Total Maximum Daily Load
For Turbidity
Storm Lake
Buena Vista County, Iowa

2005

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Storm Lake Summary.

Waterbody Name:	Storm Lake
County	Buena Vista
Use Designation Class	Primary contact recreation, A1 Aquatic life, B(LW)
Major River Basin	Des Moines River Basin
Pollutant	Turbidity
Pollutant Sources	Wind resuspension of total suspended solids
Impaired Use	Primary contact recreation
2002 303d Priority	Medium
Watershed Area	14,700 acres
Lake Area	3,150 acres
Lake Volume	24,900 acre-ft (30.8 million m^3)
Detention Time, based on outflow	2.6 years
Target, turbidity measured as Secchi depth	0.7 meters
Target, average total suspended solids (TSS) concentration, as related to Secchi depth	20 mg/l (680 tons in a volume of 30.8 million m^3)
Existing average TSS concentration and Secchi depth	48 mg/l (1620 tons in a volume of 30.8 million m^3), Secchi depth = 0.4 m
TSS load reduction as a concentration to achieve target	Reduce average water column TSS concentration by 28 mg/l (950 tons in a volume of 30.8 m^3)
Wasteload Allocation	Zero

Table 1a. Load Allocation based on lake bottom area disturbed by wind induced waves.

Extent of wave disturbed lake bottom area, acres	Load Allocation, tons per disturbed lake bottom acre to achieve 20 mg/l TSS (612 tons total load)	Load per unit area, pounds/square foot of lake bottom (20 mg/l TSS at 612 tons total load)
500	1.22	0.0562
1000	0.61	0.0281
1500	0.41	0.0187
2000	0.31	0.0140
2500	0.24	0.0112
3000	0.20	0.0094

Table 1b. Load Allocation, Little Storm Lake rainfall event discharge.

Design flow condition, 24 hour average	20 cfs discharge to Storm Lake
Target TSS concentration	50 mg/l
TSS load allocation, 24 hour average	5,400 lbs/day TSS

The Federal Clean Water Act requires the Iowa Department of Natural Resources (IDNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. Storm Lake has been identified as impaired by turbidity. The purpose of the TMDL for Storm Lake is to calculate the allowable sediment load for the lake that will meet water quality standard turbidity levels.

This document consists of a single TMDL for turbidity designed to provide Storm Lake water quality that fully supports its designated uses. The primary source of turbidity causing the impaired condition is the resuspension of lake bottom sediment caused by wind-induced waves. A secondary source of sediment is that contributed by Little Storm Lake and other Storm Lake tributaries during rainfall events. This TMDL targets sediment resuspended by waves and measured as total suspended solids to address the turbidity impairment and also TSS delivered to Storm Lake from Little Storm Lake.

This TMDL has two phases. Phase 1 consists of setting specific and quantifiable targets for Secchi depth transparency and total suspended solids. The waterbody loading capacity, existing pollutant load in excess of this capacity, and the source load allocation is estimated based on currently available information. Phase 2 will consist of implementing the load reduction and monitoring plans, evaluating collected data, and readjusting target values if needed.

Phasing TMDLs is an iterative approach to managing water quality employed when the origin, nature and sources of water quality impairments are not well understood. The monitoring plan provides data that determines if load reductions result in attainment of water quality standards. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling. Section 5.0 of this TMDL includes a monitoring plan description. Monitoring:

- Assesses the future beneficial use status;
- Detects water quality trends
- Evaluates effectiveness of implemented best management practices

The Storm Lake TMDL for turbidity has been prepared in compliance with the current regulations for TMDL development that were promulgated in 1992 as 40 CFR Part 130.7. These regulations and consequent TMDL development are summarized below:

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Storm Lake, S10, T90N, R37W, on the southern edge of the City of Storm Lake, Buena Vista County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutant causing the water quality impairments is turbidity associated primarily with internal sediment cycling. Designated uses for Storm Lake are Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). Excess turbidity has impaired aesthetic and aquatic life water quality narrative criteria (567 IAC 61.3(2)) so that designated uses are not supported.

3. **Quantification of the pollutant load that may be present in the waterbody and still allow attainment and maintenance of water quality standards:** The Phase 1 target of this TMDL is a Secchi depth transparency of 0.7 meters. This is equivalent to an average total suspended solids concentration of 20 mg/l.

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is**

being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards: The estimated existing average TSS as measured by concentration is 48 mg/l. The TSS concentration difference is 28 mg/l. To achieve and maintain lake water quality goals and protect for beneficial uses, an average TSS concentration of 20 mg/l is required.

5. **Identification of pollution source categories:** Nonpoint sources, primarily in the form of resuspended sediments, have been identified as the cause of the turbidity impairment to Storm Lake. Secondary turbidity sources are associated with rainfall event discharges from Little Storm Lake, other tributaries, and the watershed.

6. **Wasteload allocations for pollutants from point sources:** There are no significant point sources in the Storm Lake watershed, therefore the wasteload allocation is zero.

7. **Load allocations for pollutants from nonpoint sources:** The total suspended solids load is based on the resuspension areal load and TSS concentration in the Little Storm Lake discharge to Storm Lake during rainfall events. See Table 1a for the load allocation and Table 1b for the Little Storm Lake discharge load allocation.

8. **A margin of safety:** The margin of safety of 68 tons for this TMDL is an explicit 10 percent reduction in the resuspension areal load allocation.

9. **Consideration of seasonal variation**: This TMDL was developed based on annual TSS loads that will result in attainment of Secchi depth targets year round.

10. **Allowance for reasonably foreseeable increases in pollutant loads**: An allowance for increased TSS load was not included in this TMDL. The primary source of Storm Lake turbidity is resuspended bottom sediment that results from wind driven waves and currents and the shallowness of Storm Lake for its fetch distance. The wind and lake size are characteristics that will not change. A long-term program of dredging is currently increasing the lake depth. Significant changes in the Storm Lake watershed landuse are unlikely.

11. **Implementation plan:** Although not required by the current regulations, an implementation plan is outlined in Section 4 of this document.

2. Storm Lake, Description and History

2.1 The Lake

Storm Lake is one of Iowa's 34 natural, glacial lakes and is located on the south edge of Storm Lake, Iowa. Approximately 30% of the shoreline of Storm Lake is in public land including City of Storm Lake parks, City of Lakeside parks, one Buena Vista County park, the City of Storm Lake campground, and five boat ramps. The lake and park areas provide facilities for fishing, camping, boating and picnicking. Park use is approximately 267,000 visits per year.

Approximately 155 acres of the lake were dredged in the 1960s. A dredging project is currently underway in Storm Lake with plans to dredge an area of 1,500 acres to a depth of at least 13 feet.

Table 2. Storm Lake Characteristics.

Waterbody Name:	Storm Lake
Hydrologic Unit Code:	HUC10 0710000603
IDNR Waterbody ID:	IA 04-RAC-00530-L
Location:	Section 10 T90N R37W
Latitude:	42° 38' N
Longitude:	95° 12' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Powell Creek
Receiving Waterbody:	Outlet Creek to North Raccoon River
Lake Surface Area:	3,150 acres
Maximum Depth:	14 feet (not including recent or planned dredging)
Mean Depth:	8 feet (not including recent or planned dredging)
Volume:	24,900 acre-feet (30.8 million m^3)
Length of Shoreline:	52,500 feet
Watershed Area:	14,700 acres
Watershed/Lake Area Ratio:	4.4:1
Estimated Detention Time:	2.6 years

Morphometry

Storm Lake has a mean depth of 8 feet and a maximum depth of 14 feet. The lake surface area is 3,150 acres and the storage volume is 24,900 acre-feet. These measurements do not reflect the recent dredging in Storm Lake.

Temperature and dissolved oxygen sampling indicate that Storm Lake remains oxic and relatively well mixed through much of the growing season. The lake is approximately 3.5 miles long and 2 miles wide and has shoreline development ratio of 4.2.

Hydrology

Water from Powell Creek flows into Little Storm Lake then into Storm Lake. Little Storm Lake is an open water and marsh area located on the northwest edge of Storm Lake.

Little Storm Lake is 190 acres and includes the Little Storm Lake Management Area. Episcopal Creek drains the smaller southwest portion of the watershed to Storm Lake.

The estimated annual average detention time for is 2.6 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Storm Lake watershed has an area of approximately 14,700 acres excluding the lake and has a watershed to lake ratio of 4.4:1. Land use data was collected in 2002-2003 through a developmental grant from the Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation. Row crop and CRP acres were updated in 2002 by the Buena Vista County SWCD for the Storm Lake watershed. The land uses and associated areas for the watershed are shown in Table 3.

Table 3. 2002-03 Landuse in Storm Lake watershed.

Landuse	Area (acres)	Percent of Total Area
Cropland	10,990	75
Urban	1,530	10
CRP/Hay	760	5
Timber/Marsh/Park	370	3
Farmsteads	350	2
Pasture	100	1
Other	600	4
Total	14,700	100

Topography of the watershed varies from level to moderately sloping. Soils of the watershed include the Sac-Primghar-Galva soil association. These soils vary from well drained to poorly drained and are moderately erodable. Average rainfall in the area is 35 inches/year, with the greatest monthly amount (5.0 inches) occurring in June (DSC-DNR, 1991).

The urban areas of Alta, Storm Lake, and Lakeside lie within the watershed boundaries as well as unincorporated urban areas on the south and west sides of the lake. The Lake receives urban runoff from Storm Lake through 54 storm sewer outfalls, 4 of which constantly discharge due to elevated groundwater.

Current Watershed Conditions

Many best management practices and one structure are in place in the Storm Lake watershed. These include conservation tillage, contour farming, terraces, integrated crop management, buffer filter strips and riparian buffers. The control structure and sedimentation pond were constructed on Episcopal Creek.

A long-term commitment between the DNR, the Iowa Department of Agriculture and Land Stewardship (IDALS), Natural Resource Conservation Service (NRCS) and the Iowa Lakes Resource Conservation and Development (RC&D) has resulted in reducing watershed erosion and nutrient delivery to Storm Lake. This commitment began in 1989 with the creation of the Storm Lake Water Quality Protection Project funded through Section 319 funds. The project was completed in 2000 and included the installation of 6900 acres of conservation tillage, 7850 feet of terraces, 222 acres of contour farming, 7000 acres of integrated crop management, and 87 acres of filter strips and wetlands. Estimated soil saved through the implemented practices is 19,150 tons per year.

Activities in the watershed since 1990 have worked to reduce sediment and nutrient delivery to Storm Lake. A three year watershed project funded through CWA Section 319 was initiated in 2004 with the objective of reducing sediment and nutrient delivery to Storm Lake. Monitoring conducted on Little Storm Lake in 2004 will be used by the U.S. Army Corps of Engineers to assess the functionality of Little Storm Lake and possible improvements that can be made.

3. TMDL for Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The *Iowa Water Quality Standards* (12) designated uses for Storm Lake are Primary Contact Recreation (Class A) and Aquatic Life (Class B(LW)). Storm Lake also has general uses of secondary contact recreation, domestic uses, and wildlife uses.

Storm Lake was put on the 2002 impaired waters list due to partial support of primary contact recreation use caused by aesthetically objectionable turbidity that is a combination of inorganic material and blooms of algae. The State of Iowa does not have numeric water quality criteria for turbidity but the turbidity can be evaluated using transparency as measured by Secchi depth, the concentration of total suspended solids as compared to other lakes, and the partitioning of suspended solids into inorganic and volatile fractions. The applicable water quality standard is:

IAC 567 61.3(2)c: *Such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor, or other aesthetically objectionable conditions.*

The rationale for the IDNR 2002 Storm Lake water quality assessment that led to the lake’s current impaired status is found below. The assessment used the Iowa Lake Survey data from 2000 and 2001. This TMDL was developed using four years of Iowa Lake Survey data from 2000 to 2003.

ASSESSMENT EXPLANATION: Results of monitoring conducted by ISU in 2000 and 2001 as part of the statewide survey of Iowa lakes suggest that the Class A (primary contact) uses are only "partially supported." Using the median values from this survey in 2000 and 2001 (approximately six samples), Carlsons's (1977) trophic state indices for total phosphorus, chlorophyll-a, and Secchi depth are 83, 58, and 80, respectively, for Storm Lake. According to Carlson (1977), the index values for total phosphorus and Secchi depth places this lake in the mid to upper range of hyper-eutrophic lakes; the index value for chlorophyll-a is in the upper range of eutrophic lakes.

These index values suggest extremely high levels of phosphorus in the water column, relatively low (and less than expected) levels of chlorophyll-a, and very poor water transparency. Given the high levels of phosphorus, the relatively low index for chlorophyll-a indicates less than expected production of suspended algae, probably due to high levels of turbidity related to suspended inorganic material in the water column or due to nitrogen limitation.

Data on inorganic suspended solids from the ISU survey suggest that this lake is subject to high levels of non-algal turbidity. The median level of inorganic suspended solids in the 130 lakes sampled for the ISU lake survey in 2000 and 2001 was 5.27 mg/l. The median level of inorganic suspended solids at Storm Lake (40.6 mg/l) was the second highest of the 130 lakes, thus suggesting that non-algal turbidity limits the production of algae as well as impairs beneficial uses. The relatively low ratio of total nitrogen to total phosphorus (5) also suggests a limitation on the production of chlorophyll.

The presence of the extremely high levels of total phosphorus in the water column indicates potential impairments to the Class A (primary contact) uses through presence of aesthetically objectionable blooms of algae and presence of nuisance algal species (i.e., bluegreen algae). Data from Downing et al. (2002) suggest that bluegreen algae (Cyanophyta), tend to dominate the summertime phytoplankton community of Storm Lake, especially in late summer). Sampling in 2000 showed the percent wet mass of bluegreens increased from just above 60% in the mid-June sampling to approximately 90% in early August sample.

Based on this information, turbidity-related impacts to the primary contact and aquatic life uses at this lake will be attributed primarily to non-algal turbidity and secondarily to suspended algae. The hyper-eutrophic conditions at this lake, along with information from the IDNR Fisheries Bureau, suggest that the Class B(LW) aquatic life uses are "partially supported" due to excessive nutrient loading to the water column, nuisance blooms of algae, and re-suspension of sediment.

The recently completed draft 2004 assessment for Storm Lake indicates continued impairment due to very high inorganic turbidity. It also notes a strong potential for nuisance algal blooms due to very high TP concentrations when the light limiting non-algal turbidity is reduced.

Data Sources

The two most important data sources used to develop this TMDL were:

- The *Storm Lake Restoration Diagnostic/Feasibility Study* (11) completed in 1994. Samples were collected for this study 11 times from September 1992 to September 1993. Summarized results are shown in Table B-4.
- The *ISU Iowa Lakes Survey* (6, 7, 8, 9), a planned five-year survey of all the significant Iowa Lakes started in 2000. The survey monitoring consists of three growing season samples for each of 132 lakes, i.e., mid May to September. Data collected from 2000 to 2003 used to develop this TMDL are shown in Tables B-5, B-6, B-7, and B-8.

There have been several Storm Lake monitoring and water quality studies over the past 25 years. These include:

- Water quality surveys conducted on Storm Lake by Iowa State University in 1979 and 1990 (1, 2). Samples were collected three times each summer for the lake studies conducted in 1979 and 1990. This data is shown in Tables B-1 and B-3.
- *1981-82 Storm Lake Water Quality Study*, University of Iowa Hygienic Laboratory, (13). Storm Lake was monitored three times at three locations in the lake. On each date, samples were collected from the surface and just above the lakebed. These results are shown in Table B-2.
- Samples were collected by Buena Vista University in 2001 and 2003 (3) and included data for several Storm Lake tributaries. This data is summarized in Table B-9.
- Members of the Storm Lake community have regularly measured Secchi depth in 2004 and the collected data is in Table B-10.

Interpreting Storm Lake Water Quality Data

The primary data used to develop this TMDL are four years of data collected and analyzed for the Iowa Lake Study from 2000 to 2003. This is the most recent and complete data set available and includes the period when recent dredging operations began in 2002. The data collected for this evaluation of the Storm Lake water quality impairment includes transparency as measured by Secchi depth, total suspended solids (TSS), inorganic suspended solids (ISS), volatile suspended solids (VSS), chlorophyll (CHL), and total phosphorous (TP). The Table 4 shows these parameters and their relationship to turbidity (water clarity).

Table 4. Turbidity and its relationship to other parameters.

Parameter	Physical Meaning
Turbidity	Properties of the water column that cause light to be scattered and absorbed, primarily caused by algal and inorganic TSS.
Secchi depth, meters	Measures water column transparency and used as a translator for turbidity.
TSS, mg/l	Solids residue captured on an 0.45 um filter and then dried at 105 C.
ISS, mg/l (fixed solids)	Solids residue remaining after heating at 550 C. Approximates inorganic suspended solids in the water column.
VSS, mg/l	Weight lost after heating, VSS is the difference between TSS and ISS. In a lake, most of the VSS will be algae.
Chlorophyll, mg/l	Chlorophyll is a measure of the algae concentration in the water column. Usually chlorophyll will be correlated with VSS.
Total phosphorous, mg/l	Total phosphorous is often the limiting factor in algal productivity. In the absence of light limitation TP would likely control the extent of algae blooms in this lake. Can be related to chlorophyll and Secchi depth with the trophic state index in the absence of other limiting conditions.

As described in the Storm Lake water quality assessment, the main cause of the lake's turbid condition is non-algal turbidity, i.e., inorganic suspended solids. An evaluation of the ISU Iowa Lake Study data shows a strong correlation between TSS, ISS, and Secchi depth and no correlation between chlorophyll and Secchi depth.

Figure 1. TSS versus Secchi depth regression

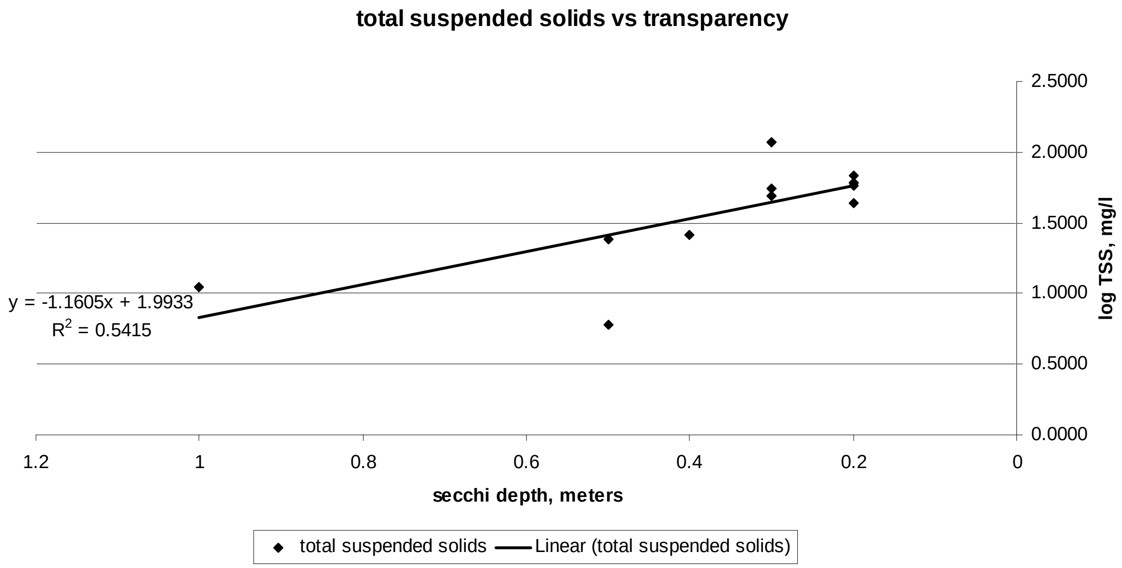


Figure 2. ISS versus Secchi depth regression

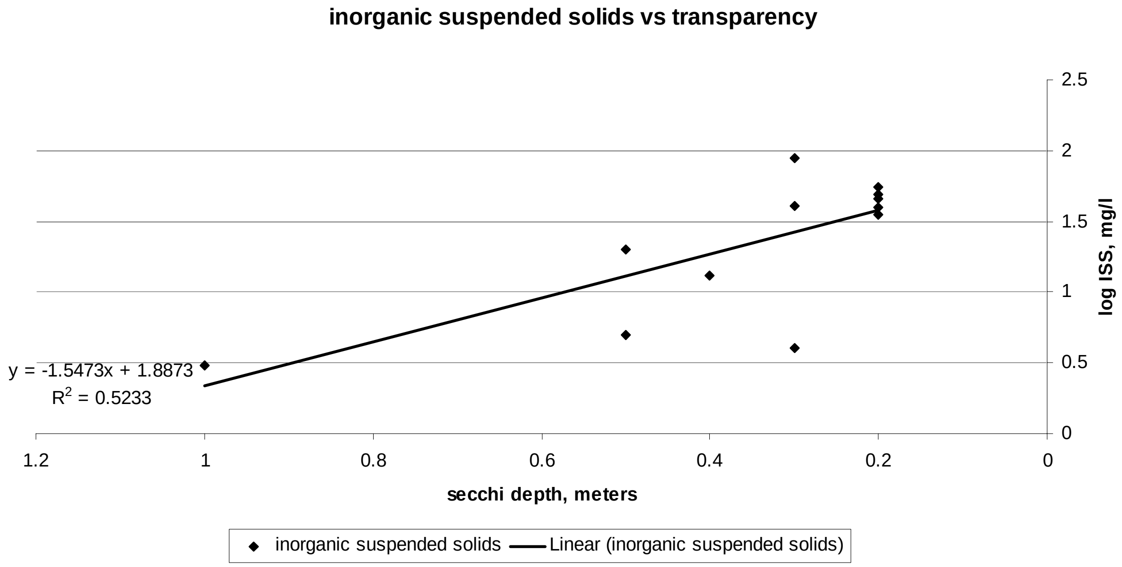


Figure 3. Chlorophyll versus Secchi depth regression

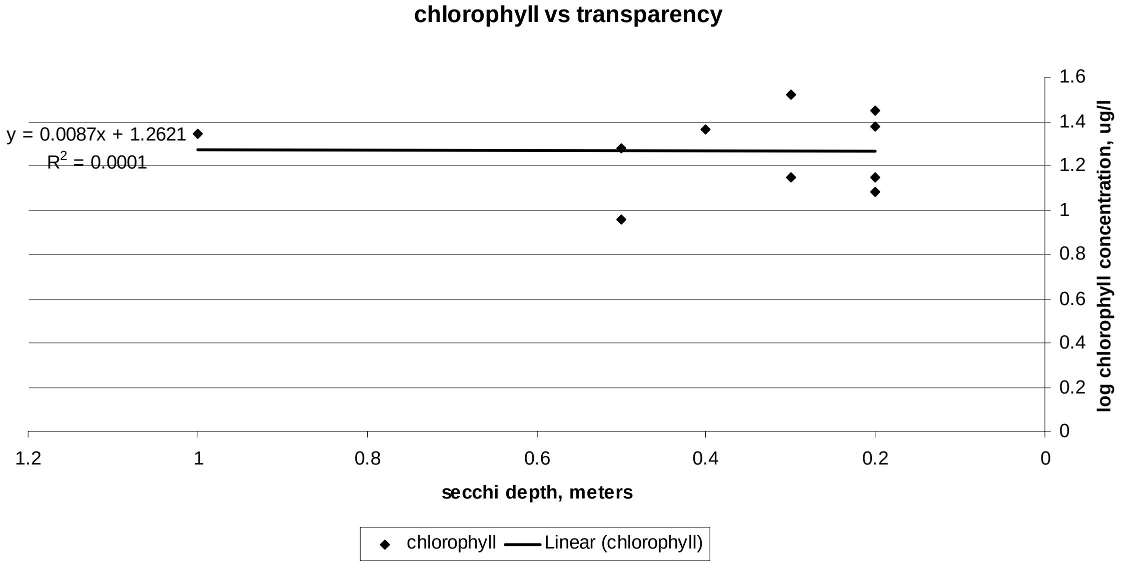


Table 5. Statistics for linear regressions of Secchi depth vs. TSS, ISS, VSS, and chlorophyll.

	r squared	r=correlation coefficient	p=probability of null hypothesis, n=12
Log TSS	0.54	0.73	0.01
Log ISS	0.52	0.72	0.01
Log VSS	0.15	0.39	Not significant, >0.05
Log Chl	0.00	0.00	Not significant, >0.05

The “r squared” term is an indication of how much of the variability in Secchi depth is explained by the regression of TSS, ISS, VSS and chlorophyll with 1 being perfect correlation. The “r” term is the linear correlation coefficient and measures the linear association between the two variables. The “p” term is the likelihood that the variability is random and for TSS and ISS is 1 in 100. A p value less than or equal to 0.05 is considered significant for this document.

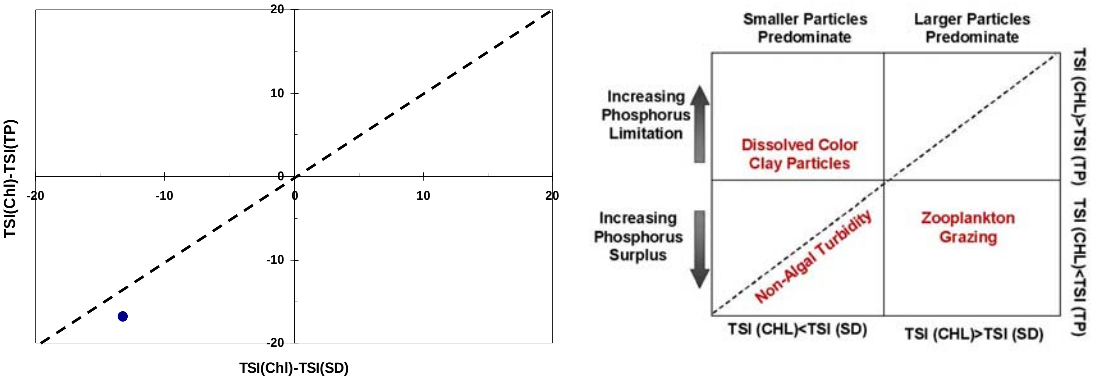
These statistics show that inorganic suspended solids cause the Storm Lake turbidity problem and that there is little correlation between algae and turbidity as measured by chlorophyll and Secchi depth transparency. However, the presence of high concentrations of total phosphorous suggest that algal blooms may increase as non-algal turbidity decreases and light is not so limiting for algal growth. The following table shows the average Secchi depth, total phosphorous, and chlorophyll and the associated TSI values for the 2000 to 2003 Iowa Lake Study data.

Table 6. Averages of Iowa Lake Study Data and associated TSI values

	Four-year average	TSI calculated for average
Secchi depth	0.4 meters	73
Total phosphorous	153 ug/l	77
Chlorophyll	20 ug/l	60

Table 6 shows that the chlorophyll TSI value is much lower compared to total phosphorous and indicates that light and not TP is the limiting factor for algal growth. Carlson's Trophic State Index (TSI) is can be used to relate total phosphorus to chlorophyll and Secchi depth. (Appendix C includes an explanation of the TSI and its application to TMDL development.) The TSI comparison plot in Figure 4 shows (point in lower left hand quadrant) that there is a large phosphorus surplus, i.e., a significant fraction of TP is not expressed as algae. This indicates that non-algal turbidity is the major factor for reduced Secchi depth transparency. Comparisons of the TSI values for chlorophyll, Secchi depth, and total phosphorus from Iowa Lake Survey data indicate limitation of algal growth from light attenuation by elevated levels of inorganic suspended solids.

Figure 4. Mean TSI Multivariate Comparison Plot of the Iowa Lake Survey data for Storm Lake.



Potential Pollution Sources for Turbidity and Suspended Solids

Sediment and sediment attached phosphorus loading to Storm Lake originates primarily from internal resuspension of bottom sediment and less importantly from watershed nonpoint sources. The potential watershed sediment sources are delivered from cropland sheet and rill erosion, shoreline erosion, streambank erosion, and gully erosion. Less significant potential watershed sources include urban runoff from the City of Storm Lake through storm sewers, construction and development activities, grasslands, and forest. There are no permitted point source discharges in the watershed. Lannie Miller, an IDNR fisheries biologist, has said that Storm has a very small rough fish population and they do not impact the turbidity.

The 1994 Diagnostic/Feasibility Study (11) evaluated the sources of the turbidity problem in Storm Lake and concluded that the suspended matter is "caused by wind resuspension of bottom sediment that is a common problem of large shallow unprotected lakes such as Storm Lake".

To support this conclusion, bathymetric surveys from 1916, 1935, 1972, and 1993 were used to evaluate historic siltation rates and the watershed model AGNPS (AGricultural Non-Point Source) was used to estimate watershed sediment delivery. The bathymetric data show that sediment delivery to Storm Lake is minimal since the estimated water volume hasn't varied much from 20,000 acre-feet since the first survey in 1916. The report concludes that the negligible sediment delivery to the lake is because the major tributary, Powell Creek, discharges into Little Storm Lake where most sediment settles before runoff enters Storm Lake.

The AGNPS watershed modeling done for the 1994 Diagnostic /Feasibility Study using data from between 1954 and 1963 estimated the sediment delivery to the lake at a annual rate of 7 acre-feet per year (9,900 tons per year). More recently, it was estimated that sediment delivery from the watershed was 2.84 acre-feet per year (4,020 tons per year) and 1.89 acre-feet per year (2,680 tons per yr) for 1998 and 1999 respectively.

In 2003, the Modified USLE (MUSLE) watershed model was used to evaluate 2-inch rainfall event sediment delivery both with and without the Episcopal Creek sediment detention structure built in 2002. Delivery without the structure was 1463 tons and with the structure in place was 1327 tons providing a further decrease in sediment delivered to the lake.

In 2003 the Revised USLE (RUSLE) model was run for the watershed and, assuming a delivery ratio of 20%, showed a delivery of 4,000 tons per year (2.82 acre-feet per year). The gross sheet and rill erosion is 1.1 tons per acre per year and the estimated sediment delivered to Little Storm Lake and Storm Lake is 0.22 tons per acre per year.

This seems to support the conclusions of the 1994 Diagnostic/Feasibility Study, that “the low overall sedimentation rate in the lake suggests that the filling in of local deeps is due to lake bottom dynamics including wave action and side slope instability … and that silting in of Storm Lake from erosion in the watershed is not a major problem.” It has also been noted by local IDNR Fisheries staff that resuspension of sediments by bottom feeding fish such as carp is a minor problem in Storm Lake. This supports the conclusion that wind resuspension is the major factor for the turbidity impairment.

However, local observations indicate that there can be severe sediment loads in the discharge to the lake during events. Seventy-five percent of the flow into Storm Lake discharges from Little Storm Lake, a 190-acre wetland. Except at very high flows, Little Storm Lake acts as a sediment trap further reducing the sediment delivered to Storm Lake but the trap efficiency is decreasing as Little Storm Lake fills in.

Monitoring was done at three sites on Powell Creek and Little Storm Lake from June through September 2004. The data shows that Little Storm Lake reduces sediment during events but that about two-thirds of TSS entering Little Storm Lake during rainfall events is not retained, but soon discharged to Storm Lake. A description and discussion of the monitoring and a discussion of results can be found in Section 5, Monitoring.

Wind Resuspension

Based on the preceding analysis of watershed delivered sediment, Storm Lake’s high turbidity is the result of resuspended bottom sediments by wind-driven waves and currents. The methods and some of the data used in the *Clear Lake, Iowa Diagnostic/Feasibility Study* (5) are used to evaluate the influence of the wind on silt resuspension in Storm Lake. A paper resulting from the Clear Lake Study, *Physical Impacts of Wind and Boat Traffic on Clear Lake, Iowa*, makes an estimate of the wind impacts on Clear Lake.

Storm Lake and Clear Lake are similar in many respects, both are in the same north central Iowa eco-region and both are shallow natural lakes of glacial origin. Table 7 compares the characteristics of these two waterbodies.

Table 7. Comparison of the characteristics of Storm and Clear Lakes.

	Storm Lake	**Clear Lake**
Lake origin	Natural of glacial origin	Natural of glacial origin
Lake area	3150 acres	3630 acres
Mean depth	8 feet	9.5 feet
Max. depth	14 feet	19.3 feet
Watershed to lake area	4.4 to 1	2.3 to 1
Stratifies?	No	No
Length orientation	East to west	East to west
Approximate length	3.5 miles	5 miles
Water volume	25,940 acre-feet	34,800 acre-feet

For the Clear Lake Study the relationship between wind speed and prevailing direction, fetch, wave height, wave period, wavelength, and the frequency of wind-induced sediment resuspension was evaluated. At a depth of one half the wave’s length or less, there begins a horizontal motion of the water over the lake bottom that can resuspend silt particles. If the fetch and wind speed are known then the wave period and length can be calculated and used to determine if the wave’s base extends to the lake bottom. Table 8 shows the depth of a wave for a given combination of wind speed and fetch.

Table 8. Wave mixing depths for fetch distance and wind speed variables (in feet).

Fetch distance	Wind speed				
	8 mph	12 mph	16 mph	20 mph	24 mph
8,000 feet	4.2	6.7	***9.1***	***11.6***	***14.0***
12,000 feet	5.0	***8.0***	***11.0***	***13.9***	***16.9***
16,000 feet	5.6	***9.1***	***12.5***	***15.9***	***19.3***
20,000 feet	6.2	***10.0***	***13.8***	***17.6***	***21.4***

The mean depth of Storm Lake is 8 feet, the maximum depth is 14 feet, and the longest fetch is about 18,500 feet. This table shows that there is silt resuspension over large areas of the lake when the wind speed exceeds 12 mph. At wind speeds in excess of 20 mph there is a potential for most of the lake bottom to be disturbed.

The Clear Lake Resuspension Study used National Climatic Data Center wind speed data from a nearby station for the years 1998 - 2000. The annual data period used was from April to October to represent the ice-free season. The mean daily wind speed was 10 mph (4.6 m/s) and the mean daily maximum was 25 mph (11.3 m/s). Table 9 shows the percentage of time that the wind speed had a given range of values.

Table 9. Percentage of time wind speed is in a given range for Clear Lake, Iowa.

Wind speed, mph	Wind speed, m/s	Fraction of time in range, %
0 to 11 mph	0 to 5	53 %
11 to 22 mph	5 to 10	45%
Greater than 22mph	Greater than 10	2%

Dredging to Increase Mean Depth

The 1994 diagnostic/feasibility study included recommendations for a program of dredging to increase the mean depth of the lake to 13 feet (4 meters).

Recent dredging activities at Storm Lake were begun in 2002 and are planned to continue until half of the lake's surface area has been dredged. The initial 2002 dredging project removed 1.3 million cubic yards of silt "downstream" of the inlet from Little Storm Lake in the northwestern part of Storm Lake. The depth of this area was increased to a mean of 14 feet and a maximum of 18 feet. This dredging was an IDNR contract project and increased the depth in the dredged area by an additional 6 to 10 feet.

In 2003 and 2004 the dredging continued in the southern part of the lake with local support. During 2003, 150,000 cubic yards were removed. The average depth after dredging is 14 feet and the maximum depth is 18 feet increasing depth from 6 to 10 feet. In 2004, 699,000 cubic yards were removed increasing the average depth to 16 feet and the maximum depth to 20 feet. This was an increase in depth of 8 to 12 feet.

Current plans are to remove 750,000 to one million cubic yards per year over a lake area of 1500 acres until the mean depth of Storm Lake is 13 to 14 feet.

Natural Background Conditions

Natural background contributions of turbidity and suspended solids were not separated from the total non-point source or resuspension loads.

3.2 TMDL Target

The Phase 1 turbidity targets for the Storm Lake TMDL are a Secchi depth of 0.7 meters and a TSS concentration of 20 mg/l. The TSS concentration target is an estimate taken from the regression of the untransformed TSS and Secchi depth data as shown in the following chart. If the regression equation is used to calculate the TSS concentration the value is 21 mg/l. The correlation coefficient "r" is 0.62 and the probability that "r" is greater than or equal to 0.62 is 0.034, falling within the 0.05 significance level selected previously.

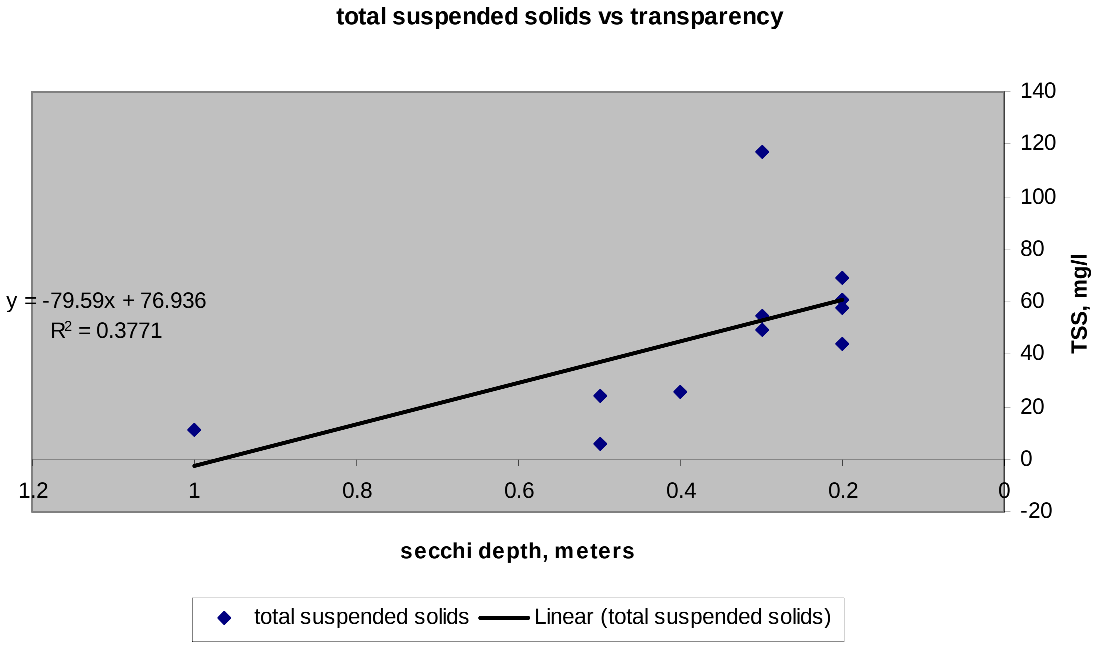
Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for turbidity. The basis for the Secchi depth target is the assessment criteria that a Secchi depth TSI of 65, which is 0.7 m, provides water quality that is not "aesthetically objectionable".

Selection of Environmental Conditions

The critical condition for which this turbidity TMDL applies is the entire year. An annual loading period was used to define Storm Lake's resuspension and watershed sediment loads. Resuspension loads are primarily the result of periods of high wind stirring the lake bottom and secondarily boat traffic and rough fish. Watershed sediment loads are the result of precipitation events. Both resuspension and watershed runoff loads are best evaluated using average annual values.

Figure 5. TSS versus Secchi depth regression.



Waterbody Pollutant Loading Capacity

The loading capacity for Storm Lake is the mass of suspended solids that meets the target value of 20 mg/l TSS. As derived in the TMDL target section, this concentration represents the target Secchi depth of 0.7 meters. At this concentration, the total mass of suspended solids in the water column (lake volume = 30.8 million m^3) is 680 tons. The following table shows the areal load (tons per acre) over a range of disturbed lake bottom area. As larger regions of the lake bottom are disturbed by waves, the allowable suspended solids load per acre decreases.

Table 10. Areal loading capacities.

disturbed area, acres	areal load, t/acre 20 mg/l TSS (680 tons)	areal load, lb/sf 20 mg/l TSS (680 tons)
500	1.36	0.062
1000	0.68	0.031
1500	0.45	0.021
2000	0.34	0.016
2500	0.27	0.012
3000	0.23	0.010

3.3 Pollution Source Assessment

Existing Load

For this TMDL, the existing TSS load is the load that causes an average water column concentration of 48 mg/l, which is the average of the four years of suspended solids data collected in the Iowa Lakes Survey. For the lake volume (30.8 million m^3) and the existing average TSS concentration, the inventory of suspended solid is 1,620 tons. The following table shows the areal load for a range of disturbed lake bottom areas.

Table 11. Range of existing areal TSS loads

Disturbed Area (acres)	Areal load, t/acre 48 mg/l TSS (1620 tons)	Areal load, lb/sf 48 mg/l TSS (1620 tons)
500	3.25	0.149
1000	1.63	0.075
1500	1.08	0.050
2000	0.81	0.037
2500	0.65	0.030
3000	0.54	0.025

In addition to the resuspension TSS load, data from the 2003 Buena Vista University monitoring and 2004 TMDL monitoring on Powell Creek and Little Storm Lake (see Appendix B) indicate that there are spikes of turbidity during precipitation events. The estimated existing rainfall event TSS concentration at the outlet to Storm Lake is 300 mg/l. At the design flow of 20 cfs, the average day event load would be 43,700 pounds per day TSS for this concentration.

Departure from Load Capacity

The difference between the existing TSS concentration of 48 mg/l and the acceptable concentration of 20 mg/l (Secchi depth of 0.7 meters) is 28 mg/l. For the lake volume (30.8 million m^3) and the existing average TSS concentration, the inventory of suspended solid is 1,620 tons. The following table shows the areal load for a range of disturbed lake bottom areas. These values represent the reductions necessary to meet the TSS target of 20 mg/l.

Table 12. Reductions in areal loadings for a range of disturbed lake bottom areas

Disturbed Area (acres)	Areal load, t/acre 28 mg/l TSS (950 tons)	Areal load, lb/sf 28 mg/l TSS (950 tons)
500	1.90	0.087
1000	0.95	0.044
1500	0.63	0.029
2000	0.48	0.022
2500	0.38	0.017
3000	0.32	0.015

For the Little Storm Lake event discharge to Storm Lake the estimated load capacity is 5,400 pounds per day TSS and the existing load is 43,700 pounds per day TSS. The departure from load capacity is 38,300 pounds per day TSS.

Identification of Pollutant Sources

Point Sources

The City of Storm Lake has a Municipal Stormwater NPDES Permit and discharges to Storm Lake through 54 outfalls. Of these outfalls, four flow continuously due to elevated groundwater. Some monitoring has been conducted on these four outfalls, although TSS has not been one of the parameters analyzed.

Nonpoint sources

The primary non-point source is wind resuspension of bottom sediment. The secondary source of sediment is in runoff from the watershed, both agricultural and urban. Streambed and bank erosion are particularly a problem close to the lake where sediment delivery is high.

As noted previously, turbidity/TSS loads are significant from Little Storm Lake during precipitation events. Based on two similar storm events, trap efficiency and event TSS and turbidity delivery to Storm Lake from Little Storm have been estimated. The two events are described in the following table.

Table 13 Impact of rainfall events on local Storm Lake TSS

Date	Data Source	24 hour precip.	Little Storm TSS	Inlet/outlet TSS in Storm Lake
July 9, 2003	Buena Vista Univ.	2.65 in.	515 mg/l (270 NTU)	300 mg/l (160 NTU)
Sept. 15, 2004	TMDL monitoring	2.52 in	unknown	450 mg/l (LSL inlet)

These two events indicate that there is a significant, episodic, turbidity impact on Storm Lake at the outlet of Little Storm Lake.

3.4 Pollutant Allocation

Wasteload Allocation

The only permitted point source discharges to Storm Lake is from the City of Storm Lake stormwater permit. The wasteload allocation for this turbidity TMDL is zero.

Load Allocation

The load allocation for this TMDL is for an annual average water column total suspended solids concentration of 20 mg/l less a 10% margin of safety. This concentration will provide an increase in transparency as measured by Secchi depth of 75% (from 0.4 to 0.7 meters) and a decrease in turbidity that will meet the water quality standards. This load is shown in the following table and is variable based on the area of disturbed lake bottom, i.e., as the disturbed area increases, the load allocation per acre decreases. As described previously, the areal load allocation is a function of lake depth and wavelength.

Table 14. Load Allocation based on lake bottom area disturbed by wind induced waves

Extent of wave disturbed lake bottom area, acres	Load Allocation, tons per disturbed lake bottom acre to achieve 20 mg/l TSS (612 tons total load)	Load per unit area, pounds/square foot of lake bottom (20 mg/l TSS at 612 tons total load)
500	1.22	0.0562
1000	0.61	0.0281
1500	0.41	0.0187
2000	0.31	0.0140
2500	0.24	0.0112
3000	0.20	0.0094

Little Storm Lake/watershed load allocation

As described in the pollutant identification section, the TSS delivered from Little Storm Lake during rainfall events can have significant local impact on Storm Lake as well as contributing to the overall turbidity impairment. The estimated TSS concentration for the Little Storm Lake outlet during precipitation events is 300 mg/l and as shown previously the existing average TSS concentration in Storm Lake is 48 mg/l. The goal for Little Storm Lake discharge during rain events is to reduce the sediment mass such that the TSS concentration is 50 mg/l.

For rainfall events, this requires a combination of Little Storm trap efficiency improvement and watershed load reduction. The existing trap efficiency during high flow events is estimated to be 33%. The trap efficiency for a shallow waterbody such as Little Storm Lake assuming a storage volume of 380 acre-feet (2 foot mean depth) and a watershed area of 15 square miles would typically be 65 to 90%.

The precipitation event load allocation is based on a 24-hour average event flow of 20 cfs and a concentration of 50 mg/l TSS. The 24-hour load allocation for Little Storm Lake is 5,400 pounds per day TSS.

Margin of Safety

The margin of safety (MOS) of 68 tons for this TMDL is an explicit 10 percent reduction in the load allocation for resuspended TSS.

Total Daily Maximum Load Equation

TMDL (Load capacity) = Wasteload allocations + Load allocations + MOS
= 0 tons + 612 tons + 68 tons

This load capacity is applied to a range of disturbed lake bottom areas to provide an estimate of the allowable load for unit areas (tons per acre) and is shown in Table 14.

4. Implementation Plan

The Iowa Department of Natural Resources recognizes that an implementation plan is not a required component of a Total Maximum Daily Load. However, the IDNR recommends the following implementation strategy to DNR staff, partners, and watershed stakeholders as a guide to improving water quality at Storm Lake.

The current plan for dredging the lake to a mean depth of 13 feet from 8 feet should provide significant improvement to water clarity problems resulting from inorganic turbidity. This is because the influence of wind driven waves on bottom sediments for typical Storm Lake fetch distances will be less frequent and have less intensity as the depth increases. This should also cause a significant reduction in water column total phosphorous concentrations since this nutrient is entrained with resuspended bottom sediments. As dredging progresses and the maximum and mean depths increase, the lake may become weakly stratified in deeper areas, perhaps providing a phosphorous sink during the growing season.

Watershed land use also will have an impact on long term Storm Lake water quality. This will be particularly true as high phosphorous concentrations begin to cause algal blooms that were suppressed because of light limitations in the water column. The following best management practices are beneficial for reducing external nutrient (phosphorous) delivery.

- Manage agricultural soils for the optimum soil test category. This soil test category is the most profitable for producers to sustain in the long term.
- Minimize the potential losses of applied phosphorus by incorporating or subsurface applying the fertilizer or manure and avoiding late fall or winter applications.
- Exclude livestock access to tributaries of Little Storm and Storm Lake.
- Encourage the adoption of management intensive grazing systems on the existing pastureland.
- Identify key locations in the watershed and construct wetlands or grade stabilization structures to settle out adsorbed and dissolved phosphorus in surface runoff.
- Through incentives and existing programs, reduce runoff volume and/or velocity through the strategic location of contour grass buffer strips and riparian buffer strips, etc.
- Continue education of the Storm Lake community, including citizens and developers on best management practices in the urban areas to reduce sediment and nutrient content of urban runoff.

Little Storm Lake

An evaluation of Little Storm Lake and its existing and future capacity to trap sediment should be conducted. If this wetland further loses it ability to capture and retain sediment from watershed runoff, Storm Lake will be increasingly susceptible to turbidity problems and siltation. Data was collected at three locations in 2004 in an effort to evaluate the impact that Little Storm Lake has on sediment from Powell Creek before it discharges into Storm Lake.

The Army Corps of Engineers (COE) were contacted about a conducting a project in Little Storm Lake. An initial meeting was held in October 2003 with the City of Storm Lake, Buena Vista County, DNR, Storm Lake Lake Improvement Commission, Storm Lake Lake Preservation Association (LPA), NRCS, and others in attendance. At this meeting, it was determined that the COE could do this type of project through Section 206 funding. The City of Storm Lake and the LPA worked with their Congressional representatives to get a line-item appropriation for the first phase of the Little Storm Lake project. This money was released to the COE on Feb. 25, 2005, and will be used for a Preliminary Restoration Plan (PRP). This plan is scheduled to be completed by the fall of 2005. Additional funding will be necessary to complete a feasibility study and if funded, this plan along with design work will be completed in 2006 and 2007, with construction in 2008.

Little Storm Lake filters approximately 70 to 80% of the water entering Storm Lake from the watershed. It typically acts as a sedimentation basin, however, during periods of high flow and high water, the sediment is washed through Little Storm into Storm Lake. During these times, a large amount of phosphorous also passes through Little Storm into Storm Lake.

The chart below shows the TSS data for the three monitoring sites, two on Powell Creek and one at the discharge from Little Storm to Storm Lake. The monitoring was done monthly from June to October 2004 and there were auto-samplers installed at the sites to capture events. One significant precipitation event during the monitoring period was recorded. The data can be found in Appendix B. Site 1 was on Powell Creek about one mile upstream from the inlet to Little Storm Lake, Site 2 was about 100 yards upstream from the inlet, and Site 3 was at the bridge where Little Storm Lake discharges into Storm Lake. The monitoring sites are shown in Figure 7.

The TSS data from monthly sampling and the single event show that suspended solids concentrations trend higher at Site 2, particularly during the precipitation event. Although the data is limited, it suggests that the high TSS load delivered by Powell Creek during events is somewhat reduced by Little Storm Lake sediment trapping. Local reports indicate that, during especially large storms, the discharge from Little Storm is visibly muddy. Improving and preserving the Little Storm trap efficiency needs to be a high priority to protect the Storm Lake dredging investment.

Figure 6. TSS data from 2004 monitoring at three sites.

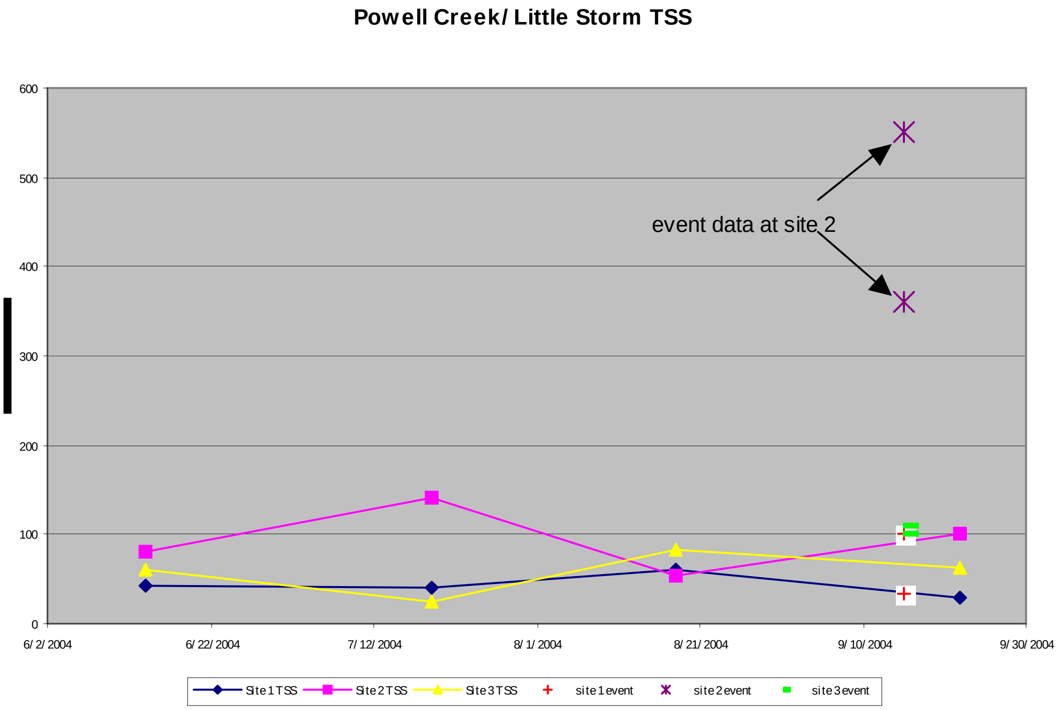
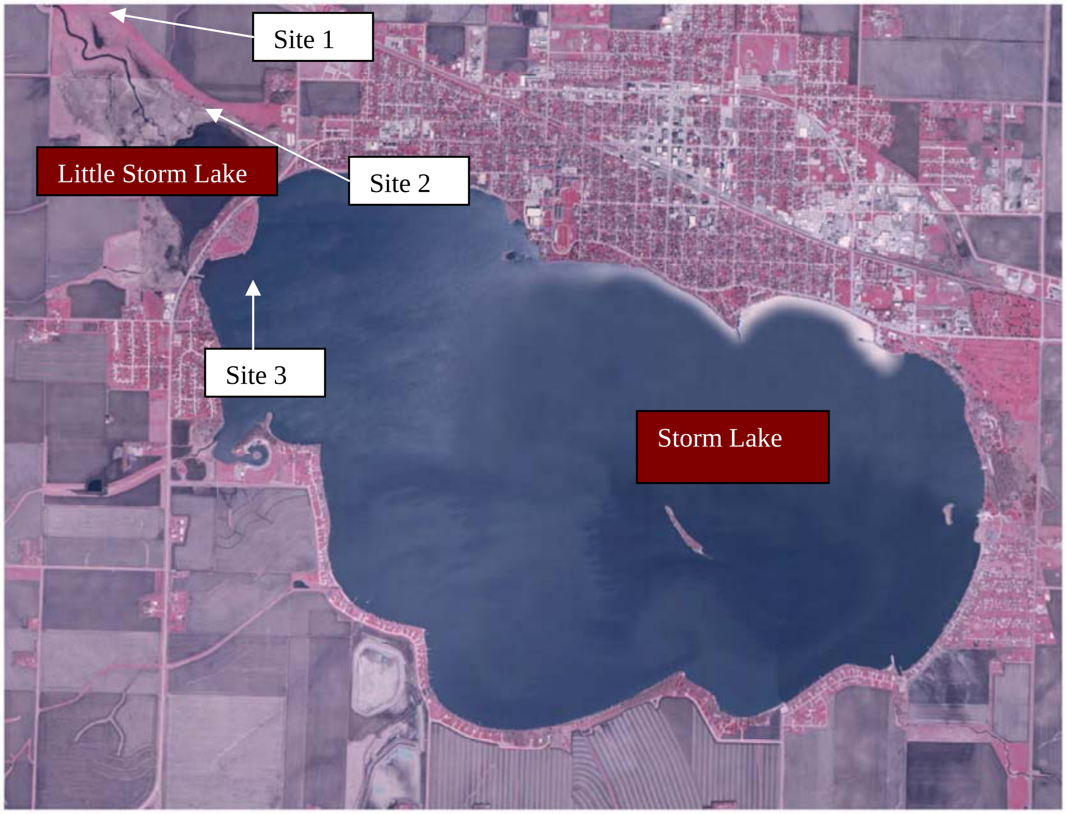


Figure 7. 2004 TMDL Monitoring Site Locations on Powell Creek and Little Storm Lake.



5. Monitoring

The turbidity as measured by Secchi depth is an important measure and is simple to perform. Frequent measurement of Secchi depth at several locations in the lake should be done as well as the collection of wind speed and direction data, either from a nearby station or with an anemometer located at the lake. This data combined with bathymetric maps can provide guidance to the Storm Lake dredging operations that will be invaluable.

Additional monitoring is needed at Storm Lake to provide data for future water quality assessments. This monitoring should, at a minimum, meet the data requirements established by Iowa's 305(b) guidelines for a complete water quality assessment (3 lake samples per year over 3 years, 10 lake samples over 2 years, etc.). This data will be collected by 2010. Storm Lake was included in the five-year lake study conducted by Iowa State University under contract with the IDNR. Although this lake monitoring program concluded in 2004, it may be extended under a new lake monitoring strategy.

The DNR has partnered with the City of Storm Lake to collect and analyze stormwater samples from the four constantly flowing stormwater outfalls to better evaluate any possible contribution to the TSS levels in Storm Lake.

The TMDL program is also planning to contract with the United States Geological Survey to conduct bathymetric mapping on Little Storm Lake in 2006. This information will be used to help determine how the efficiency of the wetland can be improved.

The IDNR is committed to monitoring waters where TMDLs have been completed, and in the absence of a statewide lake monitoring program, follow-up monitoring will be conducted through the TMDL program.

6. Public Participation

Public meetings were held in Storm Lake regarding the proposed TMDL for turbidity for Storm Lake on November 20, 2003. A second meeting was held January 26, 2005 in the Storm Lake City Hall Council Chambers to review the draft TMDL. Comments received at these meetings, through mail, and by email were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

There are approximately 127 public lakes in Iowa. The contributing watersheds for these lakes range in area from 0.028 mi^2 to 195 mi^2 with mean and median values of 10 mi^2 and 3.5 mi^2, respectively. Few, if any, of these lakes have gauging data available to determine flow statistics for the tributaries that feed into them. A select few have some type of stage information that may be useful in determining historical discharge from the lake itself.

With the large number of lakes on the State's 303(d) list and the requirement for rapid development of TMDLs for these lakes, it was realized that a method to quickly estimate flow statistics for required lake response model inputs would be desirable. In an attempt to achieve this goal, flow data and watershed characteristics for a number of USGS gauging stations with small contributing watershed areas were compiled and evaluated via both simple and multiple linear regressions. The primary focus of this evaluation was estimation of the average annual flow statistic for input to empirical lake response models. However, regression equations for monthly average and calendar year flow statistics were also developed that may be of additional use.

It should be noted that attempts were made to develop regression equations for low-flow streamflow statistics (1Q10, 7Q10, 30Q10, 30Q5 and harmonic mean) but the relationships derived were for the most part considered too weak (R^2 adj.< 70%) to be of practical use. One exception to this is the 30Q5 statistic, which gave an R^2 adj. of 85%. In addition, regression equations were developed for monthly flow prediction models for two months (January and May). Once again, the relationships did not exhibit a high level of correlation and due to the large amount of data required to develop these models, development of equations for additional months was not attempted.

Data

Flow data and watershed characteristics from 26 USGS gauging stations were used to derive the regression equations. The ranges of basin characteristics used to develop the regression equations are shown in Table A-1.

Drainage areas were taken directly from USGS gauge information available at http://water.usgs.gov/waterwatch/ . Precipitation values were obtained through the Iowa Environmental Mesonet IEM Climodat Interface at http://mesonet.agron.iastate.edu/climodat/index.phtml . Where weather and gauging stations were not located in the same town, precipitation information was obtained from the weather station located in the town with the shortest straight-line distance from the gauging station.

Average basin slope and land cover percentages were determined using Arc View and statewide coverages clipped within HUC-12 sub-watersheds. It should be noted that the smallest basin coverages used in determining land cover percentages and average basin slopes were single HUC-12 units (i.e. no attempt was made to subdivide HUC-12 basins into smaller units where the drainage area was less than the area of the HUC-12 basin). Therefore, the regression models assume that for very small watersheds the land cover percentages of the HUC-12 basin are representative of the watershed located within the basin.

The Hydrologic Region for each station was determined from Figure 1 of USGS Water-Resources Investigation Report 87-4132, Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa. None of the stations included in the analyses were located in Regions 1 or 5. This is reflected in the regression equations developed that utilize the hydrologic region as a variable.

Table A-1. Ranges of Basin Characteristics Used to Develop the Regression Equations

Basin Characteristic	Name in equations	Minimum	Mean	Maximum
Drainage Area (mi^2)	DA	2.94	80.7	204
Mean Annual Precip (inches)	$\overline{P}_A$	26.0	34.0	36.2
Average Basin Slope (%)	S	1.53	4.89	10.9
Landcover - % Water	W	0.020	0.336	2.80
Landcover - % Forest	F	2.45	10.3	29.9
Landcover - % Grass/Hay	G	9.91	31.3	58.7
Landcover - % Corn	C	6.71	31.9	52.3
Landcover - % Beans	B	6.01	23.1	37.0
Landcover - % Urban/Artificial	U	0	2.29	7.26
Landcover - % Barren/Sparse	B'	0	0.322	2.67
Hydrologic Region	H	Regions 1 - 5 used for delineation but data for USGS stations in Regions 2, 3 & 4 only.		

Methods

Simple regression models were developed for annual average and monthly average statistics with drainage area as the sole explanatory variable. Multiple linear regression models considering all explanatory variables were developed utilizing stepwise regression in Minitab. All data with the exception of the Hydrologic Region were log transformed. Explanatory variables with regression coefficients that were not statistically different from zero (p-value greater than 0.05) were not utilized.

Equation Variables

Table A-2. Regression Equation Variables

Annual Average Flow (cfs)	$\overline{Q}_{A}$
Monthly Average Flow (cfs)	$\overline{Q}_{MONTH}$
Annual Flow – calendar year (cfs)	Q_{YEAR}
Drainage Area (mi^2)	DA
Mean Annual Precip (inches)	$\overline{P}_{A}$
Mean Monthly Precip (inches)	$\overline{P}_{MONTH}$
Antecedent Mean Monthly Precip (inches)	$\overline{A}_{MONTH}$
Annual Precip – calendar year (inches)	P_{YEAR}
Antecedent Precip – calendar year (inches)	A_{YEAR}
Average Basin Slope (%)	S
Landcover - % Water	W
Landcover - % Forest	F
Landcover - % Grass/Hay	G
Landcover - % Corn	C
Landcover - % Beans	B
Landcover - % Urban/Artificial	U
Landcover - % Barren/Sparse	B'
Hydrologic Region	H

Equations

Table A-3. Drainage Area Only Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_{A} = 0.832DA^{0.955}$	96.1	0.207290
$\overline{Q}_{JAN} = 0.312DA^{0.950}$	85.0	0.968253
$\overline{Q}_{FEB} = 1.32DA^{0.838}$	90.7	0.419138
$\overline{Q}_{MAR} = 0.907DA^{1.03}$	96.6	0.220384
$\overline{Q}_{APR} = 0.983DA^{1.02}$	93.1	0.463554
$\overline{Q}_{MAY} = 1.97DA^{0.906}$	89.0	0.603766
$\overline{Q}_{JUN} = 2.01DA^{0.878}$	88.9	0.572863
$\overline{Q}_{JUL} = 0.822DA^{0.977}$	87.2	0.803808
$\overline{Q}_{AUG} = 0.537DA^{0.914}$	74.0	1.69929
$\overline{Q}_{SEP} = 0.123DA^{1.21}$	78.7	2.64993
$\overline{Q}_{OCT} = 0.284DA^{1.04}$	90.2	0.713257
$\overline{Q}_{NOV} = 0.340DA^{0.999}$	89.8	0.697353
$\overline{Q}_{DEC} = 0.271DA^{1.00}$	86.3	1.02455

Table A-4. Multiple Regression Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_{A} = 1.17 \times 10^{-3} DA^{0.998} \overline{P}_{A}^{\,1.54} S^{-0.261} (1+F)^{0.249} C^{0.230}$	98.7	0.177268 (n=26)
$\overline{Q}_{JAN} = 0.213 DA^{0.997} \overline{A}_{JAN}^{\,0.949}$	89.0	0.729610 (n=26;same for all $\overline{Q}_{MONTH}$)
$\overline{Q}_{FEB} = 2.98 DA^{0.955} \overline{A}_{FEB}^{\,0.648} G^{-0.594} (1+F)^{0.324}$	97.0	0.07089
$\overline{Q}_{MAR} = 6.19 DA^{1.10} B^{-0.386} G^{-0.296}$	97.8	0.07276
$\overline{Q}_{APR} = 1.24 DA^{1.09} \overline{A}_{APR}^{\,1.64} S^{-0.311} B^{-0.443}$	97.1	0.257064
$\overline{Q}_{MAY} = 10^{(-3.03+0.114H)} DA^{0.846} \overline{P}_{A}^{\,2.05}$ Hydrologic Regions 2, 3 & 4 Only	92.1	0.958859
$\overline{Q}_{MAY} = 1.86 \times 10^{-3} DA^{0.903} \overline{P}_{A}^{\,1.98}$	90.5	1.07231
$\overline{Q}_{JUN} = 10^{(-1.47+0.0729H)} DA^{0.891} C^{0.404} \overline{P}_{JUN}^{\,1.84} (1+F)^{0.326} G^{-0.387}$ Hydrologic Regions 2, 3 & 4 Only	97.0	0.193715
$\overline{Q}_{JUN} = 8.13 \times 10^{-3} DA^{0.828} C^{0.478} \overline{P}_{JUN}^{\,2.70}$	95.9	0.256941
$\overline{Q}_{JUL} = 1.78 \times 10^{-3} DA^{0.923} \overline{A}_{JUL}^{\,4.19}$	91.7	0.542940
$\overline{Q}_{AUG} = 4.17 \times 10^{7} DA^{0.981} (1+B')^{-1.64} (1+U)^{0.692} \overline{P}_{A}^{\,-7.2} \overline{A}_{AUG}^{\,4.59}$	90.4	1.11413
$\overline{Q}_{SEP} = 1.63 DA^{1.39} B^{-1.08}$	86.9	1.53072
$\overline{Q}_{OCT} = 5.98 DA^{1.14} B^{-0.755} S^{-0.688} (1+B')^{-0.481}$	95.7	0.375296
$\overline{Q}_{NOV} = 5.79 DA^{1.17} B^{-0.701} G^{-0.463} (1+U)^{0.267} (1+B')^{-0.397}$	95.1	0.492686
$\overline{Q}_{DEC} = 0.785 DA^{1.18} B^{-0.654} (1+U)^{0.331} (1+B')^{-0.490}$	92.4	0.590576
$Q_{YEAR} = 3.164 \times 10^{-4} DA^{0.942} P_{YEAR}^{\,2.39} A_{YEAR}^{\,1.02} S^{-0.206} \overline{P}_{A}^{\,1.27} C^{0.121} (1+U)^{0.0966}$	83.9	32.6357 (n=716)

General Application

In general, the regression equations developed using multiple watershed characteristics will be better predictors than those using drainage area as the sole explanatory variable. The single exception to this appears to be for the May Average Flow worksheet where the PRESS statistic values indicate that use of drainage area alone results in the least error in the prediction of future observations.

Although 2002 land cover grids for the state are now available with 19 different classifications, the older 2000 land cover grids with 9 different classifications were used in developing the regression equations. The 2000 land cover grids should be used in development of flow estimates using the equations.

The equations were developed from stream gauge data for watersheds with relatively minor open water surface percentages relative to other types of land cover (see Table A-1). For application to lake watersheds, particularly those with small watershed/lake area ratios, the basin slope and land cover percentages taken from HUC-12 basins may need to be adjusted so that the hydraulic budget components of surface inflow and direct precipitation on the lake itself can be treated separately. One method of accomplishing this is by subtraction of lake water surface acreage from the total land cover and slope (lakes will have 0% slope) acreages and recalculation of the % coverages. The watershed (drainage) area used in the equations should not include the area of the lake surface.

Application to Storm Lake - Calculations

The values in the following were generated from the hydrologic modeling and vary slightly from the rounded values found elsewhere in this document. The reason for this is to maintain computational consistency within the modeling configuration.

Table A5. Characteristics and variables used for hydrologic modeling

Lake	Storm Lake	
Type	Natural w/inlet	
Inlet(s)	Powell Creek	
Outlet(s)	Outlet Creek	
Volume	24944	(acre-ft)
Lake Area	3051	(acres)
Mean Depth	8.2	(ft)
Drainage Area	14803	(acres)
Mean Annual Precip	30.9	(inches)
Average Basin Slope	1.9	(%)
%Water	0.3	
%Forest	3.2	
%Grass/Hay	22.4	
%Corn	41.5	
%Beans	30.1	
%Urban/Artificial	0.9	
%Barren/Sparse	1.2	
Hydrologic Region	3	
Mean Annual Class A Pan Evap	50.0	(inches)
Mean Annual Lake Evap	37.0	(inches)
Est. Annual Average Inflow	11180	(acre-ft)
Direct Lake Precip	7864	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	1.31	(yr)
Est. Annual Average Det. Time (outflow)	2.59	(yr)

9. Appendix B - Sampling Data

Table B-1. Data collected in 1979 by Iowa State University (Bachmann, et al, 1980).

Date Collected	**7/10/1979**		**8/13/1979**			**9/17/1979**	
Depth (meters)	0	1	0	1	2	0	1
Secchi Depth (meters)	0.8		0.4			0.3	
Suspended Solids (mg/L)	10.2	14.6	33.8	31.3	24.1	39.8	39.3
Dissolved Oxygen (mg/L)	8.70	7.70	13.6	6.4	6.2	6.7	8.5
NO_3+NO_2-N (mg/L)						0.30	
Total Phosphate (mg/L) (colorimetric method)	0.0266	0.02	0.077	0.0703	0.0738	0.118	0.109
Chlorophyll a (ug/L) (Spectrophotometric Acid)	12.3	14.2		18.7	24.7	56.1	36.7

Table B-2. Data collected in 1981-82 by the University of Iowa Hygienic Laboratory (Kennedy and Splinter, 1982). For each date, samples were collected from the surface and near the bottom at three locations.

	10/5/1981		**4/1/1982**		**6/30/1982**	
Parameter	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
Temperature (°C)	11	11	7	7	21-22	22
pH	8.3-8.4	8.35	8.0-8.2	8.2	8.4-8.5	8.4
Organic Nitrogen (mg/L)	0.27-0.48	0.37	1.1-1.4	1.2	0.61-0.75	0.67
Ammonia Nitrogen (mg/L)	<0.01-0.03	0.02	0.03-0.06	0.04	0.18-0.30	0.23
Nitrate Nitrogen (mg/L)	<0.01	<0.01	0.3-0.4	0.3	0.2	0.2
Filterable Phosphorus (mg/L)	0.0-0.1	0.01	0.13	0.13	0.03	0.03
Total Phosphorus (mg/L)	0.05-0.09	0.07	0.13-0.16	0.15	0.15-0.21	0.18
Dissolved Oxygen (mg/L)	9.4-9.6	9.4	11.1-11.3	11.2	7.9-9.4	8.4
BOD (mg/L)	2	2	3	3	1-2	2

Table B-3. Data collected in 1990 by Iowa State University (Bachmann, et al., 1994). Each sample was a composite water sample from all depths of the lake.

Date Collected	**6/12/1990**			**7/13/1990**			**8/12/1990**		
Sample Number	1	2	3	1	2	3	1	2	3
Secchi (inches)	0.4			0.7			0.3		
Suspended Solids (mg/L)	53.2	47.7	50	35	42.5	36.7	39.7	41.2	35.3
Total Nitrogen (mg/L)	2.4	1.9	2.4	1.5	1.5	1.4	1.2	1.8	1.2
Total Phosphorus (ug/L)	94	112	96	71	72	69	136	120	116
Chlorophyll a (ug/L) (Corrected)	38.7	38.7	41.9	32.1	29	31.4	62.8	70.6	59.7

Table B-4. Data collected in 1992-93 for the Storm Lake Restoration Study (Hoyman et al., 1994). Samples were collected from three depths (0.5m, 1.5m, 2.5m) in the deepest part of the lake. Values shown are averages over all sample dates. Sample sizes and standard error for each value are shown in parenthesis.

Parameter	**Deepest part of Storm Lake**	**From Little Storm to Storm Lake**	**All inlets to Storm Lake**	**All inlets to Little Storm**
Secchi Depth (m)	0.6 (13, 0.1)			
Chlorophyll (ug/L)	20.7 (35, 2.75)			
NO_3-N (mg/L)	0.77 (37, 0.08)	7.19 (12, 0.74)	5.95 (38, 0.71)	9.93 (9, 1.25)
Tot. Nitrogen (mg/L as N)	1.49 (35, 0.08)	7.48 (8, 0.66)	8.79 (30, 0.74)	11.26 (6, 1.37)
Tot. Phosphorus (ug/l as P)	92 (31, 10)	224 (10, 33)	155 (31, 43)	61 (8, 14)
pH	8.5 (34, 0.0)			
Alkalinity (mg/L)	149 (34, 2)			
Tot. Susp. Solids (mg/L)	24.1 (37, 2.48)	55.2 (12, 7.2)	27.5 (42, 6.85)	15.8 (10, 4.53)

Table B-5. Data collected in 2000 by Iowa State University (Downing and Ramstack, 2001)

Parameter	**6/15/2000**	**7/14/2000**	**8/7/2000**
Secchi Depth (m)	0.3	0.2	0.3
Chlorophyll (ug/L)	14	14	
NH_3+NH_4^+ -N (ug/L)	1273	1236	1568
NH_3 –N (un-ionized) (ug/L)	70	211	159
NO_3+NO_2-N (mg/L)	0.54	0.12	0.11
Total Nitrogen (mg/L as N)	0.97	0.85	0.93
Total Phosphorus (ug/l as P)	269	256	277
Silica (mg/L as SiO_2)	63	58	93
pH	8.2	8.5	8.3
Alkalinity (mg/L)	182	186	192
Total Suspended Solids (mg/L)	48.2	43.7	54.3
Inorganic Suspended Solids (mg/L)	40.5	34.7	40.7
Volatile Suspended Solids (mg/L)	7.7	8.9	13.6

Table B-6. Data collected in 2001 by Iowa State University (Downing and Ramstack, 2002)

Parameter	**5/17/2001**	**6/14/2001**	**7/19/2001**
Secchi Depth (m)	0.2	0.2	0.5
Chlorophyll (ug/L)		24	19
NH_3+NH_4^+ -N (ug/L)	1367	1	580
NH_3 –N (un-ionized) (ug/L)	104	0	117
NO_3+NO_2-N (mg/L)	1.25	1.09	0.05
Total Nitrogen (mg/L as N)	1.82	1.48	1.25
Total Phosphorus (ug/l as P)	226	171	58
Silica (mg/L as SiO_2)	35	18	14
pH	8.3	8.3	8.6
Alkalinity (mg/L)	175	176	121
Total Suspended Solids (mg/L)	60.5	68.5	5.9
Inorganic Suspended Solids (mg/L)	45.8	55.0	4.6
Volatile Suspended Solids (mg/L)	14.7	13.5	1.3

Table B-7. Data collected in 2002 by Iowa State University (Downing et al., 2003)

Parameter	**5/23/2002**	**6/20/2002**	**7/25/2002**
Secchi Depth (m)	1.0	0.4	0.2
Chlorophyll (ug/L)	22	23	12
NH_3+NH_4^+ -N (ug/L)	190	262	526
NH_3 –N (un-ionized) (ug/L)	29	27	60
NO_3+NO_2-N (mg/L)	0.35	0.70	0.17
Total Nitrogen (mg/L as N)	1.13	1.62	1.21
Total Phosphorus (ug/l as P)	65	77	125
Silica (mg/L as SiO_2)	1	5	8
pH	8.6	8.4	8.4
Alkalinity (mg/L)	157	151	175
Total Suspended Solids (mg/L)	11.0	26.2	58.6
Inorganic Suspended Solids (mg/L)	3.3	12.8	49.3
Volatile Suspended Solids (mg/L)	7.7	13.3	9.3
Dissolved Organic Carbon (mg/L)			9.8

Table B-8. Data collected in 2003 by Iowa State University (Downing et al., 2004)

Parameter	**5/22/2003**	**6/19/2003**	**7/24/2003**
Secchi Depth (m)	0.5	0.2	0.3
Chlorophyll (ug/L)	8.7	27.7	32.8
NH_3+NH_4^+ -N (ug/L)	381	449	585
NH_3 –N (un-ionized) (ug/L)	18	62	74
NO_3+NO_2-N (mg/L)	0.70	0.16	0.55
Total Nitrogen (mg/L as N)	0.95	1.57	1.59
Total Phosphorus (ug/l as P)	73	91	146
Silica (mg/L as SiO_2)	3.84	7.69	6.25
pH	8.2	8.5	8.5
Alkalinity (mg/L)	134	103	102
Total Suspended Solids (mg/L)	24	61	117
Inorganic Suspended Solids (mg/L)	20	40	89
Volatile Suspended Solids (mg/L)	4	21	28
Dissolved Organic Carbon (mg/L)	8.41	10.45	7.03

Buena Vista University (BVU) monitoring

Faculty and students from Buena Vista University did some water quality monitoring at several sites on Powell Creek, Little Storm Lake, and Storm Lake. On one of the days (July 9, 2003) the sampling was done there was a 2.65-inch rainfall event. This shows up in the following charts as a striking increase in turbidity and total phosphorous in Powell Creek, Little Storm Lake, and Storm Lake on that day.

Table B-9. Data from the 2001-03 Buena Vista University study (BVU, Pers. Comm.). PC is Powell Creek; LL is Little Storm Lake; IN is the inlet from Little Storm Lake into Storm Lake.

Date	**pH**			**Turbidity (NTU)**			**Total P (ug/l)**		
	PC	**LL**	**IN**	**PC**	**LL**	**IN**	**PC**	**LL**	**IN**
5/22/01	7.9	8.3	8.3	1.6	11	6.9			
5/30/01	7.7	7.6	7.6	8.5	90	140			
6/12/01	7.5	7.9	7.3	18	60	75			
6/19/01	7.7	7.8	7.5	15	60	85			
7/12/01						32			
7/18/01			7.4			85			
4/5/03					55	28			
4/13/03				3.6	25	43			
5/4/03	7.4	7.6	8.2	7	23	70			
5/17/03	7.5	8.2	7.7	2.3	24	26			
5/27/03	7.7	8.0	7.6	4.5	12	27			
6/3/03	7.4	7.8	7.8	4.4	27	27	60	114	144
6/9/03	7.5	8.0	7.7	5.7	19	23	29	101	138
6/16/03	7.5	8.0	7.4	2.3	15	22	25	124	237
6/23/03	7.5	7.6	7.5	4.4	19	22	130	69	194
6/30/03	8.9	8.0	7.5	4.4	17	16	97	187	120
7/9/03	**7.2**	**7.6**	**7.2**	**17**	**270**	**160**	**198**	**452**	**506**
7/14/03	7.6	8.7	7.9	5.4	43	17	60	90	170
7/21/03	7.8	8.7	7.7	3.2	14	17	41	60	58
7/27/03	7.5	7.9	7.7	4.2	8.3	15	45	59	84

Below are two charts showing the turbidity and total phosphorous at the three sites.

Figure B1. BVU turbidity data

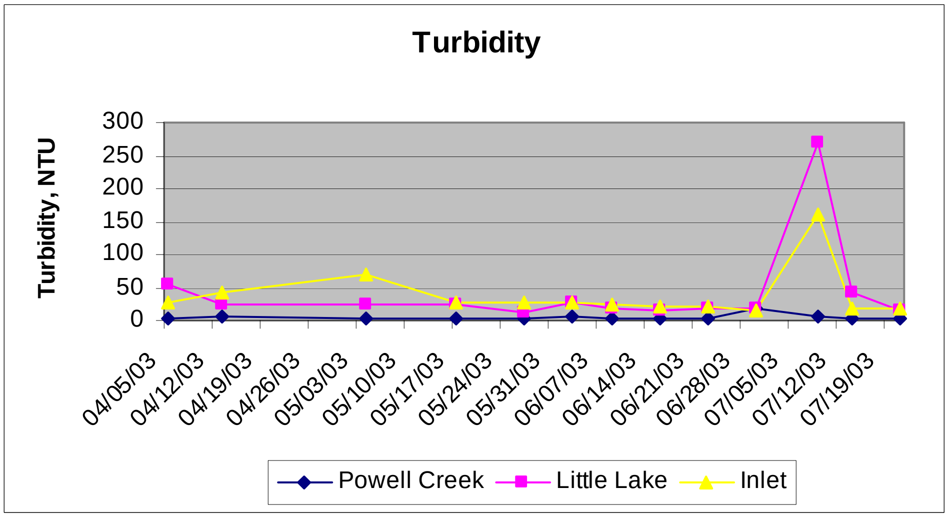
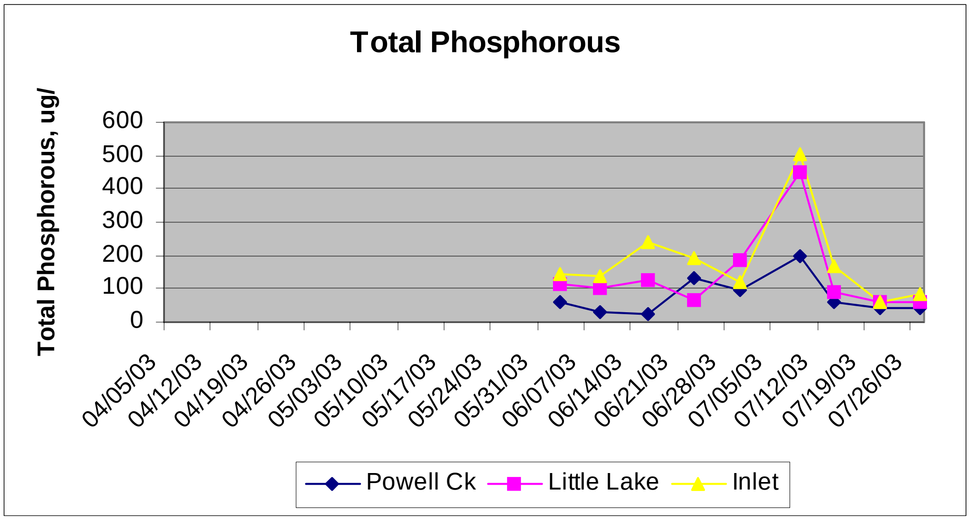


Figure B2. BVU phosphorous data



Relating turbidity as NTU to Secchi depth

The BVU data set includes Secchi depth measurements for some sites and sampling dates as well as turbidity measured as NTU. The regression charts below show the relationship between these variables. The first regression includes all of the Secchi/NTU pairs available from the 2003 data. The relationship between the two falls apart as the turbidity increases and Secchi depth transparency decreases. Turbidimeters are less reliable when values exceed 40 NTU and are subject to interference from debris and coarse rapidly settling sediment.

Figure B3. Relationship of Secchi transparency to turbidity, all data

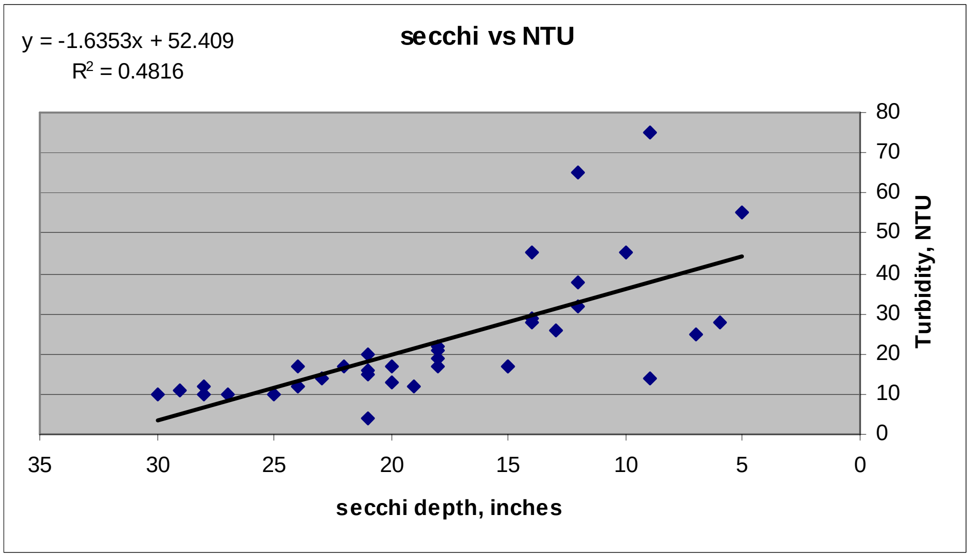


Figure B4. Relationship of Secchi transparency to turbidity

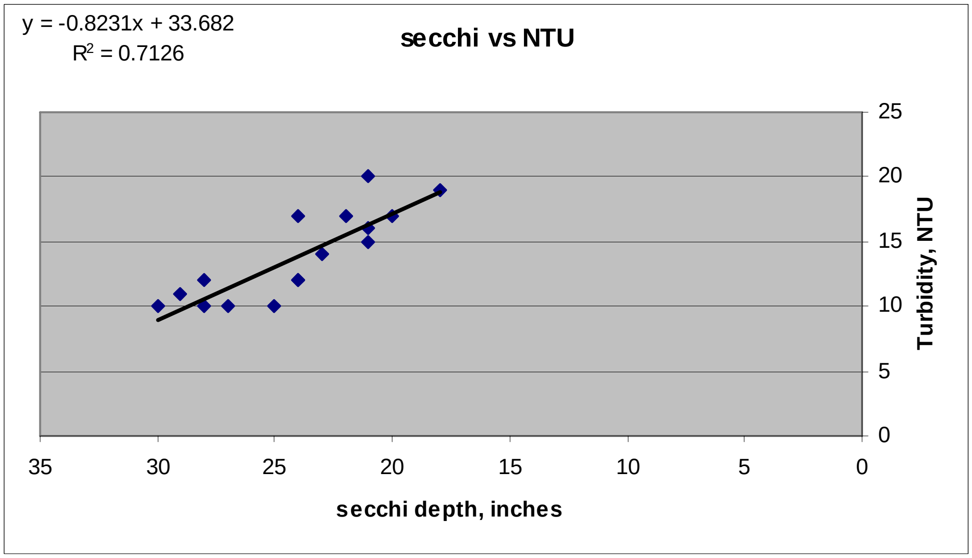


Table B10. Relationships of Secchi depth, turbidity, and TSS

	SD	NTU	TSS
	6	28.8	64.8
	12	23.8	52.6
	18	18.9	40.5
	20	17.2	36.5
	21	16.4	34.4
	24	13.9	28.4
lake target	**28.2**	**10.5**	**19.9**
	30	9.0	16.3
	36	4.1	4.1

For these reasons the range of values was narrowed to estimate Secchi transparency from the NTU values. When all values are included, r-squared is 0.48, and, when the higher NTU values are not included, r-squared is 0.71. Using the ratio of TSS, NTU, and SD variables within the range where the relationships between them are understood and applying it to higher turbidity and TSS values gives the following at the target values of TSS = 20 mg/l, Secchi depth = 28 inches, and turbidity = 11 NTU (see Table B 10):

Example:
160 NTU/unknown TSS = 11 NTU/20 mg/l TSS
Unknown TSS is about 300 mg/l

Secchi Data Collected in 2004

Figure B5. Daily Secchi disk readings collected from June through October 2004.

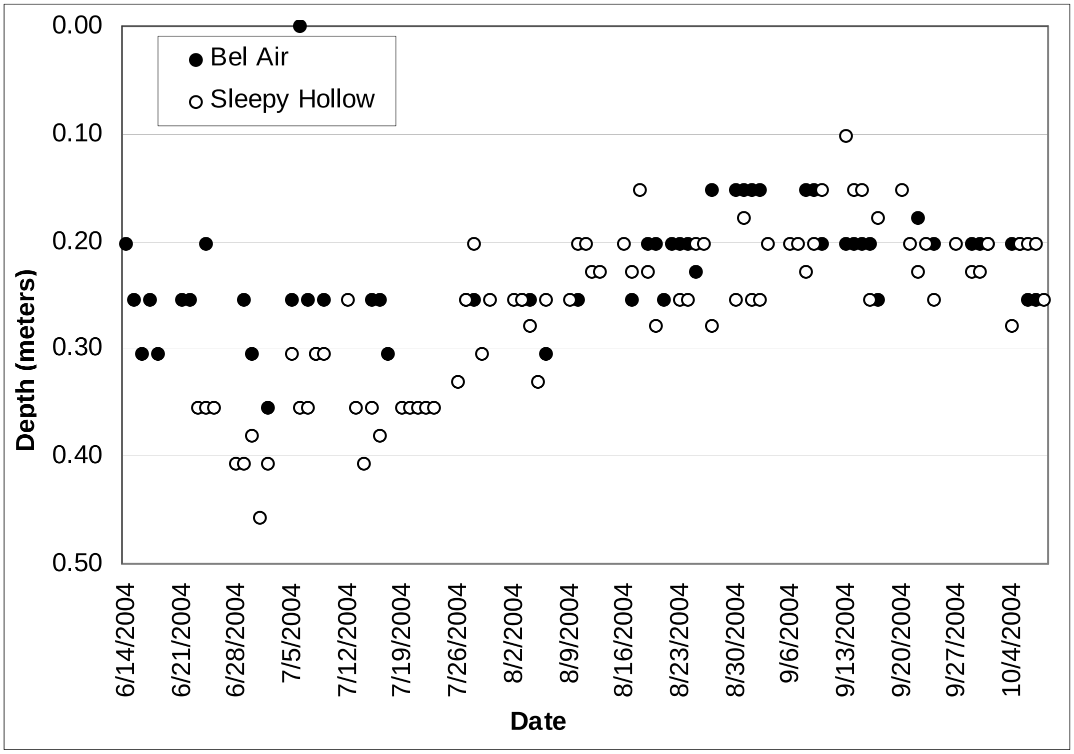


Table B-10. Daily Secchi depths (inches) recorded in Storm Lake at two locations.

Date	Bel Air	Sleepy Hollow	Date	Bel Air	Sleepy Hollow	Date	Bel Air	Sleepy Hollow
6/14/04	8		7/23/04		14	9/1/04	6	10
6/15/04	10		7/26/04		13	9/2/04	6	10
6/16/04	12		7/27/04	10	10	9/3/04		8
6/17/04	10		7/28/04	10	8	9/6/04		8
6/18/04	12		7/29/04		12	9/7/04		8
6/21/04	10		7/30/04		10	9/8/04	6	9
6/22/04	10		8/2/04		10	9/9/04	6	8
6/23/04		14	8/3/04	10	10	9/10/04	8	6
6/24/04	8	14	8/4/04	10	11	9/13/04	8	4
6/25/04		14	8/5/04		13	9/14/04	8	6
6/28/04		16	8/6/04	12	10	9/15/04	8	6
6/29/04	10	16	8/9/04		10	9/16/04	8	10
6/30/04	12	15	8/10/04	10	8	9/17/04	10	7
7/1/04		18	8/11/04		8	9/20/04		6
7/2/04	14	16	8/12/04		9	9/21/04		8
7/5/04	10	12	8/13/04		9	9/22/04	7	9
7/6/04		14	8/16/04		8	9/23/04		8
7/7/04	10	14	8/17/04	10	9	9/24/04	8	10
7/8/04	12	12	8/18/04		6	9/27/04		8
7/9/04	10	12	8/19/04	8	9	9/28/04		
7/12/04		10	8/20/04	8	11	9/29/04	8	9
7/13/04		14	8/21/04	10		9/30/04	8	9
7/14/04		16	8/22/04	8		10/1/04	8	8
7/15/04	10	14	8/23/04	8	10	10/4/04	8	11
7/16/04	10	15	8/24/04	8	10	10/5/04	8	8
7/17/04	12		8/25/04	9	8	10/6/04	10	8
7/19/04		14	8/26/04		8	10/7/04	10	8
7/20/04		14	8/27/04	6	11	10/8/04		10
7/21/04		14	8/30/04	6	10			
7/22/04		14	8/31/04	6	7			

Daily Secchi readings from June to October 2004 showed depths ranging from 0.5 to 0.1 m (Figure B1).

TMDL monitoring, 2004

Table B11. 2004 TMDL monthly monitoring data for Powell Creek and Little Storm Lake

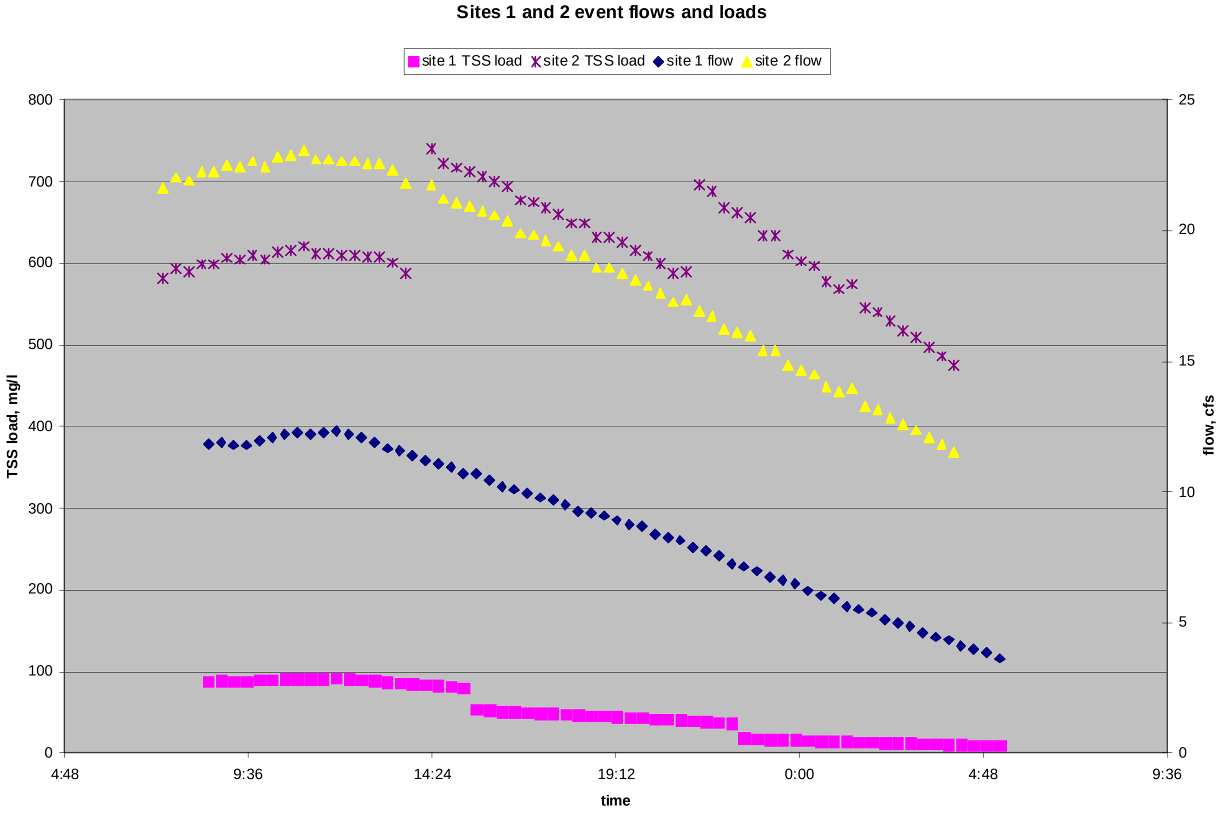
Storm Lake 2004 TMDL Monitoring
three sites

	date	TSS	TVSS	BOD	TP	flow
site 1	06/14/2004	42	7	45(2?)	80	8.7
	07/19/2004	41	6	3	100	3.4
	08/18/2004	61	17	4	140	0.8
	09/22/2004	28	6	19	300	6.5
site 2	06/14/2004	80	18	40	140	8.7
	07/19/2004	140	23	3	150	3.5
	08/18/2004	53	13	16	150	1.1
	09/22/2004	100	17	23	320	5.3
site 3	06/14/2004	60	15	30	190	1
	07/19/2004	24	8	13	90	0
	08/18/2004	83	22	8	230	0
	09/22/2004	62	16	17	160	0.1

Table B12. 2004 TMDL event monitoring data for Powell Creek and Little Storm Lake

	TSS	TVSS	BOD	TP
site 1 event		09/15/2004		
	TSS	TVSS	BOD	TP
pre	100	21	29	610
post	34	8	24	450
site 2				
pre	360	52	28	840
post	550	54	16	840
site 3				
pre	110	29	40	320
post	100	23	30	250

Figure B6. TSS and flow data for the rainfall event on 9/15/2004.



10. Appendix C - Trophic State Index

Carlson's Trophic State Index

Carlson's Trophic State Index is a numeric indicator of the continuum of the biomass of suspended algae in lakes and thus reflects a lake's nutrient condition and water transparency. The level of plant biomass is estimated by calculating the TSI value for chlorophyll-a. TSI values for total phosphorus and Secchi depth serve as surrogate measures of the TSI value for chlorophyll.

The TSI equations for total phosphorus, chlorophyll and Secchi depth are:

$$TSI\ (TP) = 14.42 \ln(TP) + 4.15$$

$$TSI\ (CHL) = 9.81 \ln(CHL) + 30.6$$

$$TSI\ (SD) = 60 - 14.41 \ln(SD)$$

TP = in-lake total phosphorus concentration, ug/L

CHL = in-lake chlorophyll-a concentration, ug/L

SD = lake Secchi depth, meters

The three index variables are related by linear regression models and *should* produce the same index value for a given combination of variable values. Therefore, any of the three variables can theoretically be used to classify a waterbody.

Table C-1. Changes in temperate lake attributes according to trophic state (modified from U.S. EPA 2000, Carlson and Simpson 1995, and Oglesby et al. 1987).

TSI Value	Attributes	Primary Contact Recreation	Aquatic Life (Fisheries)
50-60	eutrophy: anoxic hypolimnia; macrophyte problems possible	[none]	warm water fisheries only; percid fishery; bass may be dominant
60-70	blue green algae dominate; algal scums and macrophyte problems occur	weeds, algal scums, and low transparency discourage swimming and boating	Centrarchid fishery
70-80	hyper-eutrophy (light limited). Dense algae and macrophytes	weeds, algal scums, and low transparency discourage swimming and boating	Cyprinid fishery (e.g., common carp and other rough fish)
>80	algal scums; few macrophytes	algal scums, and low transparency discourage swimming and boating	rough fish dominate; summer fish kills possible

Table C-2. Summary of ranges of TSI values and measurements for chlorophyll-a and Secchi depth used to define Section 305(b) use support categories for the 2004 reporting cycle.

Level of Support	**TSI value**	**Chlorophyll-a (ug/l)**	**Secchi Depth (m)**
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for Section 303(d) listing)	65-70	*33 ➔ 55*	*0.7➔ 0. 5*
not supported (monitored or evaluated: candidates for Section 303(d) listing)	>70	*>55*	*<0.5*

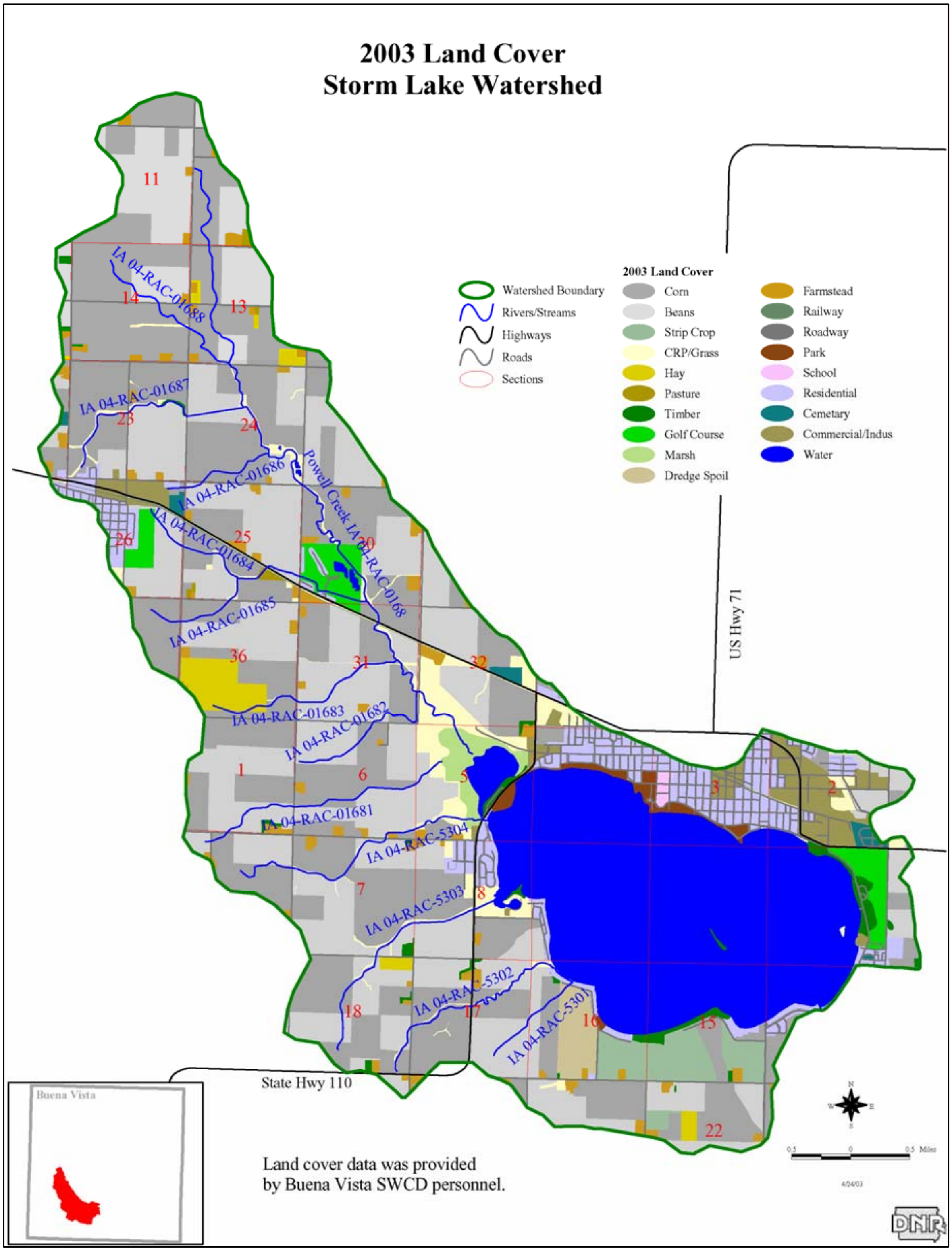
Table C-3. Descriptions of TSI ranges for Secchi depth, phosphorus, and chlorophyll-a for Iowa lakes.

TSI value	**Secchi description**	**Secchi depth (m)**	**Phosphorus & Chlorophyll-a description**	**Phosphorus levels (ug/l)**	**Chlorophyll-a levels (ug/l)**
> 75	extremely poor	< 0.35	extremely high	> 136	> 92
70-75	very poor	0.5 – 0.35	very high	96 - 136	55 – 92
65-70	poor	0.71 – 0.5	high	68 – 96	33 – 55
60-65	moderately poor	1.0 – 0.71	moderately high	48 – 68	20 – 33
55-60	relatively good	1.41 – 1.0	relatively low	34 – 48	12 – 20
50-55	very good	2.0 – 1.41	low	24 – 34	7 – 12
< 50	exceptional	> 2.0	extremely low	< 24	< 7

The relationship between TSI variables can be used to identify potential causal relationships. For example, TSI values for chlorophyll that are consistently well below those for total phosphorus suggest that something other than phosphorus limits algal growth. The TSI values can be plotted to show potential relationships as shown in Figure C-1.

11. Appendix D - Maps

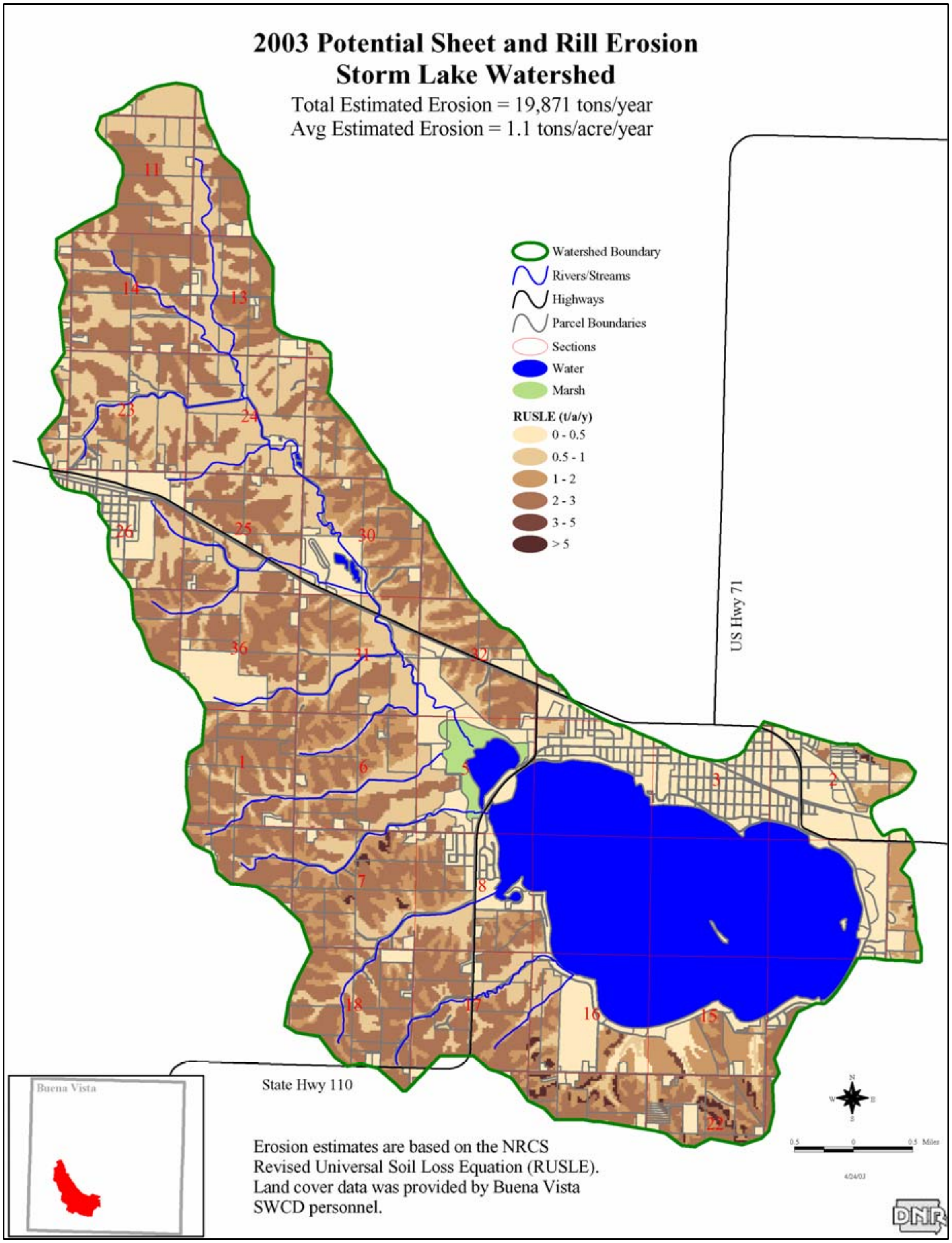
Figure D-1. 2003 land uses in the Storm Lake watershed.



2003 Land Cover
Storm Lake Watershed

Land cover data was provided
by Buena Vista SWCD personnel.

Figure D-2. Soil loss (RUSLE) coverage for the Storm Lake watershed.



2003 Potential Sheet and Rill Erosion
Storm Lake Watershed

Total Estimated Erosion = 19,871 tons/year
Avg Estimated Erosion = 1.1 tons/acre/year

Erosion estimates are based on the NRCS Revised Universal Soil Loss Equation (RUSLE). Land cover data was provided by Buena Vista SWCD personnel.

4/24/03