.9%
4	07-May-01	12:15 PM	903.0	832.0	15.6	13.8	8.5	8.07	14,000	>2420	140	0	788	156	632	1.49	0.4	0.05	0.866	0.564	65.1%
4	31-May-01	9:15 AM	21.0	21.0	15.6	17.5	6.8	8.20	290	687.0	273	0	1190	18	1172	0.75	0.1	<0.02	0.302	0.240	79.5%
4	14-Jun-01	12:30 PM	46.0	46.0	18.3	21.1	8.5	8.28	1,300	1,990.0	233	0	1207	39	1168	1.44	0.2	<0.02	0.397	0.264	66.5%
4	02-Jul-01	9:30 AM	10.0	9.9	15.6	18.5	7.2	8.41	880	727.0	263	7	1117	37	1080	0.75	0.1	0.03	0.353	0.256	72.5%
4(D)	02-Jul-01	-	-	-	-	-	-	-	1,200	920.0	259	0	1124	38	1086	0.75	0.1	0.04	0.347	0.256	-
4(B)	02-Jul-01	-	-	-	-	-	-	-	<10	<1	<6	0	7	<1	-	<0.36	0.1	<0.02	<0.002	0.002	-
4	27-Jul-01	1:25 PM	3.1	2.9	23.9	23.8	7.9	8.33	NA	NA	290	3	1331	46	1285	1.28	<0.1	<0.02	0.277	0.077	27.8%
4	30-Mar-02	10:15 AM	41.0	47.0	-	0.5	12.9	8.26	NA	NA	87	0	462	41	421	2.29	1.1	0.52	0.864	0.669	77.4%
4	02-Apr-02	9:30 AM	17.0	17.0	-1.1	2.0	12.5	8.40	10	21.3	104	0	617	26	591	1.90	1.0	0.34	0.727	0.601	82.7%
4	08-Apr-02	10:45 AM	15.0	15.0	10.0	8.5	11.2	8.27	5	5.2	118	0	590	40	550	2.11	0.6	<0.02	0.522	0.359	68.8%
4	22-Apr-02	9:30 AM	2.2	2.1	4.4	6.1	12.6	8.48	5	7.4	201	0	1020	17	1003	1.31	<0.1	<0.02	0.181	0.054	29.8%
4	29-Apr-02	9:00 AM	2.6	2.7	5.6	7.4	12.2	8.50	5	9.8	220	0	1151	35	1116	1.29	<0.1	<0.02	0.175	0.035	20.0%
4	09-May-02	9:30 AM	7.8	7.9	5.6	5.7	12.5	8.58	110	>2420	242	2	1398	33	1365	1.14	0.1	<0.02	0.199	0.041	20.6%
4	22-Aug-02	8:15 AM	5.1	3.8	21.1	22.3	4.0	8.03	16,000	>2420	211	0	1131	236	895	1.20	0.2	0.03	0.620	0.059	9.5%
4	17-Mar-03	8:45 AM	8.3	7.5	7.2	0.4	13.7	8.18	<10	5.2	125	0	545	11	534	1.14	0.2	0.02	0.310	0.226	72.9%
4(D)	17-Mar-03	-	-	-	-	-	-	-	10	2.0	126	0	541	12	529	1.30	0.2	0.03	0.322	0.240	-
4(B)	17-Mar-03	-	-	-	-	-	-	-	<10	<1	<6	0	<7	<1	-	<0.11	<0.1	<0.02	<0.002	<0.002	-
4	11-Apr-03	11:00 AM	1.0	0.9	12.8	13.2	10.2	8.33	NA	NA	202	0	936	64	872	1.08	<0.1	<0.02	0.244	0.030	12.3%
4	25-Jun-03	9:15 AM	0.8	0.7	12.8	21.2	2.6	na	7,400	>2420	242	0	1795	94	1701	1.74	<0.1	<0.02	0.372	0.048	12.9%
4	19-Mar-04	9:30 AM	0.3	0.6	10.0	5.5	15.0	8.56	NA	NA	191	0	985	19	966	1.15	<0.1	<0.02	0.134	0.023	17.2%
4	01-Apr-04	9:00 AM	1.5	1.8	7.2	9.3	11.2	8.39	20	30.5	209	0	1043	49	994	0.83	<0.1	<0.02	0.164	0.029	17.7%
4	22-Apr-04	9:45 AM	1.3	0.8	4.4	11.7	9.7	8.43	130	121.0	276	0	1473	48	1425	1.36	<0.1	<0.02	0.184	0.033	17.9%
4	17-May-04	10:00 AM	5.6	3.4	8.9	12.9	7.4	8.22	320	326.0	236	0	1300	78	1222	1.31	<0.1	<0.02	0.224	0.030	13.4%
4	24-May-04	2:00 PM	36.0	31.0	9.4	14.5	6.3	8.11	1,800	1,550.0	173	0	773	66	707	1.87	0.6	0.08	0.548	0.260	47.4%
4	01-Jun-04	9:00 AM	259.0	240.0	12.8	15.6	5.6	8.01	2,700	2,420.0	108	0	484	154	330	2.43	0.5	0.07	1.170	0.730	62.4%
4	10-Jun-04	9:45 AM	288.0	315.0	16.7	17.2	2.0	8.01	2,800	>2420	104	0	588	164	424	2.65	1.8	0.19	1.110	0.678	61.1%
4	14-Jun-04	1:00 PM	506.0	509.0	23.9	24.6	0.0	7.93	230	184.0	132	0	543	52	491	1.85	<0.1	<0.02	1.000	0.857	85.7%
4	24-Sep-04	12:45 PM	14.0	14.0	18.9	14.3	11.0	8.46	NA	NA	305	0	1184	52	1132	1.01	<0.1	<0.02	0.214	0.059	27.6%

Site 4 Water Quality Raw Data, 1999 – 2007 cont.

Site	Date	Time	inst. flow (cfs)	daily flow (cfs)	air temp (C)	H_2O temp (C)	DO (mg/L)	pH	fecal coliform (per 100 ml)	E. coli (per 100 ml)	alkalinity-m (mg/L)	alkalinity-p (mg/L)	TS (mg/L)	SS (mg/L)	DS (mg/L)	TKN (mg/L)	nitrate (mg/L)	ammonia (mg/L)	total P (mg/L)	total diss P (mg/L)	% diss P
4	29-Mar-05	9:30 AM	1.9	1.9	12.8	11.2	10.6	8.46	10	8.5	257	0	1435	24	1411	0.59	<0.1	<0.02	0.132	0.036	27.3%
4(D)	29-Mar-05	-	-	-	-	-	-	-	20	9.8	257	0	1431	24	1407	0.57	<0.1	<0.02	0.128	0.037	-
4(B)	29-Mar-05	-	-	-	-	-	-	-	<2	<1	<6	0	<7	<1	-	<0.50	<0.1	<0.02	<0.002	<0.002	-
4	12-Apr-05	9:15 AM	1.5	1.8	5.6	9.0	10.5	8.51	<10	42.8	270	1	1501	26	1475	0.73	<0.1	<0.02	0.166	0.064	38.6%
4	22-Apr-05	10:30 AM	10.0	11.0	7.2	9.6	10.8	8.39	NA	NA	293	0	1621	29	1592	0.71	<0.1	<0.02	0.190	0.089	46.8%
4	26-Apr-05	8:45 AM	19.0	20.0	5.6	9.5	9.5	8.43	280	344.0	283	0	1978	44	1934	1.56	2.4	<0.02	0.278	0.128	46.0%
4	12-May-05	10:30 AM	7.3	4.3	8.3	9.6	10.4	8.40	700	649.0	268	0	1461	28	1433	1.13	<0.1	<0.02	0.184	0.067	36.4%
4	17-May-05	2:15 PM	74.0	60.0	23.9	20.5	10.8	8.45	450	770.0	271	0	1755	29	1726	1.46	0.6	<0.02	0.272	0.166	61.0%
4	26-May-05	9:00 AM	16.0	9.2	12.8	14.9	7.2	8.31	910	525.0	262	0	1469	60	1409	1.79	<0.1	0.07	0.244	0.100	41.0%
4	06-Jun-05	10:15 AM	13.0	10.0	22.8	21.1	8.6	8.44	1,900	2,420.0	262	0	606	53	553	1.48	<0.1	<0.02	0.269	0.057	21.2%
4	08-Jun-05	10:15 AM	28.0	20.0	18.3	22.4	7.3	8.45	1,300	1,410.0	280	1	1386	39	1347	1.36	<0.1	<0.02	0.270	0.086	31.9%
4	10-Jun-05	11:30 AM	66.0	37.0	16.7	18.8	6.5	8.24	NA	NA	223	0	1278	47	1231	2.07	1.7	0.19	0.363	0.221	60.9%
4	16-Jun-05	10:15 AM	548.0	541.0	18.3	22.1	3.7	8.16	420	291.0	137	0	560	76	484	1.72	0.4	0.09	0.917	0.669	73.0%
4	23-Jun-05	8:45 AM	99.0	80.0	23.9	25.8	4.4	8.24	400	579.0	218	0	744	26	718	1.89	0.2	0.19	1.110	0.887	79.9%
4	19-Jul-05	8:45 AM	1.8	4.2	22.2	23.0	5.7	8.45	150	5.1	403	3	1313	92	1221	2.20	<0.1	<0.02	0.649	0.239	36.8%
4(D)	19-Jul-05	-	-	-	-	-	-	-	220	8.3	403	2	1313	92	1221	2.57	<0.1	<0.02	0.633	0.228	-
4(B)	19-Jul-05	-	-	-	-	-	-	-	<10	<1	<6	0	<7	<1	-	<0.5	<0.1	<0.02	0.003	0.005	-
4	04-Aug-05	9:45 AM	5.1	2.0	17.8	22.4	3.9	8.30	2,500	244.0	291	0	1338	94	1244	2.89	0.1	0.11	0.695	0.239	34.4%
4	20-Sep-05	9:30 AM	0.3	0.2	14.4	17.7	4.3	8.23	7,500	>2420	323	0	1921	52	1869	2.16	<0.1	<0.02	0.365	0.014	3.8%
4	03-Apr-06	11:45 AM	1.9	0.9	8.9	7.5	11.7	8.38	<10	2.0	228	0	1415	12	1403	0.85	<0.1	<0.02	0.116	0.036	31.0%
4	07-Apr-06	9:45 AM	29.0	37.0	5.6	8.5	10.4	8.32	NA	NA	213	0	1405	156	1249	1.34	0.3	0.06	0.314	0.076	24.2%
4	20-Apr-06	11:00 AM	5.9	7.9	8.9	8.1	12.4	8.59	60	52.0	238	0	1486	39	1447	1.77	0.1	<0.02	0.264	0.052	19.7%
4	14-Mar-07	9:15 AM		700.0	4.4	2.0	9.6	7.76	20	28.5	91	0	457	186	271	2.94	0.7	0.92	0.976	0.532	54.5%
4	19-Mar-07	8:50 AM	122.0	131.0	1.7	5.6	10.7	8.07	30	21.3	93	0	424	24	400	2.27	0.6	0.41	0.734	0.684	93.2%
4	26-Mar-07	9:00 AM	40.0	42.0	12.8	11.2	NA	8.08	20	11.0	138	0	661	39	622	2.07	0.2	<0.02	0.525	0.378	72.0%
4	02-Apr-07	9:00 AM	37.0	37.0	4.4	NA	NA	8.04	1,500	>2420	185	0	1001	27	974	2.54	<0.1	0.13	0.571	0.390	68.3%
4	16-Apr-07	9:20 AM	19.0	15.0	10.0	11.2	9.7	8.41	10	8.6	210	0	1168	22	1146	1.00	<0.1	<0.02	0.278	0.191	68.7%
4	24-Apr-07	10:00 AM	317.0	320.0	9.4	14.3	6.8	8.09	400	921.0	143	0	717	184	533	1.52	0.3	0.05	0.590	0.276	46.8%
4(D)	24-Apr-07	-	-	-	-	-	-	-	390	816.0	143	0	720	180	540	1.56	0.3	0.06	0.630	0.270	-
4(B)	24-Apr-07	-	-	-	-	-	-	-	<10	<1	<6	0	<7	<3		<0.50	<0.1	<0.02	<0.002	<0.002	
4	26-Apr-07	10:00 AM	199.0	195.0	12.8	12.7	8.3	7.95	90	276.0	132	0	636	39	597	1.33	0.2	<0.02	0.539	0.412	76.4%
4	03-May-07	9:15 AM	35.0	28.0	10.0	16.1	7.9	8.21	20	24.3	197	0	833	14	819	1.33	<0.1	<0.02	0.421	0.326	77.4%
4	07-May-07	10:30 AM	2440.0	2350.0	14.4	17.7	4.1	7.91	3,200	2,420.0	121	0	626	244	382	1.73	0.5	0.18	0.973	0.397	40.8%
4	10-May-07	9:15 AM	800.0	802.0	18.3	21.0	3.9	7.94	1,200	1,300.0	108	0	370	51	319	1.12	0.1	<0.02	0.650	0.510	78.5%
4	16-May-07	9:30 AM	90.0	86.0	11.1	16.7	7.4	8.27	220	229.0	173	0	561	23	538	0.92	0.1	0.06	0.737	0.611	82.9%
4	23-May-07	9:15 AM	28.0	26.0	12.8	19.1	7.8	8.45	630	690.0	222	0	756	21	735	1.16	<0.1	<0.02	0.475	0.363	76.4%
4	04-Jun-07	9:00 AM	226.0	198.0	18.3	19.6	6.9	8.12	700	1,160.0	119	0	460	54	406	1.34	1.2	0.05	0.803	0.585	72.9%
4	11-Jun-07	10:30 AM	46.0	39.0	24.4	24.8	6.7	8.31	1,900	3,110.0	196	0	725	27	698	1.38	<0.1	<0.02	0.625	0.497	79.5%
4	15-Jun-07	9:15 AM	371.0	311.0	-	22.9	6.1	7.95	NA	NA	124	0	558	68	490	2.29	1.4	0.13	1.410	1.200	85.1%
4	26-Jun-07	10:30 AM	73.0	77.0	22.2	25.2	6.4	8.31	640	519.0	205	0	610	36	574	1.54	<0.1	<0.02	1.050	0.879	83.7%

Site 5 Water Quality Raw Data, 2007

Site	Date	Time	air temp (C)	H_2O temp (C)	DO (mg/L)	fecal coliform (per 100 ml)	E. coli (per 100 ml)	SS (mg/L)	total P (mg/L)	Comments
5	14-Mar-07	10:40 AM	4.4	3.6	8.3	130	272	30	0.856	
5	19-Mar-07	9:15 AM	1.7	5.2	9.5	<10	26.9	13	0.722	
5	26-Mar-07	9:30 AM	12.8	11.8	NA	30	55.6	22	0.598	
5	2-Apr-07	9:30 AM	4.4	NA	NA	80	72.8	24	0.538	
5	7-May-07	10:10 AM	14.4	17.5	3.3	3100	>2420	63	0.791	sample taken at next bridge below Site 5
5	10-May-07	10:00 AM	18.3	20.5	2.1	340	449	16	0.528	sample taken at next bridge below Site 5
5	16-May-07	10:10 AM	11.1	16.3	4.6	80	62.8	8	0.745	

Site 6 Water Quality Raw Data, 2007

Site	Date	Time	air temp (C)	H_2O temp (C)	DO (mg/L)	fecal coliform (per 100 ml)	E. coli (per 100 ml)	SS (mg/L)	total P (mg/L)
6	14-Mar-07	11:00 AM	4.4	2.7	9.7	10	32.3	170	1.000
6	19-Mar-07	9:30 AM	1.7	5.1	10.8	<10	6.3	15	0.716
6	26-Mar-07	9:45 AM	12.8	11.3	NA	<10	1.0	24	0.420
6	2-Apr-07	9:45 AM	4.4	NA	NA	210	236.0	9	0.290
6	7-May-07	9:45 AM	14.4	17.4	5.8	1600	1120.0	180	0.984
6	10-May-07	9:45 AM	18.3	20.2	5.9	360	345.0	78	0.837
6	16-May-07	9:50 AM	11.1	16.4	7.7	120	123.0	12	0.687

Site 8 Water Quality Raw Data, 1999 - 2007

Site	Date	Time	air temp (C)	H_2O temp (C)	DO (mg/L)	pH	fecal coliform (per 100 ml)	E. coli (per 100 ml)	alkalinity-m (mg/L)	alkalinity-p (mg/L)	TS (mg/L)	SS (mg/L)	DS (mg/L)	TKN (mg/L)	nitrate (mg/L)	ammonia (mg/L)	total P (mg/L)	total diss P (mg/L)	% diss P
8	30-Mar-99	11:45 AM	15.6	7.7	13.0	8.63	<2	NA	215	0	1102	18	1084	1.25	0.1	<0.02	0.279	0.202	72.4%
8	6-Apr-99	2:00 PM	15.6	9.3	10.7	NA	<10	NA	218	0	1108	21	1087	1.11	<0.1	<0.02	0.244	0.144	59.0%
8	13-Apr-99	10:15 AM	12.8	9.5	10.5	8.26	370	NA	193	0	1122	24	1098	1.47	0.5	0.03	0.277	0.176	63.5%
8	6-May-99	10:30 AM	10.0	13.9	8.9	8.04	<10	NA	163	0	910	10	900	1.73	0.6	0.16	0.250	0.089	35.6%
8	8-Jun-99	10:30 AM	23.9	21.4	6.0	7.88	10	NA	187	0	882	17	865	1.86	0.2	0.18	0.198	0.155	78.3%
8(D)	8-Jun-99	-	-	-	-	-	<10	NA	184	0	881	15	866	1.73	0.2	0.19	0.198	0.152	-
8(B)	8-Jun-99						<10	NA	<7	0	<5	<1		<0.14	<0.1	<0.02	<0.002	<0.002	-
8	20-Jul-99	3:00 PM	26.7	29.3	8.9	8.42	<10	NA	193	10	781	8	773	1.20	<0.1	0.18	0.268	0.233	86.9%
No samples taken over spillway in 2000 due to drought conditions																			
8	3-Apr-01	12:30 PM	3.9	2.2	10.6	7.92	<10	3.1	72	0	302	17	285	1.74	0.4	0.58	0.468	0.316	67.5%
8	9-Apr-01	9:15 AM	2.8	3.1	10.5	7.81	320	272.0	86	0	414	48	366	1.85	0.6	0.58	0.501	0.334	66.7%
8	12-Apr-01	12:30 PM	8.9	6.3	9.8	8.13	50	51.2	144	0	665	54	611	1.63	0.5	0.48	0.564	0.403	71.5%
8	24-Apr-01	9:00 AM	5.0	8.2	9.2	7.98	130	219.0	113	0	524	295	229	1.23	0.4	0.15	0.435	0.364	83.7%
8	7-May-01	1:00 PM	15.6	16.2	7.6	8.02	10	10.9	110	0	473	25	448	2.33	0.3	0.13	0.388	0.295	76.0%
8	31-May-01	9:45 AM	15.6	18.0	5.8	8.12	<10	4.1	154	0	662	4	658	1.24	0.1	0.27	0.302	0.279	92.4%
8	14-Jun-01	1:15 AM	18.3	21.3	8.8	8.26	10	4.1	167	0	721	8	713	1.49	0.1	0.17	0.238	0.207	87.0%
8	2-Jul-01	10:15 AM	15.6	23.7	6.0	8.38	<10	7.4	184	4	786	5	781	0.92	0.1	0.16	0.271	0.246	90.8%
No samples taken over spillway in 2002 due to drought conditions																			
No samples taken over spillway in 2003 due to drought conditions																			
8	1-Jun-04	9:30 AM	12.8	17.5	8.0	8.47	<10	<1	226	0	1230	9	1221	1.51	0.2	0.20	0.151	0.119	78.8%
8	10-Jun-04	10:30 AM	16.7	20.8	6.3	8.35	100	7.2	196	0	1064	7	1057	1.61	0.3	0.31	0.166	0.143	86.1%
8	14-Jun-04	1:30 PM	23.9	24.3	6.6	8.19	<10	35.0	140	0	635	16	619	1.74	0.5	0.19	0.342	0.267	78.1%
8	22-Apr-05	11:15 AM	7.2	13.5	9.3	8.55	NA	NA	224	2	897	9	888	0.98	<0.1	0.08	0.195	0.174	89.2%
8(D)	-	-	-	-	-	-	-	-	224	2	892	8	884	0.92	<0.1	0.08	0.194	0.156	-
8(B)	-	-	-	-	-	-	-	-	<6	0	<7	<1		<0.50	<0.1	<0.02	<0.002	<0.002	-
8	26-Apr-05	9:15 AM	5.6	13.0	9.6	8.54	<10	<1	225	2	891	10	881	1.39	<0.1	0.10	0.203	0.155	76.4%
8	12-May-05	11:00 AM	8.3	13.6	9.0	8.48	<10	3.1	227	1	928	8	920	1.19	0.1	0.18	0.177	0.140	79.1%
8	17-May-05	3:00 PM	23.9	14.6	10.5	8.52	<10	4.1	225	4	923	6	917	1.12	<0.1	0.13	0.150	0.128	85.3%
8	26-May-05	8:30 AM	12.8	18.1	8.2	8.48	<10	1.0	221	4	973	7	966	1.15	0.1	<0.02	0.110	0.073	66.4%
8	6-Jun-05	9:30 AM	22.8	20.4	11.0	8.51	10	8.6	222	5	1329	11	1318	1.25	<0.1	<0.02	0.125	0.068	54.4%
8	8-Jun-05	9:30 AM	18.3	20.9	11.7	8.57	10	4.1	223	7	1009	4	1005	1.09	<0.1	<0.02	0.142	0.065	45.8%
8	10-Jun-05	11:00 AM	16.7	20.8	11.6	8.56	NA	NA	221	1	1006	18	988	2.47	<0.1	<0.02	0.213	0.061	28.6%
8	16-Jun-05	10:45 AM	18.3	20.9	8.0	8.50	<10	2.0	203	1	941	4	937	0.94	0.4	0.11	0.142	0.120	84.5%
8	23-Jun-05	8:00 AM	23.9	24.6	6.3	8.23	<10	5.2	153	0	660	1	659	1.47	0.8	0.17	0.341	0.127	37.2%

Site 8 Water Quality Raw Data, 1999 – 2007 cont.

Site	Date	Time	air temp (C)	H_2O temp (C)	DO (mg/L)	pH	fecal coliform (per 100 ml)	E. coli (per 100 ml)	alkalinity-m (mg/L)	alkalinity-p (mg/L)	TS (mg/L)	SS (mg/L)	DS (mg/L)	TKN (mg/L)	nitrate (mg/L)	ammonia (mg/L)	total P (mg/L)	total diss P (mg/L)	% diss P
8	7-Apr-06	10:30 AM	5.6	8.4	11.4	8.65	NA	NA	230	4	840	3	837	1.02	<0.1	<0.02	0.352	0.323	91.8%
8	20-Apr-06	10:30 AM	8.9	11.9	9.8	8.57	<10	1.0	229	2	858	2	856	1.15	0.2	0.09	0.341	0.304	89.1%
8	14-Mar-07	8:15 AM	4.4	1.5	8.0	7.91	110	248.0	200	0	850	18	832	2.10	0.4	0.64	0.473	0.351	74.2%
8	19-Mar-07	8:15 AM	1.7	2.6	5.9	7.92	<10	7.3	84	0	304	41	263	2.65	0.6	0.94	0.582	0.390	67.0%
8	26-Mar-07	8:15 AM	12.8	8.3	NA	7.97	10	<1	123	0	507	16	491	2.32	0.5	0.54	0.465	0.352	75.7%
8D	-	-	-	-	-	-	<10	1.0	123	0	504	16	488	2.64	0.5	0.55	0.444	0.344	-
8B	-	-	-	-	-	-	<10	<1	<6	0	<7	<3		<0.5	<0.1	<0.02	<0.002	<0.002	-
8	2-Apr-07	8:30 AM	4.4	NA	NA	7.94	<10	3.1	167	0	695	5	690	1.74	0.4	0.51	0.388	0.358	92.3%
8	16-Apr-07	8:40 AM	10.0	6.5	11.1	8.34	10	1.0	167	0	716	6	710	1.38	0.4	0.33	0.316	0.276	87.3%
8	24-Apr-07	9:00 AM	9.4	12.3	8.9	8.31	<10	2.0	168	0	732	10	722	1.08	0.4	0.20	0.278	0.259	93.2%
8	26-Apr-07	10:45 AM	12.8	13.1	9.8	8.32	<10	<1	169	0	744	4	740	1.38	0.4	0.24	0.284	0.246	86.6%
8	3-May-07	8:30 AM	10.0	15.9	7.4	8.15	10	4.1	172	0	762	<3		1.36	0.3	0.23	0.269	0.239	88.8%
8	7-May-07	11:15 AM	14.4	17.3	8.3	8.05	20	20.1	171	0	754	10	744	1.32	0.3	0.37	0.286	0.241	84.3%
8	10-May-07	8:30 AM	18.3	19.6	4.4	7.95	10	6.2	113	0	430	16	414	1.27	0.4	0.22	0.341	0.283	83.0%
8	16-May-07	8:40 AM	11.1	19.3	5.9	8.28	<10	2.0	129	0	479	13	466	1.21	0.2	0.22	0.381	0.324	85.0%
8	23-May-07	8:40 AM	12.8	20.5	6.1	8.35	20	12.0	132	0	465	9	456	1.30	0.2	0.28	0.340	0.291	85.6%
8	4-Jun-07	8:15 AM	18.3	20.2	6.8	8.21	30	4.0	138	0	480	5	475	0.99	0.2	0.40	0.283	0.268	94.7%
8	11-Jun-07	11:10 AM	24.4	21.8	7.2	8.36	<10	6.0	149	1	537	5	532	1.32	0.3	0.36	0.254	0.224	88.2%
8	15-Jun-07	9:45 AM	-	23.1	7.0	8.16	NA	NA	146	0	523	3	520	1.20	0.4	0.33	0.251	0.234	93.2%
8	26-Jun-07	11:00 AM	22.2	24.8	6.4	8.23	130	142.0	152	1	554	6	548	1.10	0.4	0.21	0.329	0.289	87.8%

Firesteel Creek Water Quality Budgets for Site #4 (Inlet) and Site #8 (Outlet), 1999 – 2007.

Mar 1 - Oct 31, 1999

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	1,687	9	2,140,141	12,829	59,237	218	2,080,905	12,611	221	3	72	2	1,512	14	57	1	160	0
April	16,367	13,681	21,999,021	18,098,391	2,833,420	341,869	19,165,601	17,756,522	11,154	4,476	4,710	2,538	35,899	24,749	20,222	7,449	1,833	951
May	28,284	21,980	35,737,943	24,422,989	7,557,216	366,376	28,180,727	24,056,613	28,505	6,128	9,314	3,296	86,616	48,579	31,069	11,106	2,757	4,562
June	2,901	869	3,495,325	922,608	541,574	14,162	2,953,751	908,446	2,892	244	1,550	176	8,602	1,775	1,156	251	110	189
July	6,233	3,824	7,362,511	3,859,759	1,039,516	57,410	6,322,995	3,802,349	6,200	1,090	3,722	909	17,871	7,063	932	569	116	837
August	287	0	367,047	0	47,935	0	319,112	0	229	0	114	0	671	0	28	0	5	0
September	614	69	435,203	33,364	36,393	342	398,810	33,022	168	11	61	10	641	51	38	2	4	8
October	86	0	61,229	0	5,120	0	56,109	0	24	0	9	0	90	0	5	0	1	0
TOTALS	**56,458**	**40,433**	**71,598,420**	**47,349,940**	**12,120,411**	**780,377**	**59,478,008**	**46,569,563**	**49,394**	**11,952**	**19,552**	**6,932**	**151,901**	**82,232**	**53,507**	**19,378**	**4,985**	**6,547**

Mar 1 - Oct 31, 2000

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	74	0	75,132	0	1,924	0	73,208	0	9	0	2	0	51	0	2	0	1	0
April	72	0	131,151	0	3,187	0	127,965	0	15	0	3	0	93	0	4	0	1	0
May	115	0	281,586	0	6,748	0	274,839	0	32	0	7	0	200	0	7	0	1	0
June	67	0	186,935	0	5,211	0	181,724	0	24	0	5	0	129	0	4	0	1	0
July	8	0	16,572	0	969	0	15,603	0	4	0	1	0	17	0	1	0	0	0
August	36	0	66,117	0	4,222	0	61,895	0	17	0	2	0	75	0	2	0	2	0
September	2	0	1,479	0	189	0	1,290	0	1	0	0	0	3	0	0	0	0	0
October	7	0	4,461	0	570	0	3,891	0	2	0	0	0	10	0	0	0	0	0
TOTALS	**381**	**0**	**763,432**	**0**	**23,018**	**0**	**740,414**	**0**	**103**	**0**	**20**	**0**	**577**	**0**	**20**	**0**	**6**	**0**

Mar 1 - Oct 31, 2001

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	1,362	0	769,273	0	121,391	0	647,883	0	1,496	0	1,149	0	3,544	0	1,360	0	1,591	0
April	49,221	31,142	35,079,903	18,962,871	11,558,998	4,213,967	23,520,906	14,748,905	55,951	18,456	32,739	13,481	81,136	62,608	41,064	17,690	17,949	15,164
May	13,048	15,759	14,599,353	10,343,024	2,016,693	1,520,560	12,582,660	8,822,464	11,292	7,335	7,309	5,957	19,333	35,451	5,513	5,291	811	3,296
June	1,849	1,209	2,688,255	1,082,527	79,435	9,477	2,608,820	1,073,050	839	389	588	348	2,540	1,923	348	149	37	283
July	308	27	451,639	21,754	15,269	148	436,371	21,606	119	8	65	7	377	27	30	3	8	5
August	66	0	54,333	0	1,878	0	52,455	0	11	0	3	0	52	0	2	0	0	0
September	29	0	23,902	0	826	0	23,076	0	5	0	1	0	23	0	1	0	0	0
October	18	0	14,621	0	505	0	14,069	0	3	0	1	0	14	0	1	0	0	0
TOTALS	**65,901**	**48,137**	**53,681,279**	**30,410,176**	**13,794,994**	**5,744,152**	**39,886,239**	**24,666,025**	**69,716**	**26,188**	**41,856**	**19,792**	**107,019**	**100,009**	**48,319**	**23,134**	**20,396**	**18,747**

Mar 1 - Oct 31, 2002

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	269	0	128,956	0	10,248	0	118,708	0	223	0	175	0	765	0	288	0	130	0
April	530	0	448,964	0	20,612	0	428,352	0	354	0	258	0	1,360	0	426	0	95	0
May	219	0	345,573	0	29,551	0	316,021	0	96	0	13	0	319	0	36	0	5	0
June	13	0	20,449	0	2,175	0	18,274	0	7	0	1	0	19	0	2	0	0	0
July	0	0	681	0	72	0	608	0	0	0	0	0	1	0	0	0	0	0
August	148	0	114,943	0	22,766	0	92,177	0	60	0	6	0	120	0	20	0	3	0
September	14	0	9,491	0	1,981	0	7,511	0	5	0	1	0	10	0	2	0	0	0
October	8	0	5,562	0	1,161	0	4,401	0	3	0	0	0	6	0	1	0	0	0
TOTALS	**1,201**	**0**	**1,074,619**	**0**	**88,566**	**0**	**986,053**	**0**	**748**	**0**	**453**	**0**	**2,599**	**0**	**774**	**0**	**234**	**0**

Firesteel Creek Water Quality Budgets for Site #4 (Inlet) and Site #8 (Outlet), 1999 - 2007 cont.

Mar 1 - Oct 31, 2003

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	87	0	53,533	0	2,001	0	51,532	0	25	0	15	0	94	0	14	0	2	0
April	21	0	30,724	0	1,774	0	28,951	0	8	0	1	0	34	0	2	0	0	0
May	75	0	125,948	0	7,287	0	118,662	0	28	0	4	0	130	0	5	0	1	0
June	8	0	13,846	0	773	0	13,074	0	3	0	0	0	14	0	1	0	0	0
July	10	0	10,540	0	552	0	9,988	0	2	0	0	0	10	0	0	0	0	0
August	6	0	6,390	0	335	0	6,055	0	1	0	0	0	6	0	0	0	0	0
September	5	0	5,951	0	312	0	5,639	0	1	0	0	0	6	0	0	0	0	0
October	5	0	5,138	0	269	0	4,869	0	1	0	0	0	5	0	0	0	0	0
TOTALS	**216**	**0**	**252,070**	**0**	**13,301**	**0**	**238,769**	**0**	**69**	**0**	**21**	**0**	**299**	**0**	**21**	**0**	**3**	**0**

Mar 1 - Oct 31, 2004

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	42	0	37,989	0	1,049	0	36,940	0	5	0	1	0	40	0	2	0	0	0
April	21	0	31,916	0	1,295	0	30,621	0	5	0	1	0	28	0	1	0	0	0
May	1,486	158	1,413,798	119,929	175,756	878	1,238,042	119,051	1,267	15	679	12	3,586	147	875	20	120	20
June	10,094	7,560	7,890,857	6,398,805	1,263,106	92,021	6,627,751	6,306,785	11,929	1,954	8,491	1,556	25,906	12,488	8,523	2,958	958	1,698
July	283	17	301,661	6,653	18,166	168	283,495	6,485	212	4	160	3	500	18	18	5	4	2
August	139	0	147,862	0	8,904	0	138,958	0	104	0	78	0	245	0	9	0	2	0
September	278	1	252,832	461	12,633	12	240,199	450	95	0	58	0	291	1	12	0	2	0
October	361	62	263,894	24,214	11,590	610	252,304	23,603	48	13	13	10	225	66	11	19	2	7
TOTALS	**12,703**	**7,798**	**10,340,807**	**6,550,062**	**1,492,499**	**93,687**	**8,848,308**	**6,456,375**	**13,664**	**1,986**	**9,480**	**1,581**	**30,821**	**12,721**	**9,451**	**3,002**	**1,088**	**1,727**

Mar 1 - Oct 31, 2005

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	110	0	107,730	0	1,806	0	105,925	0	10	0	3	0	45	0	4	0	1	0
April	350	68	747,683	75,360	14,924	799	732,760	74,561	95	17	42	14	478	100	440	4	4	8
May	879	322	1,736,123	378,685	42,079	2,620	1,694,044	376,065	270	52	136	40	1,624	452	459	30	29	29
June	11,246	11,405	11,435,672	12,117,515	817,304	93,541	10,618,368	12,023,974	10,920	2,769	7,860	1,424	25,829	19,615	9,532	5,328	1,826	1,297
July	484	161	633,319	65,555	37,395	99	595,924	65,456	513	34	316	13	1,251	146	71	80	57	17
August	33	0	61,690	0	3,175	0	58,515	0	23	0	6	0	103	0	3	0	3	0
September	8	0	12,082	0	425	0	11,657	0	3	0	1	0	16	0	0	0	0	0
October	9	0	11,021	0	298	0	10,723	0	2	0	0	0	12	0	0	0	0	0
TOTALS	**13,119**	**11,956**	**14,745,320**	**12,637,116**	**917,405**	**97,060**	**13,827,916**	**12,540,056**	**11,836**	**2,871**	**8,363**	**1,490**	**29,358**	**20,314**	**10,510**	**5,442**	**1,919**	**1,351**

Mar 1 - Oct 31, 2006

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	24	0	21,066	0	179	0	20,887	0	2	0	1	0	13	0	1	0	0	0
April	811	290	1,347,493	301,677	90,651	898	1,256,843	300,779	268	123	60	112	1,442	385	186	43	33	17
May	88	1	80,456	631	2,112	2	78,345	629	14	0	3	0	96	1	5	0	1	0
June	13	0	12,107	0	318	0	11,789	0	2	0	0	0	14	0	1	0	0	0
July	1	0	800	0	21	0	779	0	0	0	0	0	1	0	0	0	0	0
August	4	0	3,436	0	90	0	3,346	0	1	0	0	0	4	0	0	0	0	0
September	9	0	7,889	0	207	0	7,682	0	1	0	0	0	9	0	1	0	0	0
October	2	0	1,945	0	51	0	1,894	0	0	0	0	0	2	0	0	0	0	0
TOTALS	**951**	**291**	**1,475,192**	**302,308**	**93,628**	**899**	**1,381,563**	**301,409**	**289**	**124**	**64**	**112**	**1,582**	**385**	**194**	**43**	**33**	**17**

Firesteel Creek Water Quality Budgets for Site #4 (Inlet) and Site #8 (Outlet), 1999 - 2007 cont.

Mar 1 - Oct 31, 2007

Month	acre-feet		TSOL (kg)		TSSOL (kg)		TDSOL (kg)		TP (kg)		TDP (kg)		TKN (kg)		NO_3 (kg)		NH_3 (kg)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
March	8,986	8,054	4,226,462	5,851,355	1,115,416	217,523	3,111,046	5,633,832	7,615	4,510	4,904	3,259	23,624	20,434	5,423	4,212	6,052	6,420
April	3,275	2,651	3,249,754	2,401,610	323,452	16,600	2,926,302	2,385,010	2,070	976	1,316	864	6,102	4,518	722	1,261	155	902
May	17,755	15,911	11,862,215	11,399,150	2,959,015	237,909	8,903,200	11,161,241	17,470	6,304	10,049	5,309	30,536	25,283	6,379	6,360	2,077	5,470
June	7,374	5,991	5,184,496	3,774,510	430,991	33,911	4,753,505	3,740,599	9,261	2,032	7,623	1,843	15,271	8,296	6,558	2,468	529	2,231
July	454	277	170,904	94,705	10,086	1,026	160,817	93,679	294	56	246	49	432	188	14	68	3	36
August	27	0	10,275	0	606	0	9,669	0	18	0	15	0	26	0	1	0	0	0
September	9	0	3,433	0	203	0	3,230	0	6	0	5	0	9	0	0	0	0	0
October	209	0	78,568	0	4,637	0	73,931	0	135	0	113	0	198	0	6	0	1	0
TOTALS	**38,088**	**32,883**	**24,786,107**	**23,521,330**	**4,844,406**	**506,970**	**19,941,701**	**23,014,360**	**36,869**	**13,878**	**24,271**	**11,325**	**76,198**	**58,719**	**19,103**	**14,369**	**8,818**	**15,059**

Lake Mitchell 2003

Date	Site	Time	Water temp (°C)	Total P (ppb)	Alkalinity (mg/L)	Total Al (ppb)	Color (CO-PT)	Secchi depth (m)	Chlorophyll						
									C/P ratio	CHL a corrected for phenophytin	CHL a uncorrected for phenophytin	Trichromatic CHL a	Trichromatic CHL b	Trichromatic CHL c	CHL a ignoring phenophytin
12-May-03	12A	10:00 AM	13.3	264	245	170	15	2.1	2.00	2.40	1.82	1.83	0.52	0.63	1.49
	12B	10:30 AM	13.6	282	244	120	15	2.5	2.03	1.30	1.07	1.07	0.47	0.36	0.78
	13A	10:45 AM	14.1	302	246	<75	20	5.1	1.14	1.00	1.40	1.34	1.25	1.47	1.28
27-May-03	12A	8:40 AM	19.3	254	245	-	-	1.8	1.83	1.70	1.82	1.80	0.88	0.85	1.77
	12B	9:00 AM	18.4	250	246	-	-	4.3	1.31	1.10	1.44	1.42	0.90	0.96	1.11
	13A	9:15 AM	17.9	256	244	-	-	4.8	1.23	0.70	1.20	1.14	1.14	1.31	1.07
03-Jun-03	12A	9:55 AM	-	-	-	-	-	1.3	-	-	-	-	-	-	-
	12B	10:15 AM	-	-	-	-	-	1.8	-	-	-	-	-	-	-
	13A	10:30 AM	-	-	-	-	-	2.2	-	-	-	-	-	-	-
09-Jun-03	12A	10:15 AM	18.7	242	247	<75	-	0.9	1.29	2.10	3.42	3.40	1.59	2.09	3.26
	12B	10:00 AM	18.8	249	249	<75	-	2.4	1.27	0.70	2.93	2.96	0.92	0.82	2.68
	13A	9:30 AM	19.2	258	249	<75	-	3.0	2.10	4.31	4.04	4.09	1.23	0.43	3.71
LAKE MITCHELL ALUM TREATMENT, JUNE 9 - 13 (150,000 gallons)															
16-Jun-03	12A	9:30 AM	24.5	140	220	460	-	0.6	1.55	54.77	61.55	63.58	2.53	5.80	60.51
	12B	10:00 AM	23.2	76	229	250	-	3.4	1.35	4.91	6.60	6.74	1.16	1.55	6.76
	13A	10:30 AM	22.7	80	227	210	-	2.7	1.33	4.81	6.27	6.36	1.62	1.67	6.56
30-Jun-03	12A	10:00 AM	23.4	164	-	-	-	1.0	2.03	179.42	141.74	147.36	-5.39	6.21	139.96
	12A(D)	-	-	172	-	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	2	-	-	-	-	-	-	-	-	-	-	-
	12B	10:20 AM	24.2	126	-	-	-	1.1	1.54	95.42	108.24	112.47	-3.32	5.65	106.92
	13A	10:35 AM	24.4	82	-	-	-	1.3	1.34	22.03	30.81	31.98	-0.50	2.20	30.81
14-Jul-03	12A	12:30 PM	26.6	356	194	280	30	0.5	1.56	189.34	218.13	227.18	-12.77	5.65	215.37
	12B	12:45 PM	26.4	239	193	250	25	1.2	1.44	42.85	57.92	60.40	-4.26	0.26	57.50
	13A	1:00 PM	26.1	168	197	140	20	3.5	NA	0.70	0.29	0.31	-0.14	-0.04	0.58
21-Jul-03	12A	9:45 AM	-	-	-	-	-	0.8	-	-	-	-	-	-	-
	12B	9:50 AM	-	-	-	-	-	0.9	-	-	-	-	-	-	-
	13A	10:00 AM	-	-	-	-	-	4.8	-	-	-	-	-	-	-
28-Jul-03	12A	9:25 AM	25.3	369	-	-	-	0.5	1.57	108.44	122.43	127.48	-6.77	3.54	121.03
	12B	9:45 AM	26.2	333	-	-	-	1.0	1.67	79.00	80.23	83.43	-3.38	4.50	79.45
	13A	10:00 AM	26.6	400	-	-	-	0.8	1.32	156.90	269.45	280.65	-16.06	6.94	266.02
11-Aug-03	12A	9:00 AM	25.5	462	197	<75	-	1.1	1.72	80.20	78.91	82.08	-3.43	3.54	77.26
	12A(D)	-	-	-	197	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	-	<6	-	-	-	-	-	-	-	-	-	-
	12B	9:20 AM	26.1	427	197	<75	-	2.8	1.63	38.85	41.13	42.70	-0.99	2.95	39.85
	13A	9:35 AM	26.5	491	198	<75	-	2.1	1.60	34.14	37.33	38.74	-0.73	3.04	36.13
18-Aug-03	12A	9:00 AM	-	-	-	-	-	0.4	-	-	-	-	-	-	-
	12B	9:20 AM	-	-	-	-	-	1.4	-	-	-	-	-	-	-
	13A	9:40 AM	-	-	-	-	-	4.0	-	-	-	-	-	-	-
02-Sep-03	12A	8:55 AM	23.3	678	-	-	-	0.6	1.69	193.64	194.95	202.89	-9.85	7.39	191.98
	12A(D)	-	-	637	-	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-	-
	12B	9:15 AM	24.0	532	-	-	-	1.1	1.55	26.23	29.87	30.96	-0.24	2.86	28.79
	13A	9:35 AM	24.3	487	-	-	-	2.5	1.44	7.71	7.01	7.24	0.23	1.22	6.19
16-Sep-03	12A	9:05 AM	19.7	519	211	97	30	0.7	2.01	134.97	111.62	116.08	-4.78	6.04	109.77
	12B	9:35 AM	20.2	474	208	<75	20	2.4	2.04	45.76	35.52	36.82	-0.27	3.83	34.69
	13A	10:05 AM	20.4	476	211	<75	20	3.0	1.44	5.71	5.45	5.52	1.24	2.79	4.95
30-Sep-03	12A	8:55 AM	13.9	420	-			1.1	2.00	75.09	62.29	64.50	0.35	7.05	61.59
	12B	9:10 AM	14.1	432	-			1.1	2.07	112.04	88.52	91.93	-2.31	5.97	87.00
	13A	9:25 AM	14.9	413	-			1.8	2.46	87.71	58.82	61.01	-0.89	6.07	57.67
15-Oct-03	12A	9:25 AM	15.0	498	218	<75	-	1.5	1.94	45.36	37.99	39.29	0.87	4.01	37.62
	12B	9:45 AM	15.2	392	213	87	-	1.7	1.86	21.23	18.19	18.70	1.60	3.75	18.15
	13A	10:00 AM	15.1	377	213	<75	-	2.7	1.62	10.21	9.45	9.62	1.79	3.30	9.57

Total P
QA/QC @ Site 12A on Jun 30
QA/QC @ Site 12A on Sep 2

Alkalinity
QA/QC @ Site 12A on Aug 11

Note: C/P ratios should be between 1 and 1.7 in order to be considered a high quality sample

Lake Mitchell 2004

Date	Site	Time	Water temp (°C)	Total P (ppb)	Alkalinity (mg/L)	Total Al (ppb)	Secchi depth (m)	Chlorophyll						
								C/P ratio	CHL a corrected for phenophytin	CHL a uncorrected for phenophytin	Trichromatic CHL a	Trichromatic CHL b	Trichromatic CHL c	CHL a ignoring phenophytin
16-Apr-04	12A	9:40 AM	12.9	241	236	59.2	2.0	6.20	6.21	3.75	3.82	0.81	0.77	1.69
	12B	10:00 AM	12.5	262	236	37.0	5.0	13.91	5.11	2.47	2.52	0.50	0.50	0.41
	13A	10:15 AM	12.4	294	241	24.2	6.1	4.62	5.21	2.76	2.73	1.48	2.00	0.87
30-Apr-04	12A	8:45 AM	13.1	272	241	124.0	1.7	3.31	9.71	6.72	6.83	1.65	1.33	4.62
	12B	9:00 AM	13.1	277	240	82.7	2.7	3.19	5.61	3.84	3.87	1.15	1.41	1.86
	13A	9:15 AM	13.3	279	242	92.7	2.8	3.88	6.91	3.71	3.76	1.01	1.15	1.77
LAKE MITCHELL ALUM TREATMENT, MAY 3 - 5 (120,000 gallons)														
10-May-04	12A	8:30 AM	18.1	103	233	251.0	3.0	9.09	7.51	3.84	3.95	0.29	0.22	1.73
	12B	8:45 AM	17.5	108	228	265.0	4.6	4.28	6.21	3.26	3.27	1.20	1.58	1.57
	13A	9:00 AM	17.2	131	229	282.0	6.1	4.43	6.11	3.59	3.60	1.41	1.57	1.73
26-May-04	12A	9:20 AM	15.8	126	-	-	2.9	2.83	4.41	2.81	2.92	-0.16	0.19	3.30
	12A(D)	-	-	125	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	9:40 AM	16.0	133	-	-	3.6	NA	0.00	0.00	0.00	0.00	0.00	0.00
	13A	10:00 AM	16.3	156	-	-	4.6	NA	0.00	0.00	0.00	0.00	0.00	0.00
09-Jun-04	12A	10:30 AM	20.5	200	185	435.0	0.8	NA	5.69	2.34	2.46	-0.41	0.01	2.24
	12A(D)	-	-	-	185	464.0	-	-	-	-	-	-	-	-
	12A(B)	-	-	-	<6	8.5	-	-	-	-	-	-	-	-
	12B	10:45 AM	21.0	140	193	105.0	3.0	NA	0.00	0.00	0.00	0.00	0.00	0.00
	13A	11:00 AM	21.3	163	199	96.9	3.2	NA	5.85	2.41	2.56	-0.74	-0.03	2.64
22-Jun-04	12A	9:10 AM	20.5	308	-	-	0.6	0.97	4.41	19.37	17.82	23.89	36.28	19.21
	12B	9:25 AM	20.9	322	-	-	1.1	0.89	1.84	13.86	12.80	16.57	25.13	13.66
	13A	9:40 AM	21.1	295	-	-	1.9	1.09	15.38	23.00	22.84	10.58	17.28	22.77
07-Jul-04	12A	10:00 AM	22.6	363	171	385.0	0.6	1.13	34.76	49.83	49.31	24.56	40.54	49.37
	12B	10:20 AM	22.5	354	163	89.0	1.4	1.44	30.28	36.76	38.40	-3.29	-1.12	36.37
	13A	10:35 AM	22.7	322	162	73.0	1.9	1.28	15.38	21.48	22.47	-2.34	-0.67	21.25
20-Jul-04	12A	10:00 AM	27.5	370	-	-	0.8	1.71	119.35	120.05	124.57	-1.76	8.28	118.70
	12B	10:15 AM	27.0	289	-	-	1.8	1.84	8.01	7.23	7.54	-0.59	-0.05	7.43
	13A	10:30 AM	27.1	290	-	-	2.5	1.88	6.65	5.97	6.18	0.16	0.58	6.11
05-Aug-04	12A	9:30 AM	25.2	464	182	90.8	1.7	1.35	3.50	4.21	3.96	4.19	6.55	4.58
	12A(D)	-	-	475	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	9:50 AM	24.8	394	179	42.9	2.6	1.40	7.01	7.26	7.03	5.15	8.46	7.30
	13A	10:10 AM	24.9	375	177	23.9	2.3	1.49	14.62	14.60	14.71	4.47	8.14	14.64
19-Aug-04	12A	10:00 AM	21.8	458	-	-	0.8	1.62	69.21	68.31	70.53	2.33	12.15	68.01
	12B	10:15 AM	22.2	462	-	-	0.8	1.61	57.67	58.01	59.82	2.97	11.08	57.62
	13A	10:30 AM	22.2	458	-	-	1.1	1.81	28.20	24.12	24.78	2.25	5.50	24.12
02-Sep-04	12A	8:50 AM	24.1	467	185	67.9	1.4	1.57	12.34	11.98	12.21	2.08	4.41	12.14
	12B	8:35 AM	23.1	468	183	56.8	2.2	1.36	9.21	9.64	9.61	3.97	6.90	9.87
	13A	8:15 AM	22.3	436	181	53.9	2.3	1.47	7.77	8.25	8.31	2.45	4.52	8.48
16-Sep-04	12A	9:10 AM	20.1	420	-	-	1.2	1.74	14.74	14.75	15.18	1.15	2.77	14.72
	12B	9:30 AM	20.5	461	-	-	2.0	1.58	8.41	7.19	7.14	3.31	5.55	7.26
	13A	9:45 AM	20.6	474	-	-	2.0	1.63	46.62	47.82	49.41	1.37	7.25	47.65
30-Sep-04	12A	9:15 AM	17.5	425	196	86.5	1.2	1.52	65.76	69.27	71.25	5.41	15.53	68.61
	12B	9:30 AM	17.4	405	195	110.0	1.3	1.58	25.23	23.00	23.55	3.02	6.51	22.87
	13A	9:45 AM	17.6	399	194	63.9	2.2	1.18	4.81	4.36	4.17	3.64	5.73	4.42
14-Oct-04	12A	12:30 PM	14.0	373	-	-	1.6	1.33	12.90	14.22	14.29	4.66	8.60	14.29
	12A(D)	-	-	360	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	12:45 PM	14.2	397	-	-	1.7	1.69	86.67	83.29	85.98	3.15	15.10	82.53
	13A	1:00 PM	14.3	375	-	-	2.8	1.50	18.82	19.04	19.42	3.17	6.99	19.07

Total P
QA/QC @ Site 12A on May 26
QA/QC @ Site 12A on Aug 4
QA/QC @ Site 12A on Oct 14

Alkalinity
QA/QC @ Site 12A on Jun 9

Total Al
QA/QC @Site 12A on Jun 9

Note: C/P ratios should be between 1 and 1.7 in order to be considered a high quality sample

Lake Mitchell 2005

Date	Site	Time	Water temp (°C)	Total P (ppb)	Alkalinity (ppm)	Total Al (ppb)	Secchi depth (m)	Chlorophyll						
								C/P ratio	CHL a corrected for phenophytin	CHL a uncorrected for phenophytin	Trichromatic CHL a	Trichromatic CHL b	Trichromatic CHL c	CHL a ignoring phenophytin
18-Apr-05	12A	8:35 AM	14.2	175	228	86.2	1.7	1.28	5.69	6.76	6.69	3.31	5.83	6.90
	12A(D)	-	-	-	227	81.6	-	-	-	-	-	-	-	-
	12A(B)	-	-	-	<6	9.4	-	-	-	-	-	-	-	-
	12B	9:00 AM	13.5	171	226	66.6	2.6	1.27	2.52	3.15	3.12	1.47	2.60	3.22
	13A	9:25 AM	12.8	174	225	40.5	3.4	1.19	2.04	2.97	2.85	2.34	3.90	3.05
03-May-05	12A	9:30 AM	9.8	142	-	-	3.2	1.25	1.40	1.72	1.65	1.37	2.19	1.78
	12B	9:50 AM	10.5	159	-	-	3.6	1.23	1.44	1.80	1.73	1.35	2.27	1.88
	13A	10:10 AM	10.8	163	-	-	3.6	1.23	1.72	2.19	2.10	1.78	2.91	2.26
19-May-05	12A	9:00 AM	16.5	132	232	79.3	1.7	1.69	12.02	10.89	11.02	2.75	5.02	10.79
	12B	9:25 AM	16.3	144	229	27.1	4.5	1.43	2.28	2.38	2.29	1.85	2.75	2.36
	13A	9:45 AM	16.1	145	227	23.3	5.3	1.57	2.88	2.52	2.44	1.84	2.74	2.47
PARTIAL LAKE MITCHELL ALUM TREATMENT, MAY 24														
1-Jun-05	12A	9:15 AM	17.7	135	231	197.0	1.2	1.71	10.25	9.37	9.56	1.55	3.13	9.31
	12A(D)	-	-	131	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	2	-	-	-	-	-	-	-	-	-	-
	12B	9:45 AM	17.7	108	226	156.0	2.4	1.64	12.14	11.63	11.93	1.27	2.87	11.52
	13A	10:15 AM	17.5	119	228	164.0	1.8	1.60	33.08	35.31	36.04	6.99	3.70	34.81
20-Jun-05	12A	9:00 AM	25.7	561	-	-	0.5	1.66	62.64	61.45	63.32	3.54	12.57	60.98
	12B	9:30 AM	24.9	468	-	-	0.8	1.41	10.33	11.09	11.00	5.14	8.90	11.19
	13A	10:00 AM	23.8	294	-	-	1.8	1.68	4.17	3.60	3.46	2.81	4.65	3.76
PARTIAL LAKE MITCHELL ALUM TREATMENT, JUNE 21 - 23 (128,387 gallons)														
27-Jun-05	12A	9:20 AM	25.7	336	152	436.0	0.7	1.14	11.05	20.20	20.43	5.20	9.69	19.97
	12B	8:45 AM	25.4	301	148	381.0	1.0	1.04	4.89	9.24	9.10	5.05	8.34	9.17
	13A	8:20 AM	25.0	305	150	217.0	1.5	1.18	5.29	7.29	7.09	4.92	8.04	7.16
12-Jul-05	12A	8:30 AM	26.2	383	-	-	0.6	1.20	9.45	24.85	25.55	2.13	5.44	24.25
	12B	8:55 AM	26.8	518	-	-	0.4	1.35	297.65	476.65	496.22	-25.69	16.00	470.98
	13A	9:15 AM	27.3	316	-	-	1.2	1.20	19.22	44.81	46.36	0.70	6.37	43.92
27-Jul-05	12A	9:15 AM	24.6	548	190	489.0	0.5	1.43	21.31	23.10	23.55	4.10	8.35	22.97
	12A(D)	-	-	-	189	458.0	-	-	-	-	-	-	-	-
	12A(B)	-	-	-	<6	<2	-	-	-	-	-	-	-	-
	12B	9:45 AM	25.2	534	187	273.0	0.8	1.66	112.22	108.44	112.39	-0.55	11.46	107.12
	13A	10:10 AM	25.1	446	180	95.2	1.3	1.96	108.70	86.10	89.07	1.26	11.54	85.07
10-Aug-05	12A	9:20 AM	26.2	642	-	-	0.7	1.07	7.13	14.49	14.50	5.40	9.52	14.26
	12A(D)	-	-	648	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	9:45 AM	26.3	562	-	-	1.5	1.18	9.21	13.13	13.19	4.39	7.86	12.97
	13A	10:05 AM	26.1	553	-	-	1.9	0.92	1.52	10.16	10.14	4.11	7.10	10.07
24-Aug-05	12A	8:30 AM	23.2	698	203	190.0	1.0	1.46	27.79	28.94	29.61	3.93	9.31	28.68
	12B	8:50 AM	-	668	201	191.0	1.0	1.36	21.07	23.17	23.45	5.71	11.63	23.07
	13A	9:15 AM	-	649	199	151.0	1.2	1.48	20.91	19.34	19.51	5.47	10.65	19.21
08-Sep-05	12A	9:20 AM	23.1	564	-	-	0.9	1.79	63.36	54.75	56.56	1.47	9.52	54.42
	12B	9:45 AM	23.2	591	-	-	1.2	1.92	44.38	33.83	34.80	2.35	8.69	33.73
	13A	10:05 AM	23.0	602	-	-	1.3	2.04	33.96	24.55	25.16	2.72	8.16	24.59
21-Sep-05	12A	11:15 AM	22.1	602	214	52.6	1.9	1.33	14.74	17.23	17.53	3.36	7.02	17.19
	12B	10:50 AM	21.7	622	212	37.6	2.0	1.45	18.74	19.97	20.46	2.41	5.68	19.87
	13A	10:30 AM	21.3	621	212	41.7	2.4	1.24	4.13	4.95	4.90	2.39	3.90	5.02
12-Oct-05	12A	9:10 AM	13.6	503	-	-	1.9	1.40	15.94	17.09	17.43	2.94	6.51	17.13
	12B	9:30 AM	13.5	516	-	-	2.3	1.48	14.62	15.26	15.66	1.55	4.43	15.21
	13A	9:55 AM	13.2	524	-	-	2.0	1.40	12.74	13.17	13.36	2.94	5.97	13.20

Total P
QA/QC @ Site 12A on Jun 1
QA/QC @ Site 12A on Aug 10

Alkalinity
QA/QC @ Site 12A on Apr 18
QA/QC @ Site 12A on Jul 27

Total Al
QA/QC @ Site 12A on Apr 18
QA/QC @ Site 12A on Jul 27

Note: C/P ratios should be between 1 and 1.7 in order to be considered a high quality sample

Lake Mitchell 2006

Date	Site	Time	Water temp (°C)	Total P (ppb)	Alkalinity (ppm)	Total Al (ppb)	Secchi depth (m)	Chlorophyll						
								C/P ratio	CHL a corrected for phenophytin	CHL a uncorrected for phenophytin	Trichromatic CHL a	Trichromatic CHL b	Trichromatic CHL c	CHL a ignoring phenophytin
11-May-06	12A	9:40 AM	14.1	223	227	74.6	2.7	1.30	3.48	4.57	4.60	1.48	2.30	4.55
	12B	10:05 AM	14.1	234	227	43.6	3.0	1.30	2.84	4.01	4.07	0.97	1.58	3.98
	13A	10:30 AM	14.6	242	228	27.5	4.0	1.14	1.44	2.71	2.66	1.56	2.22	2.69
26-May-06	12A	10:00 AM	19.0	213	-	-	2.2	1.23	2.52	3.84	3.85	1.46	1.74	3.83
	12A(D)	-	-	209	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	10:25 AM	19.1	202	-	-	2.9	1.24	3.56	4.42	4.38	2.22	2.90	4.37
	13A	10:45 AM	19.3	215	-	-	3.6	1.14	4.33	6.01	5.88	3.73	5.26	5.97
05-Jun-06	12A	8:35 AM	24.1	264	233	105.0	1.0	1.24	17.62	23.10	23.36	6.34	9.52	22.97
	12B	9:00 AM	23.5	236	231	86.9	1.5	1.30	15.46	16.86	16.69	8.61	11.74	16.73
	13A	9:20 AM	22.5	243	231	43.4	2.3	1.23	12.06	16.62	16.65	6.37	7.62	16.53
LAKE MITCHELL ALUM TREATMENT, JUNE 6 - 8 (111,000 gallons)														
12-Jun-06	12A	8:45 AM	19.6	235	227	377.0	0.7	1.61	60.96	60.69	62.59	3.04	10.66	60.36
	12A(D)	-	-	-	227	393.0	-	-	-	-	-	-	-	-
	12A(B)	-	-	-	<6	<1.6	-	-	-	-	-	-	-	-
	12B	9:10 AM	20.5	188	225	437.0	1.0	1.46	17.54	18.48	18.73	4.58	7.23	18.45
	13A	9:30 AM	20.7	186	227	367.0	1.7	1.40	8.57	9.74	9.80	3.21	4.53	9.74
28-Jun-06	12A	9:40 AM	23.3	265	-	-	1.2	1.54	20.83	21.38	21.90	2.63	6.55	21.35
	12B	10:00 AM	24.5	177	-	-	1.2	1.69	67.28	65.64	68.05	-0.64	6.83	65.14
	13A	10:15 AM	24.8	336	-	-	0.7	1.73	166.69	161.50	167.80	-5.36	11.93	160.35
13-Jul-06	12A	8:50 AM	26.7	317	209	113.0	0.7	1.74	119.27	113.98	118.49	-4.52	7.46	113.09
	12B	9:10 AM	26.1	363	217	156.0	1.4	1.50	13.70	14.06	14.42	1.49	3.93	14.06
	13A	9:35 AM	25.1	309	218	68.6	2.6	1.58	10.77	10.66	10.97	0.72	2.48	10.63
27-Jul-06	12A	9:30 AM	27.3	720	-	-	0.3	1.59	419.96	465.37	484.73	-29.30	21.88	460.61
	12B	9:50 AM	26.9	568	-	-	0.6	1.64	355.96	376.23	391.91	-23.76	16.09	372.21
	13A	10:10 AM	26.4	351	-	-	3.7	1.25	5.73	8.50	8.74	0.68	2.14	8.48
10-Aug-06	12A	12:25 PM	27.0	614	229	126.0	0.5	1.53	283.71	333.33	347.04	-18.65	13.71	329.74
	12A(D)	-	-	622	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	12:50 PM	26.7	414	222	97.0	2.0	1.72	19.94	16.68	17.19	0.92	3.63	16.60
	13A	1:10 PM	26.2	442	221	63.6	2.1	0.74	26.83	11.10	11.25	2.67	5.33	11.02
24-Aug-06	12A	8:55 AM	25.7	513	-	-	0.5	1.63	260.33	275.91	287.39	-17.23	11.94	273.37
	12B	9:15 AM	25.3	465	-	-	1.2	1.06	9.85	40.89	42.10	2.58	9.17	40.56
	13A	9:35 AM	24.8	452	-	-	2.3	1.25	7.89	11.63	11.95	1.09	3.11	11.55
06-Sep-06	12A	9:10 AM	21.3	488	221	40.2	1.1	NA						
	12B	9:30 AM	21.3	488	219	32.0	2.9	NA						
	13A	9:55 AM	21.2	506	219	33.9	3.7	NA						
20-Sep-06	12A	9:50 AM	14.8	493	-	-	1.3	1.41	38.85	41.75	43.00	2.45	9.64	41.35
	12B	10:10 AM	15.9	481	-	-	1.7	1.27	21.79	25.77	26.36	3.51	9.02	25.51
	13A	10:30 AM	16.6	536	-	-	1.5	1.28	26.03	29.50	30.07	5.09	11.60	29.24
10-Oct-06	12A	9:15 AM	15.0	391	225	80.1	1.1	1.60	23.87	21.91	22.48	2.33	6.27	21.71
	12A(D)	-	-	-	225	125.0	-	-	-	-	-	-	-	-
	12A(B)	-	-	-	<6	<2.0	-	-	-	-	-	-	-	-
	12B	9:40 AM	15.2	417	225	272.0	1.0	1.82	36.77	29.80	30.71	1.61	6.54	29.50
	13A	10:00 AM	15.2	426	225	97.1	1.2	1.80	54.31	46.33	47.99	-0.09	6.43	45.90

Total P
QA/QC @ Site 12A on May 26
QA/QC @ Site 12A on Aug 10

Alkalinity
QA/QC @ Site 12A on Jun 12
QA/QC @ Site 12A on Oct 10

Total Al
QA/QC @ Site 12A on Jun 12
QA/QC @ Site 12A on Oct 10

Note: C/P ratios should be between 1 and 1.7 in order to be considered a high quality sample

Lake Mitchell 2007

Date	Site	Time	Water temp (°C)	Total P (ppb)	Alkalinity (ppm)	Total Al (ppb)	Secchi depth (m)	Chlorophyll						
								C/P ratio	CHL a corrected for phenophytin	CHL a uncorrected for phenophytin	Trichromatic CHL a	Trichromatic CHL b	Trichromatic CHL c	CHL a ignoring phenophytin
14-Jun-07	12A	9:30 AM	23.3	238	148	102.0	1.2	1.18	6.17	9.11	9.00	4.64	7.68	9.04
	12B	9:50 AM	23.2	239	147	74.9	1.9	1.25	2.96	3.00	2.88	2.42	3.79	2.81
	13A	10:15 AM	22.6	240	147	50.3	2.0	1.27	3.68	3.99	3.79	3.65	5.70	3.86
27-Jun-07	12A	9:15 AM	25.2	452	-	-	0.4	1.40	18.98	21.25	21.63	4.15	7.67	20.99
	12A(D)	-	-	464	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	9:40 AM	25.3	376	-	-	0.9	1.60	29.32	28.48	29.29	2.24	6.40	28.05
	13A	10:00 AM	25.2	342	-	-	1.3	1.38	15.78	16.43	16.65	3.92	7.86	16.20
11-Jul-07	12A	9:15 AM	25.2	424	173	213.0	0.6	1.70	46.38	45.08	46.75	-0.53	4.10	44.58
	12B	9:35 AM	25.4	410	168	376.0	0.6	1.50	42.29	44.06	45.63	0.12	4.63	43.43
	13A	10:00 AM	25.4	356	163	144.0	0.7	1.63	53.83	53.66	55.58	-0.05	6.82	53.20
26-Jul-07	12A	8:15 AM	28.1	548	-	-	0.9	1.57	43.73	43.73	45.16	1.45	7.37	43.33
	12B	8:40 AM	27.4	505	-	-	1.4	1.30	10.57	11.02	11.13	3.07	5.92	10.99
	13A	9:00 AM	26.7	542	-	-	2.4	1.06	4.97	5.58	5.73	0.51	1.51	5.53
09-Aug-07	12A	8:50 AM	26.1	613	184	116.0	0.7	3.18	180.71	108.67	113.02	-5.31	9.57	107.98
	12B	9:15 AM	25.7	558	182	80.0	1.2	3.18	61.84	35.84	36.75	3.83	10.74	35.44
	13A	9:35 AM	25.6	580	182	46.8	1.5	2.13	38.69	27.39	27.97	4.17	9.87	27.06
24-Aug-07	12A	9:15 AM	23.5	562	-	-	0.8	1.51	45.34	52.93	54.94	-1.18	5.07	52.37
	12B	9:35 AM	23.7	614	-	-	1.4	1.56	25.03	24.05	24.89	0.24	3.46	23.88
	13A	10:00 AM	23.9	627	-	-	1.8	1.67	17.92	16.87	17.48	-0.03	1.95	16.71
06-Sep-07	12A	8:30 AM	24.6	586	194	155.0	1.2	1.61	17.70	18.35	18.93	0.65	4.38	18.15
	12A(D)	-	-	599	-	-	-	-	-	-	-	-	-	-
	12A(B)	-	-	<2	-	-	-	-	-	-	-	-	-	-
	12B	8:55 AM	24.3	536	192	55.4	1.8	1.48	11.13	11.52	11.74	1.98	4.74	11.42
	13A	9:15 AM	24.0	624	191	39.0	2.2	1.64	6.01	6.29	6.48	0.31	1.34	6.22
24-Sep-07	12A	8:30 AM	19.6	606	-	-	0.9	1.45	25.79	29.77	30.78	0.55	4.18	29.54
	12B	8:50 AM	19.3	651	-	-	1.3	1.53	22.43	23.33	24.08	1.01	3.95	23.10
	13A	9:05 AM	18.9	657	-	-	1.3	1.33	20.19	23.10	23.70	2.43	5.91	22.84
17-Oct-07	12A	9:10 AM	NA	219	203	55.2	1.7	1.47	11.93	12.41	12.66	2.02	4.57	12.21
	12A(D)	-	-	-	203	52.6	-	-	-	-	-	-	-	-
	12A(B)	-	-	-	<6	2.9	-	-	-	-	-	-	-	-
	12B	9:30 AM	NA	237	201	40.8	1.7	1.48	15.14	14.98	15.32	2.14	4.81	14.72
	13A	9:50 AM	NA	255	200	84.9	1.5	1.42	14.18	14.69	14.87	3.64	6.91	14.45

Total P
QA/QC @ Site 12A on Jun 27
QA/QC @ Site 12A on Sep 6

Alkalinity
QA/QC @ Site 12A on Oct 17

Total Al
QA/QC @ Site 12A on Oct 17

Note: C/P ratios should be between 1 and 1.7 in order to be considered a high quality sample

Appendix C

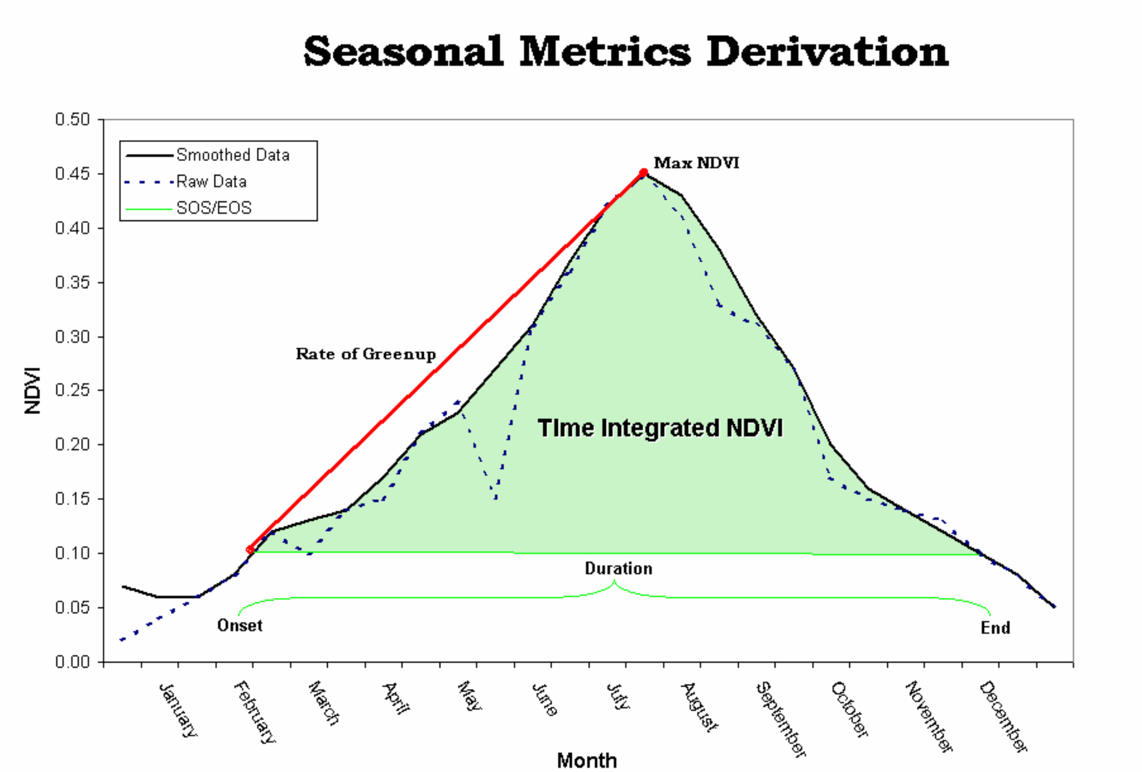
EROS Final Report

Range Condition Estimates for South Dakota DENR

Bruce Wylie, Eric Wood (PRIZM), Susan Maxwell (Assessment/Inspection) and Jesslyn Brown (AVHRR NDVI)
SAIC, USGS EROS, Sioux Falls

Intensive use of rangelands can degrade plant communities, infiltration rates, and increase erosion. Water and wind erosion models as well as carbon flux model would be improved if estimates of range condition were available spatially. We investigate a method for mapping range condition estimates using the seasonally integrated NDVI as a surrogate for forage production. Seasonally integrated NDVI is the area under the NDVI versus time curve. Further a baseline NDVI is established between start of season and end of season NDVI. NDVI values below this (usually associated with soils and dormant vegetation) are removed from the Seasonal integrated NDVI (Figure 1).

Fig 1. What is Time Integrated NDVI?



Seasonal integrated NDVI has been correlated to carbon fluxes, gross primary production, and forage production in grasslands (Wylie poster, Wylie Africa).

Methods

The interannual variability of forage production systems is greatly influenced by precipitation and is quite variable though time and space. Therefore, we seek to identify areas that are producing less forage that what would be expected based on the climatic and soil conditions. If an area is consistently producing vegetation below it climatic and edaphic potential, there is a strong possibility that grazing or other uses could be improved with management. We used the USGS National Land Characterization data (1992) and a South Dakota land cover map (2000) produced by USGS EROS (Susan Maxwell personal communication) to restrict our analysis to only grassland, shrubland, and pasture areas within the state of South Dakota. We utilized only areas with greater that 70% rangeland (grass, or shrub, or pasture) within a 1 km pixel for development of the model. We extracted ~6,000 random 1 km pixels which met this criteria and extracted climate data, seasonal integrate NDVI derived from AVHRR (1998-2004), and STATSGO derived data sets such as percent clay, available water capacity, and percent C_4 (warm season rangeland species). These attributes were extracted for each year from 1998 – 2004.

The climate data were obtained from interpolated monthly climate data set using the PRIZM model (http://www.ocs.orst.edu/prism/products/). Both monthly and seasonal grouping of climate data were tested as predictors. Seasonal groupings consisted of early summer (April – June; see Smart et al. 2005) Analysis were conducted in SAS using R^2 analysis of the best possible regression assessed with the Cp criterion.

The analysis indicated that the STATSGO data could be replaced effectively with the seasonal integrated NDVI averaged from 1989-2004. This represented the long term production potential of rangeland vegetation at a higher spatial resolution than the STATSGO data sets.

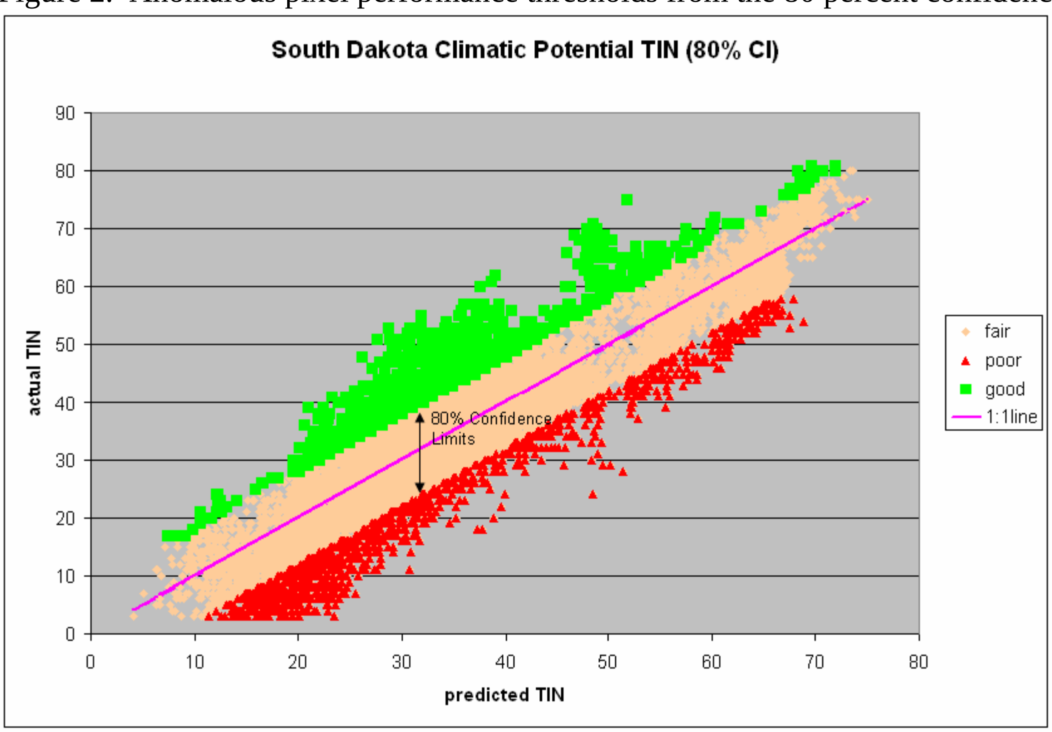
The final model selected used average tin (avgtin, a surrogate historic site potential), early summer (April – June) precipitation (ppt456), minimum temperature in early summer (min456), minimum temperature in spring (tmin3), and the difference between minimum and maximum temperature in winter—Nov – Feb).

TIN = 28.7 + avgtin(0.79) + ppt456(0.07) – 0.61(min456) + 0.94(tmin3) – 0.44(difmnmx111212)

Root MSE 6.18570 R-Square 0.8530

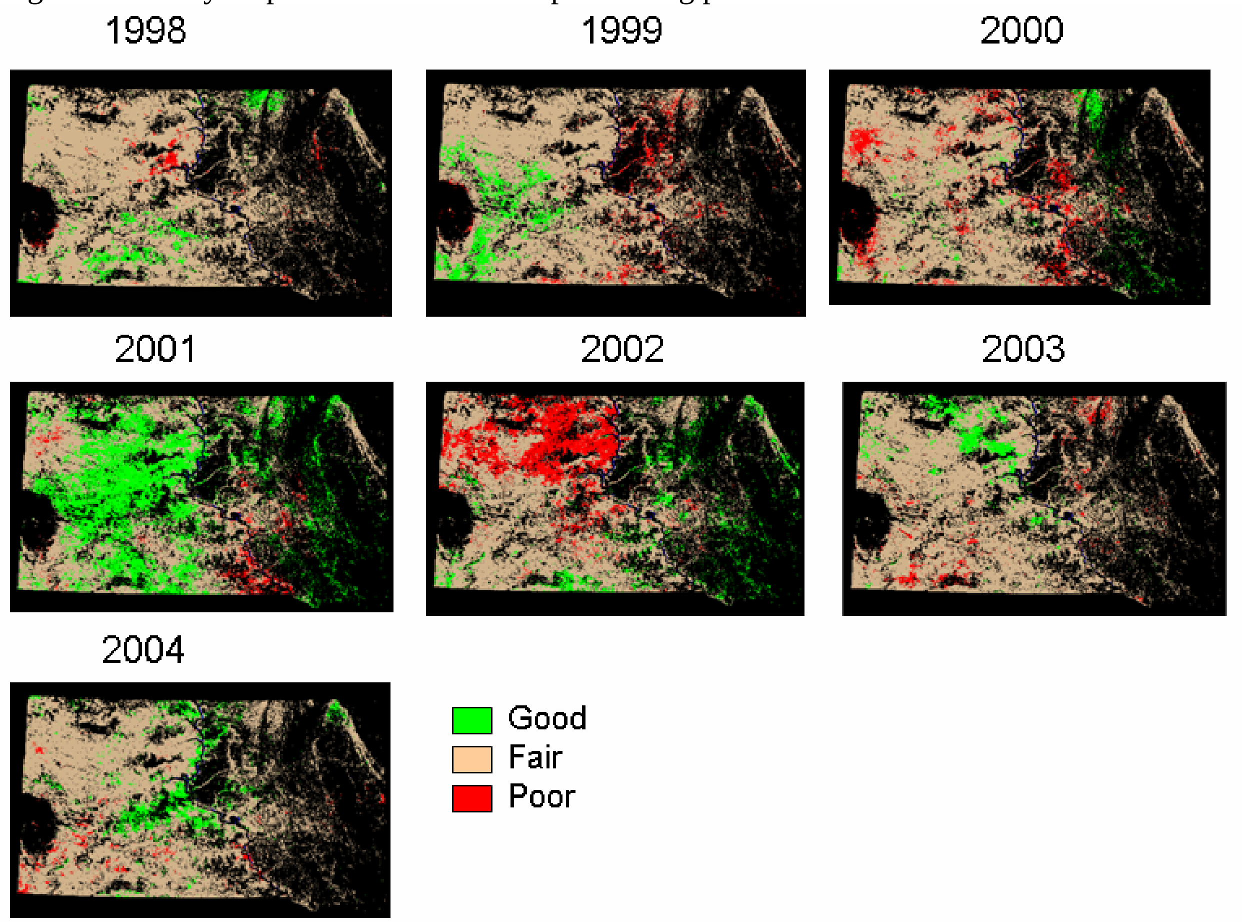
The 80 % confidence limits of the regression between model estimated TIN and observed TIN for the training pixels was used to identify anomalous performing pixels (Figure 2). This approach accounts for, or de-trends for climatic variation. In a wet year a pixel maybe in upper left of figure 2, but in a dry year the same pixel maybe in the lower left. The deviation of each pixel from its climatically predicted TIN can be mapped. Pixels that consistently perform less than expected, the red in figure 2, represent heavily grazed grasslands or grasslands, grasslands with other management effects, or grasslands affected by insects.

Figure 2. Anomalous pixel performance thresholds from the 80 percent confidence intervals.



This allows mapping of under-performing pixels (red) and over-performing pixels each year (Figure 3). From this we can see that the model has not entirely compensated for yearly climatic variations with 2001 having large areas of over-performance and 2002 having large areas of under-performance. By looking at multi-year statistics, areas that consistently under- or over-performed can be identified.

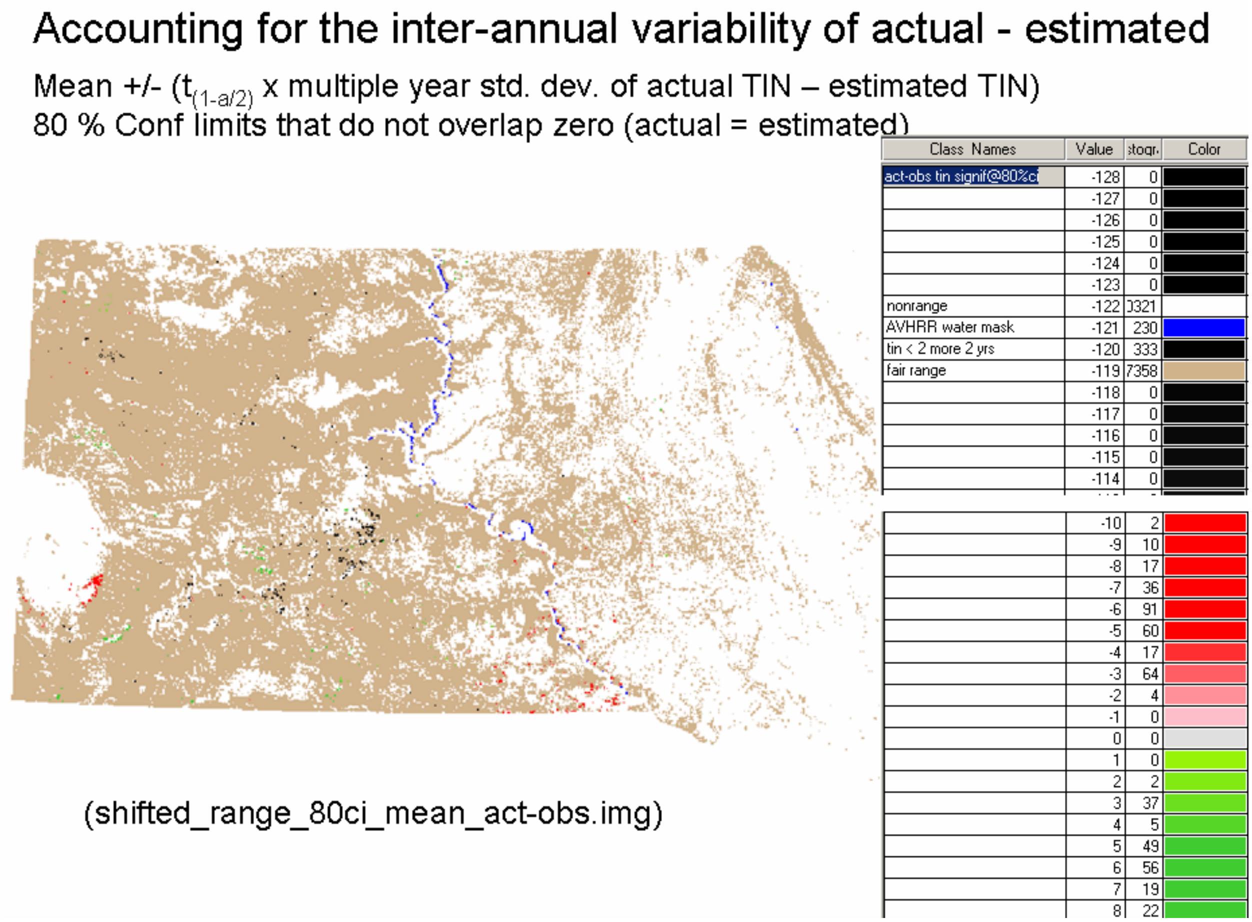
Figure 3. Yearly maps of under- and over-performing pixels



One multiple year statistic was the mean pixel value of the differences maps in figure 3. This map of mean differences was then threshold into anomalous pixels using a simple two-tailed *t* test with an 80 percent confidence level (Figure 4). Note that some areas had anomoulsly low TIN values that we suspect are related to the incorrect identification of start of season which is used to calculate TIN. Pixels with these low TIN values for 2 or more years are colored black.

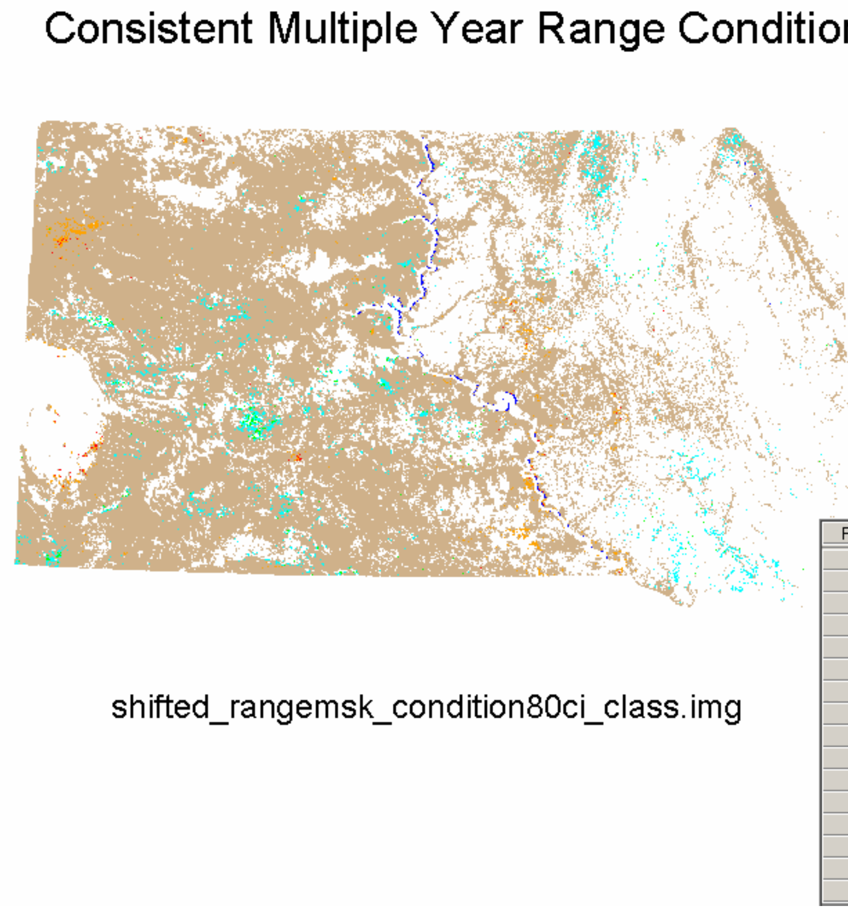
Figure 4 identifies the Galena fire on the western edge of the Black Hills. Fire intensities were particularly high in this fire causing long-term effects on soil productivity and resulted in high soil erosion (http://pubs.usgs.gov/wri/wri034323/). Other regions of abnormally low average performance relative to climatic potential were the south-central part of the state.

Figure 4. Mean difference image (1998-2004) for rangelands in South Dakota.



Another multiple year statistic was a map of the frequency of under performance across the seven years (Figure 5). Four classes are mapped: areas with under-performance for four or more years (red), areas with three or more years of under-performance but with only one year or less of over-performance (orange), areas with four or more over-performing years (green), and areas with three or more years of over-performance but with one or less years of under-performance. This map was investigated using Landsat imagery and MODIS 250m NDVI (2000-2003). Point validation was in general agreement, but localized variations (fence lines versus pixel alignment, minor georegistration issues in the daily AVHRR images used to make the maximum value NDVI composites, or temporal of sets between the validation and TIN data sets) existed. These maps appear to identify general areas to look for range condition issues and are not specific to particular fields on the ground. Further more, problems were seen in the south eastern section of the state where small field sizes and crop rotations (alfalfa was considered a pasture type and included as rangeland) caused confusion.

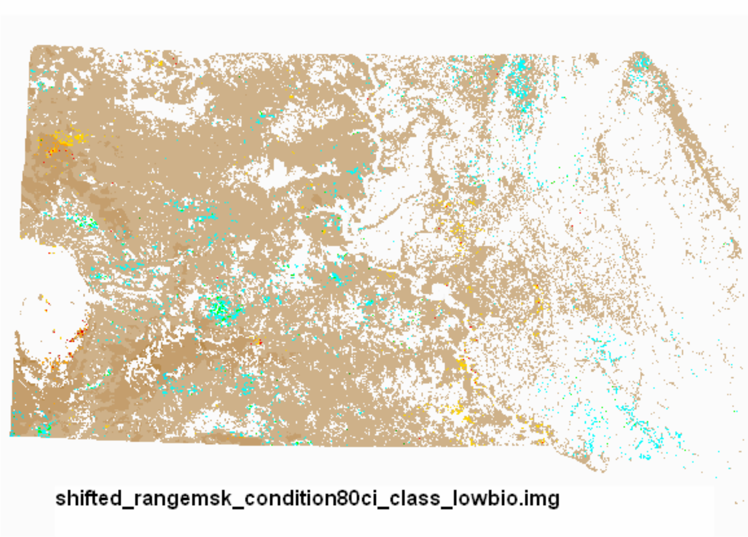
Figure 5. Frequency class map of under- and over-performing rangelands



Row	Histogram	Class Names	Color
0	94280	fair	
1	84	poor>=4 yrs	
2	890	poor>=3 yrs,good <=1yr	
3	269	good>=4 yrs	
4	2691	good>=3yrs, poor<=1yr	
5	0		
6	0		
7	0		
8	0		
9	0		
10	0		
11	0		
12	0		
13	0		
14	230	AVHRR water mask	
15	179686	< 60% rangeland	

Another map separated the classes in figure 5 into three levels of biomass (Figure 5, very low, low, moderate-high). The biomass levels were derived from the long-term average TIN image. The thresholds for very low and low biomass were determined interactively using very low biomass areas (badlands) and low biomass areas (north of the Black Hills) seen on the Landsat images.

Figure 5. Performance classes by biomass levels.



Row	Histogram	Class Names	Color
0	366	v low bio fair	
1	2	v low bio >=4yr poor	
2	5	v low bio>=3yr poor,<=1yr g	
3	15	v low bio >=4yr good	
4	0	v low bio >=3yr good,<=1yr	
5	0		
6	0		
7	0		
8	0		
9	0		
10	10021	low bio fair	
11	24	low bio >=4yr poor	
12	147	low bio>=3yr poor,<=1yr go	
13	6	low bio >=4yr good	
14	110	low bio >=3yr good,<=1yr p	
15	0		
16	0		
17	0		
18	0		
19	0		
20	84528	fair	
21	58	>=4yr poor	
22	738	>=3yr poor,<=1yr good	
23	248	>=4yr good	
24	2581	>=3yr good,<=1yr poor	

Future improvements

1) The spatial representation could be improved by using MODIS 250m NDVI. This should reduce mixed pixel effects considerably relative to the 1 km AVHRR data.
2) Using long-term average TIN as a surrogate for historic performance could result in the model missing and not capturing sites that have been degraded for a long time. The SSURGO data would be an improvement over using STATSGO to get site potential estimates, but county line difference are often evident in SSURGO. An approach I used in Alaska was to build a model to estimate average long-term TIN from soils, elevation, slope, etc. (data sets that vary in space but not time) and used the map of long-term average estimated TIN as a surrogate for site potential. Another option might be to use the average TIN from the upper quartile of TIN across years at each pixel. This would be like a maximum yearly TIN but not as extreme as a maximum statistic.

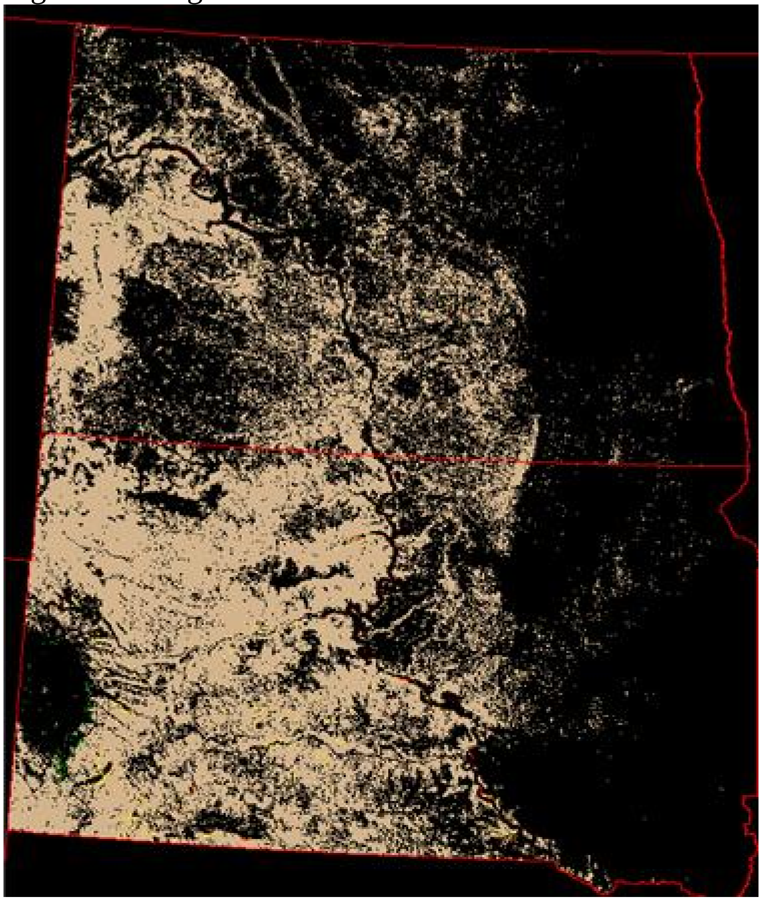
MODIS 250 m

OBJECTIVE
The consensus was that a higher spatial variation would be beneficial to the SD DENR and have less mixed pixel effects than the 1 km AVHRR NDVI.

STUDY AREA

We attempted to refine our product using Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI at the 250m resolution for the time period 2002 to 2005. The area included rangelands in North and South Dakota (figure 6).

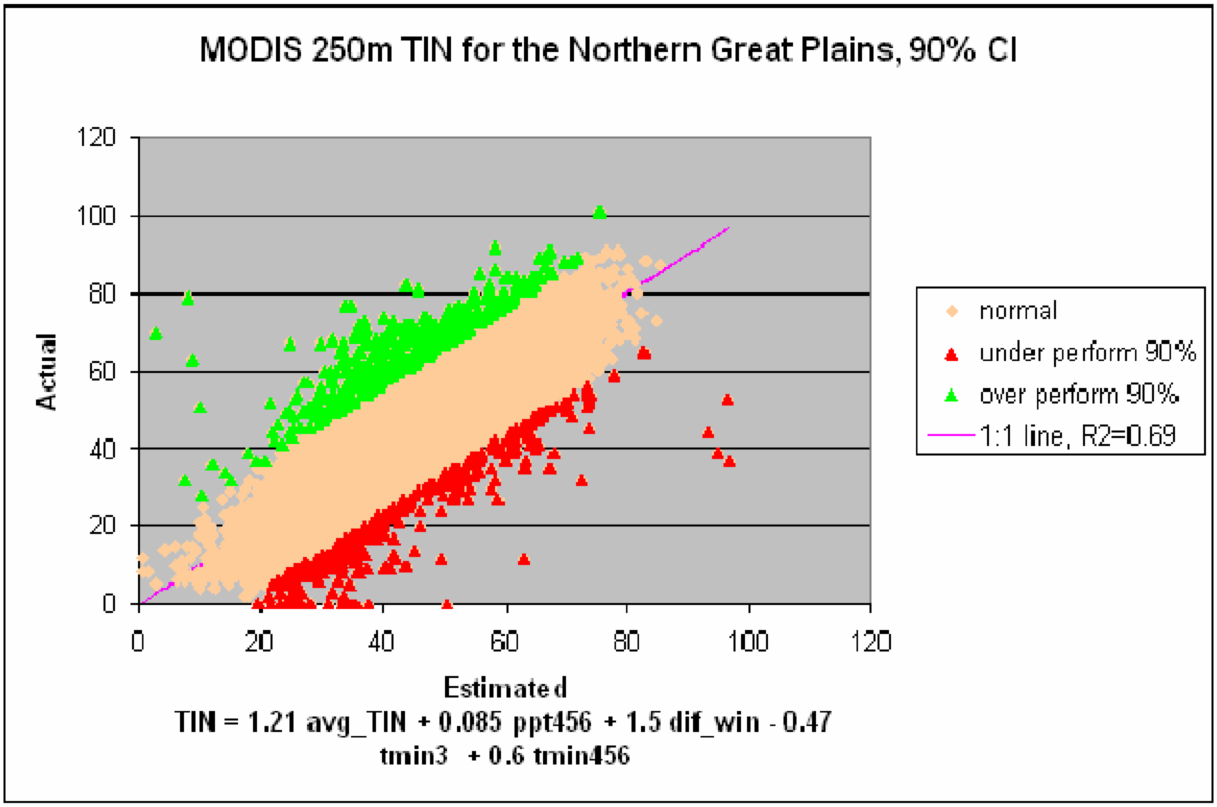
Figure 6. Rangelands in North and South Dakota derived from USGS NLCD Landsat land cover 1991.



MODEL DEVELOPMENT

Random points where cast and sampled across the study period. This data base was used to develop a multiple regression equation to estimate the time integrated NDVI (figure 7). The regression used long term time integrated NDVI (1989 to 2004) from AVHRR (avg_TIN) as a surrogate for site potential. Precipitation in early summer, April through June (ppt456), the difference between minimum and maximum temperature in the winter (November through February; dif_win), minimum temperature in March (tmin3), and the minimum temperature in early summer (tmin456) were used to predict time integrated NDVI along with site potential (avg_TIN). We sought to minimize over fitting by the model by selecting a small set of independent variables which gave a reasonably accurate model (R^2 = 0.69). The 90% confidence intervals served to identify anomalous pixels which exceeded the normal expected model error.

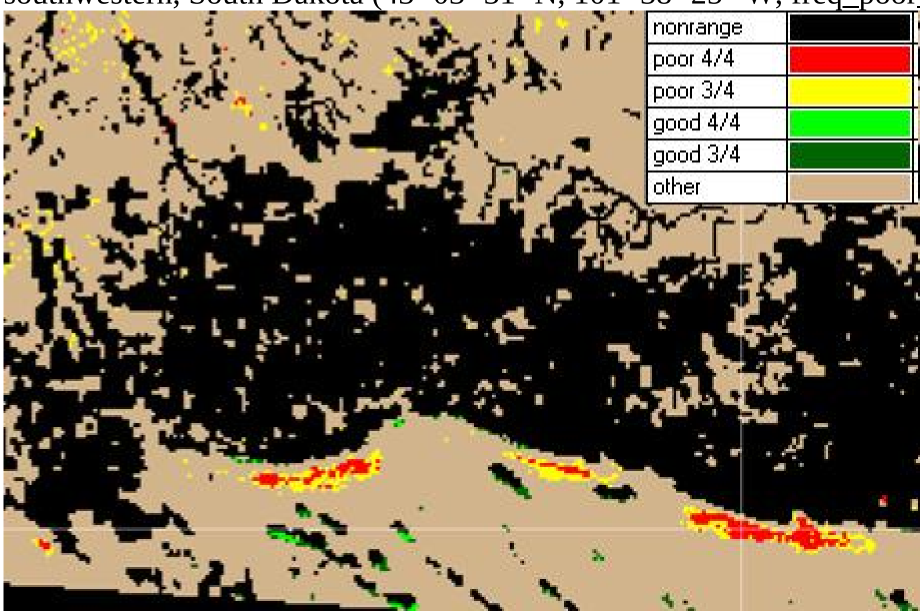
Figure 7. Regression model (X axis) accuracy when compared to actual time integrated NDVI from MODIS.



MAPS PRODUCED

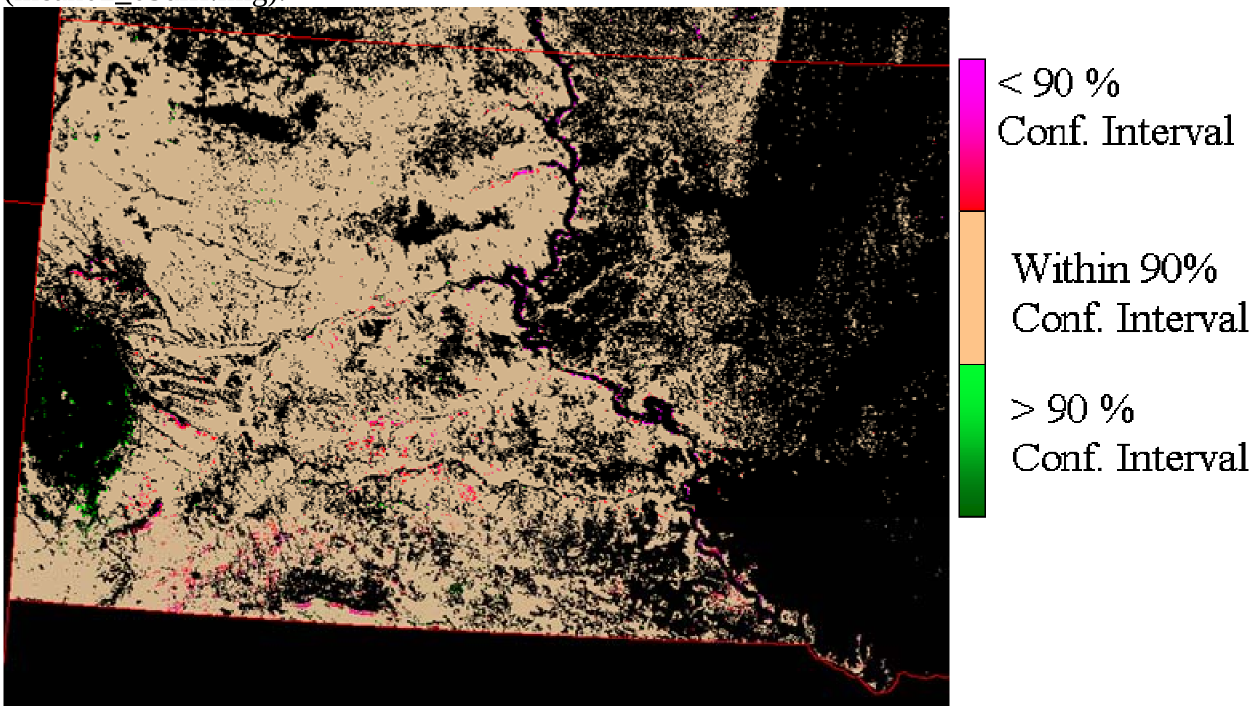
Annual maps were made of the anomalous pixels for each year and summarize in an inter-annual map showing overperforming (good) areas 3 and 4 years out of the 4 year study (figure 8).

Figure 8. Intra-annual map showing overperforming (good) and underperforming areas in southwestern, South Dakota (43° 03' 31' N, 101° 38' 25" W, freq_poor_good.img)



To further identify areas where the anomaly from climate was consistently under or overperforming, the mean anomaly value for the 4 years was mapped.

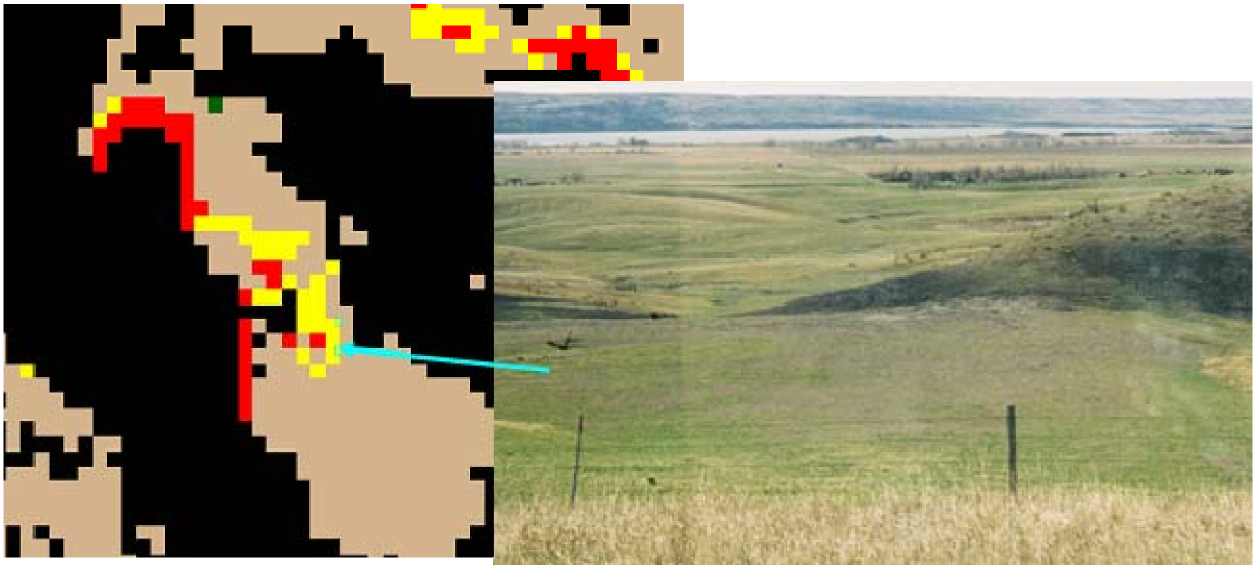
Figure 9. Inter-annual anomaly values (2002 to 2005) for the state of South Dakota (mean02_05diff.img).



VALIDATION

Validation was attempted using field trips and higher resolution imagery. The imagery approach showed general agreement but a quantitative analysis was not done. Field observations were mixed (figure 10). The temporal time lag between the field visit and the dates of the anomaly maps contributed to the confusion. However inspection of litter levels and species composition gave indication that some refinement was needed. Recommendations were to include MLRA boundaries and make models for smaller geographic areas. However, project funding was depleted and USGS demanded focus on another area in FY07.

Figure 10. Field validation.



FUTURE DIRECTION

The USGS Land Remote Sensing project is considering focusing FY 2008 efforts in the Northern Great Plains. Some researchers have found the MODIS 250m products to be noisier than the standard 500m and 1 km products (Olofsson et al. 2007). Possiblities exist using 56m resolution Advanced Wide Field Sensor (AWiFS) data procured by the USDA National Agricultural Statistics Service for their cropland data layer.

Literature Cited

Olofsson, P., F. Lagergren, A. Lindroth, J. Lingstrom, L. Klemedtsson, and L. Eklundh. 2007. Towards and operational remote sensing of forest carbon balance across Northern Europe. Biogeosciences Discussions, 4, 3143-3193.

Appendix D

Alum Demonstration Project Final Report

OSGOOD CONSULTING

Lake Mitchell / Firesteel Creek Water Quality Improvement Project

Final Progress Report on the 2003-2005 Alum Demonstration Project

January 2006

Dick Osgood

OSGOOD CONSULTING

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Lake Mitchell / Firesteel Creek Water Quality Improvement Project

Final Progress Report on the 2003-2005 Alum Demonstration Project

January 2006

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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.

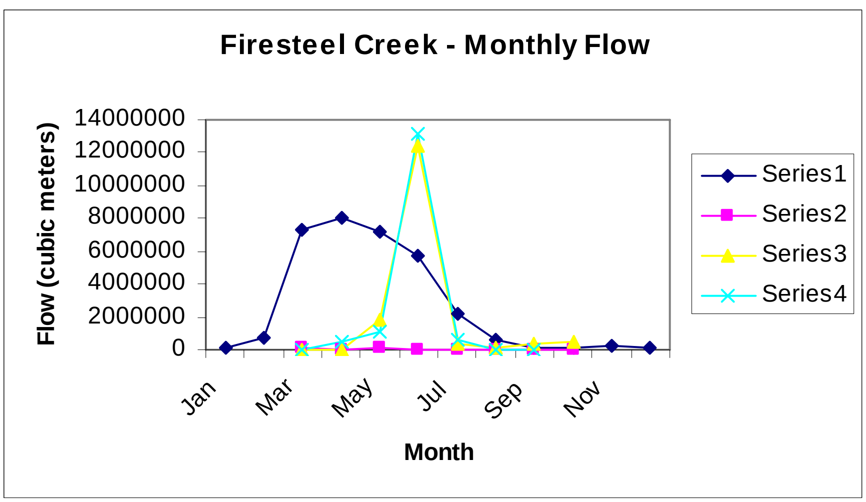
Following the sediment analysis, recommendations were made to the City in late-2004 regarding the needed alum dose to complete the treatment program for immobilizing sediment phosphorus. The City decided at that time to continue with the planned treatments and complete the three-year demonstration project.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

D. Water and Phosphorus Inputs

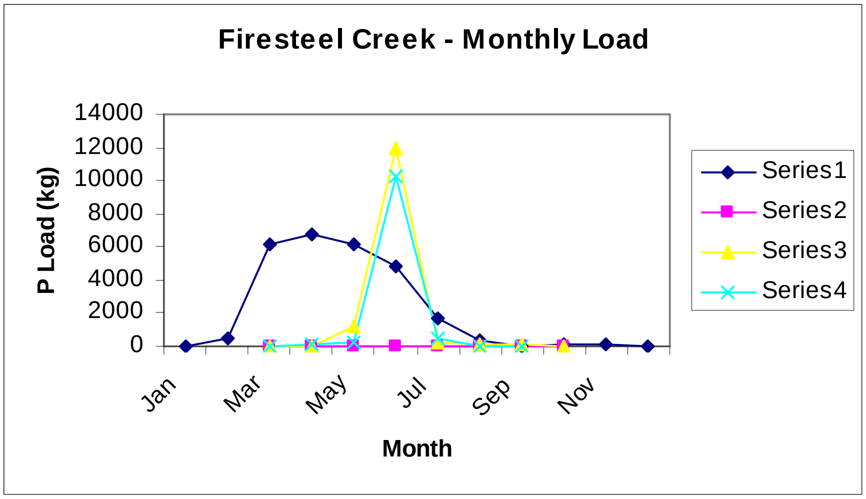
1. Runoff

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).

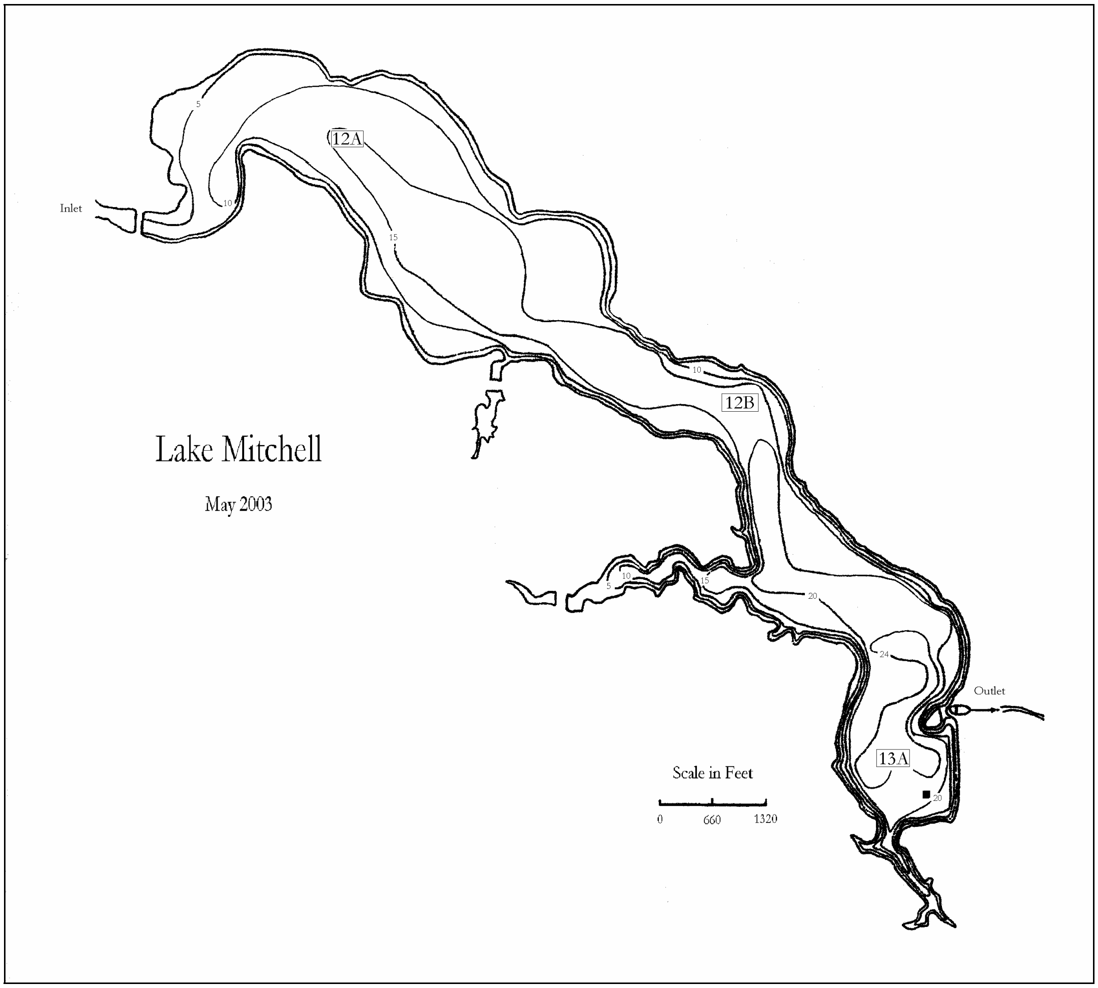
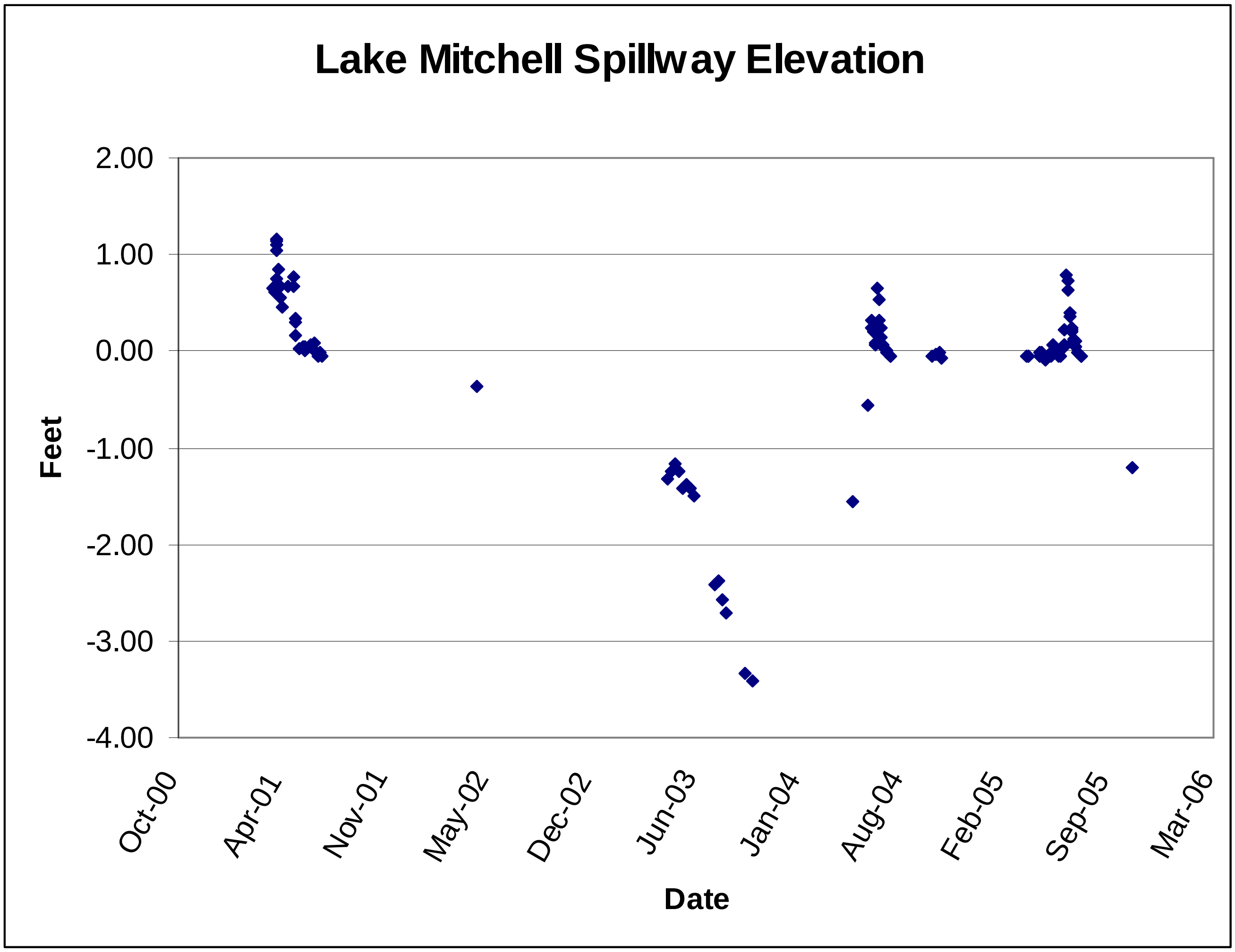


Figure 1. 2003, 2004 & 2005 Water Quality Sampling Sites

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.

	<u>Summer Ranges</u>
2003	- 1.3 to - 3.3 feet
2004	- 0.5 to + 1.7 feet
2005	- 0.1 to + 0.8 feet



b. Phosphorus

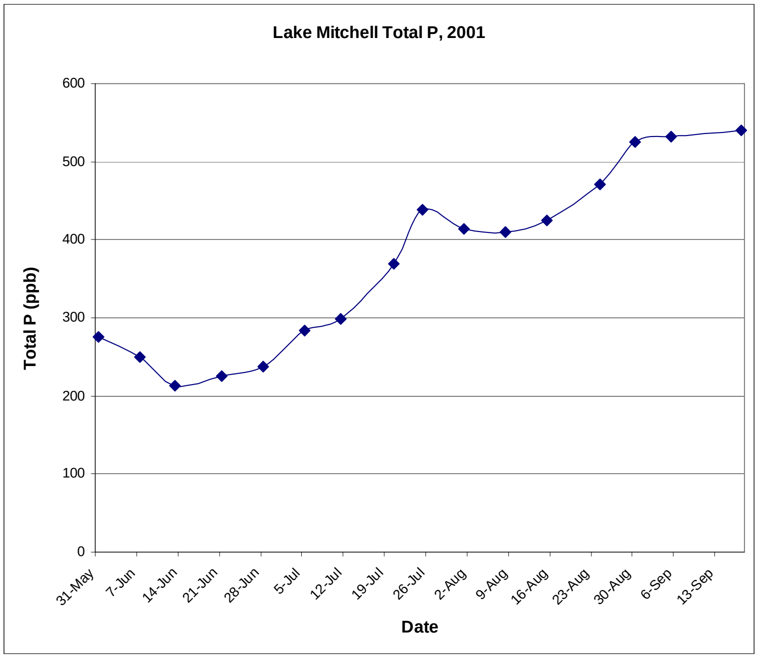
Phosphorus concentration was measured from the surface of the lake. Because Lake Mitchell is well mixed, surface samples represent a good approximation of water column phosphorus content.

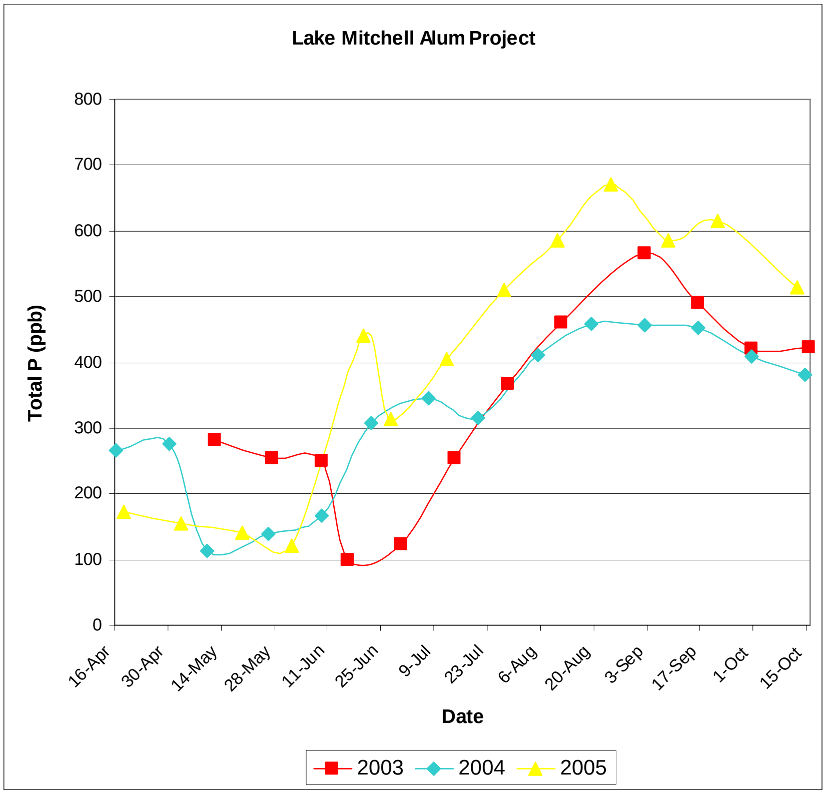
Lake phosphorus concentrations were reduced following the alum applications:

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 than 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 their 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.

Copper sulfate

Copper sulfate is an algaecide that is reasonably 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.

Circulation

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.

Corn meal and barley straw

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 (11×10^6 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

Appendix E

Information & Education

http://denr.sd.gov/dfta/wp/tmdl/fciesegment1.pdf