Total Maximum Daily Load
For Turbidity
Spring Lake
Greene County, Iowa

2006

Iowa Department of Natural Resources
Watershed Improvement Section

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1. Executive Summary

Table 1. Spring Lake Summary

Waterbody Name:	Spring Lake
County:	Greene
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	North Raccoon River Basin
Pollutant:	Non-algal turbidity
Pollutant Sources:	Nonpoint
Impaired Use(s):	A1 (primary contact recreation) B(LW) (aquatic life)
2004 303(d) Priority:	Medium
Watershed Area:	467 acres
Lake Area:	49 acres
Lake Volume:	179 acre-ft
Detention Time:	0.56 years
Transparency Target:	Secchi Depth of more than 0.7 meters for non-algal turbidity
Load Capacity	124 tons of sediment per year
Existing Total Suspended Solids Load:	186 tons of sediment per year
Load Reduction to Achieve TMDL:	62 tons of sediment per year
Margin of Safety	12 tons of sediment per year
Wasteload Allocation:	0
Load Allocation:	112 tons of sediment per year

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. Spring Lake has been identified as impaired by turbidity. The purpose of the TMDL for Spring Lake is to calculate the maximum allowable non-algal turbidity loading that will meet water quality standards and fully supports its designated uses. The water quality impairment will be addressed by using transparency as measured by Secchi depth measurements as the target.

Phasing TMDLs is an iterative approach to managing water quality that becomes necessary when the origin, nature and sources of water quality impairments are not well understood. The TMDL will have two phases. In Phase 1, the waterbody load capacity, existing pollutant load in excess of this capacity, and the source load allocations are estimated based on the limited information available. Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Phase 1 will consist of setting specific and quantifiable targets for transparency as measured by Secchi depth. The existing condition is not phosphorus limited and attenuates light. Reducing the quantity of turbidity may increase algal production, resulting in an algal turbidity impairment in the future.

A monitoring plan will be used to determine if prescribed load reductions result in attainment of water quality standards and whether or not the target values are sufficient to meet designated uses. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling.

Monitoring is essential to TMDLs in order to:

- Assess the future beneficial use status;
- Determine if the water quality is improving, degrading or remaining status quo;
- Evaluate the effectiveness of implemented best management practices.

The additional data collected will be used to determine if the implemented TMDL and watershed management plan are effective in addressing the identified water quality impairment(s). The data and information can also be used to determine if the TMDL has accurately identified the required components (i.e. loading/assimilative capacity, load allocations, in-lake response to pollutant loads, etc.) and if revisions are appropriate.

This TMDL 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:** Spring Lake, Section 25, T84N, R30W, 3 miles northwest of Grand Junction, Greene County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutant causing the water quality impairment is non-algal turbidity. Designated uses for Spring Lake are Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). Excess turbidity has impaired aesthetic and aquatic life water quality standards (11) narrative criteria (567 IAC 61.3(2)) and hindered the designated uses.

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 0.7 m Secchi depth. This is equivalent to 124 tons of total suspended solids.

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 existing mean value for Secchi depth based on 2000-2004 sampling is 0.6 meters. The existing sediment load is 186 tons per year. In order to increase Secchi depth (transparency) to the target 0.7 meters, the sediment load must be decreased by 62 tons per year.

5. **Identification of pollution source categories:** Suspended Sediment from internal recycling has been identified as causing the turbidity impairment.

6. **Wasteload allocations for pollutants from point sources:** No point sources have been identified in the Spring Lake watershed. Therefore, the wasteload allocation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources:** Transparency as measured by Secchi depth is a function of inorganic and organic components. Sediment will have to be decreased by 62 tons to meet the transparency target of 0.7 meters Secchi depth.

8. **A margin of safety:** The Margin of Safety (MOS) for this TMDL is an explicit numerical MOS of 12 tons of sediment per year (10% of the calculated allowable sediment load) and has been included to ensure that the required load reduction will result in attainment of water quality targets.

9. **Consideration of seasonal variation:** This TMDL was developed based on transparency that will result in attainment of targets on an average annual basis.

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increased sediment loading was not included in this TMDL. Significant changes in the Spring Lake watershed land use are unlikely. The slight reduction in grass/hay land for residential sites along county road 195th Street is minimal. Future increases in the carp and rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids. Because such events cannot be predicted or quantified at this time, a future allowance for their potential occurrence was not included in the TMDL.

11. **Implementation plan:** Although not required by the current regulations, an implementation plan is outlined in the body of the report.

2. Spring Lake, Description and History

2.1 The Lake and Park

Spring Lake is a county-owned lake located in west-central Iowa, 3 miles northwest of Grand Junction in Greene County. The lake enjoys frequent use by campers with an annual estimate of 13,825 campers with additional visitors for fishing, picnicking, boating, hiking, bicycling, bird watching, and ice-skating. Two shelter houses with grills, an indoor roller-skating rink, an older camphouse, and picnic areas complement the area for outdoor activities. Camping is possible at both electrical and non-electrical sites, and these sites are often filled to capacity during summer months. A concession provides boat, canoe, and kayak rentals. Only electric motors are authorized on the lake. Table 2 summarizes selected features of Spring Lake.

Early historical records indicate that the area was prairie grass and marshland. The lake originated as a sand and gravel pit in private ownership by the Northwestern rail company and was used as their source of materials for building the rail line in the region and for maintenance. During winter months, the lake served as a source of ice for storage and later use by residents in the area. The rail line sold the lake to private interests in the early 1900's, and it became a local minor attraction with the addition of an indoor roller-skating rink, band shell, cabins along the lake's edge, and several other leisure-time businesses. The State of Iowa obtained ownership of the lake about ten years later and began leasing it to the County in 1969. In 2002, the state passed ownership to Greene County and Spring Lake is now owned and maintained by the county.

Table 2. Spring Lake Features

Waterbody Name:	Spring Lake
Hydrologic Unit Code:	HU8 07100006
IDNR Waterbody ID:	IA 04-RAC-00805-L_0
Location:	Section 25, T84N R30W
Latitude:	42° 4' N
Longitude:	94° 17' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	None
Receiving Waterbody:	Unnamed trib to Buttrick Creek, a tributary of North Raccoon River
Lake Surface Area:	49 acres
Maximum Depth:	9.0 feet (2.7 m)
Mean Depth:	3.6 feet (1.1 m)
Volume:	179 acre-feet
Length of Shoreline:	15,910 feet
Watershed Area:	467 acres
Watershed/Lake Area Ratio:	10:1
Estimated Detention Time:	0.56 years

Morphometry

The lake has a mean depth of 3.6 feet and a maximum depth of 9 feet (1). However, a local County Conservation Board Member's estimate of maximum depth is no more than 5 to 7 feet. It has a surface area of 49 acres and a storage volume of approximately 179 acre-feet. Spring Lake originated as a sand and gravel pit that was not mined out, although certain portions were originally about 30 feet deep. Over time, the sand and gravel walls in the lake have caved-in, filling in the lake to its present shallow depth. There still remain several levels or drop-offs, typical of a sand and gravel pit, and these levels continue to slough off when disturbed by wind or fish action. The west basin is the most shallow, 1-2 feet, of the three elongated basins that comprise the lake. Due to the shallow mean depth, the lake does not stratify and the majority of the lake is likely well mixed and oxic. Dikes extend along each side of the lake as a result of the pilings from operations when it was an active sand pit. These dikes prevent surface runoff from surrounding land or fields to enter the lake.

Hydrology

Historically the lake was known to be spring-fed from the bottom and this feature contributed to the name for the lake. Swimmers would speak of distinctly cooler water concentrated in certain areas of the lake. The County Conservation Park Ranger states that there are still some cooler spots in the lake, but overall there seems to be less than years ago and some apparent sealing-off of the springs' inflow. Spring Lake does not receive inflow from an inlet stream. There are two tile outlets in the park area on the west. One tile does not discharge and is non-functional. The other tile outlet is observed to flow only on a few occasions, and carries sediment-free water that filters through riparian vegetation. A small spring flows from the wooded area on the west side just west of the park road into an underground pipe that feeds to the lake at its northwest corner. This water is clear.

A small portion of the watershed lies to the north of 195th Street, which runs east and west and lies along the north boundary of the park and lake. A small ditch carries this drainage into West Buttrick Creek upstream and to the north of Spring Lake. The roadway blocks any other runoff that might come from the north into the lake. The western portion of the Spring Lake watershed lies within a drainage district whose tile lines connect with an open channel south and west of Spring Lake in the section to the south. Berms or dikes, as previously mentioned, run alongside the full length of the lake, one on the east and one on the west side, relicts of the mining of sand and gravel. These serve as natural blockage to any overflows from West Buttrick Creek on the east, and from surface runoff of the cropped fields on the west side.

Lake discharge occurs at the SE corner of the east basin into an unnamed ditch that runs directly south, exits the park's southern boundary, flows through a culvert under the road, continues south and enters Buttrick Creek approximately one mile to the south in the next section. Discharge is not continual and during dry months there is no overflow from Spring Lake. The lake's depth varies with the level of ground water and West Buttrick Creek, and as these rise, the lake rises accordingly. During major storm events or wet years, discharge from the lake will be greater than what the culvert can handle and the excess water flows east in the road ditch of 205th St., across the adjoining golf course, and enters West Buttrick Creek which runs parallel to Spring Lake about a ¼ mile to the east.

Average rainfall in the area is 31.6 inches/year. The estimated annual average detention time for Spring Lake is 0.56 years (204 days) based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix D.

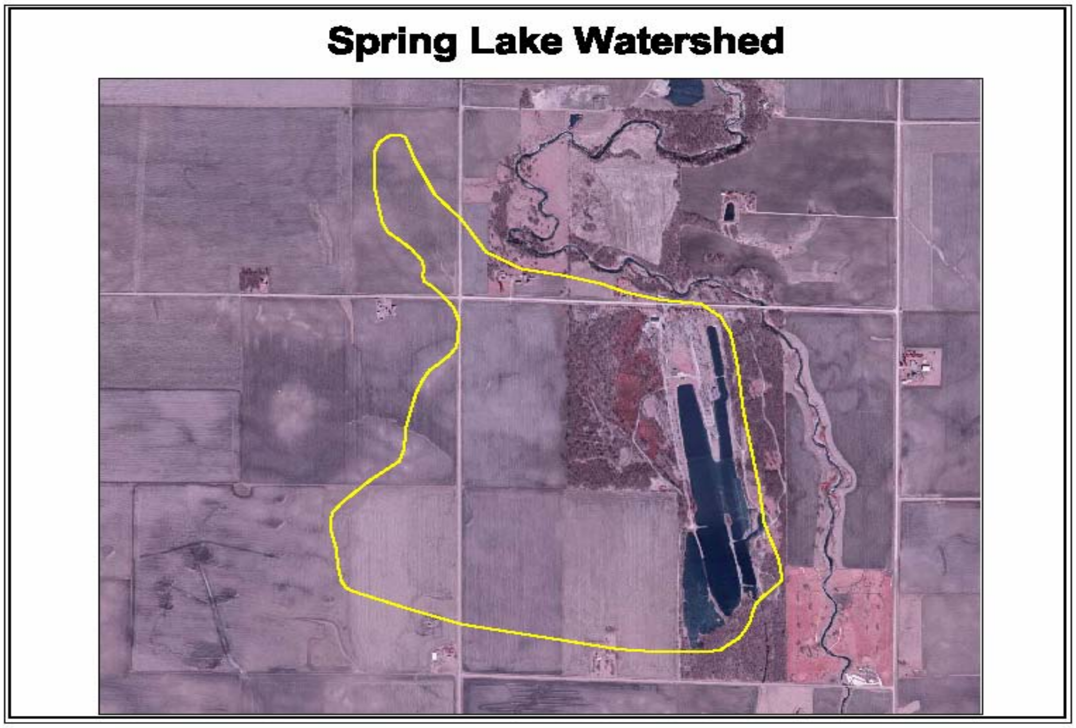
2.2 The Watershed

The Spring Lake watershed has an estimated area of 467 acres and has a watershed to lake ratio of approximately 10:1. Land use data for the watershed based on 2002 satellite imagery is shown in Table 3. The lake and watershed are shown in Figure 1. A land use map is in Appendix B.

Table 3. 2002 Land use in Spring Lake watershed.

Landuse	Area in Acres	Percent of Total Area
Row Crop	315	68
CRP / Grass / Hay / Pasture	80	17
Timber	62	13
Other (water, roads, residential)	10	2
Total	467	100

Figure 1. Color Infrared Aerial Photography of Spring Lake Watershed.



A general field inspection of the watershed was completed in August, 2005, to confirm current land use, lake specifics, and watershed features as reported in the color infrared photography information. Land use has remained steady over the past ten years with the exception of some increase in wooded and vegetative cover in the western portion of the park.

There are no confined animal feeding operations or open feedlots existing in the watershed.

The watershed's soil association is the Mayer-Biscay-Coland association, defined as nearly level, poorly drained, loamy and silty soils that formed in glacial outwash sediments and alluvium and is typically found on outwash plains, terraces, and bottom land (USDA Soil Survey, 1983). The Mayer-Biscay-Coland association as a whole has slopes that range from 0 to 2% with an average basin slope in this watershed of 1.6%. Several sites of higher elevations to the north and west of the lake are Clarion or Salida-Storden loams with slopes of 2-5%, 5-9%, and 9-14%, and classed as moderately eroded. Mayer soils, 25% of the association, is calcareous (alkaline, basic pH) while Bascay soils (24% of the association) are not. These two soil types are found in low areas. The available water capacity ranges from low to high. Soil management includes measures to improve drainage, control flooding, and maintain fertility.

3. TMDL for Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (11) list the designated uses for Spring Lake as Primary Contact (Class A1) and Aquatic Life (Class B(LW)). In 1998 and 2000, Spring Lake was included on the 303(d) Impaired Waters List as "partially supporting" the Class B(LW) uses as recommended by the DNR Fisheries Bureau due to excessive growth of rooted aquatic vegetation (macrophytes). In 2002, Spring Lake continued to be listed on the impaired waters list.

In 2004, the lake continued to be listed, but the impairment was changed from rooted aquatic macrophytes to turbidity to more accurately describe the impairments at Spring Lake. The Class A (primary contact recreation) uses were assessed (monitored) as "partially supporting" due to high levels of turbidity that reduce water transparency and may adversely affect the Class A uses of Spring Lake. The Class B(LW) aquatic life uses were assessed (evaluated) as "fully supporting/threatened" due to excessive growth of aquatic macrophytes. The sources of data for this assessment include results of the statewide survey of Iowa lakes (Iowa Lakes Study) conducted from 2000 through 2004 by Iowa State University (5,6,7,8,9), information from the IDNR Fisheries Bureau (13), and information on plankton communities at Iowa lakes in 2000 from Downing et al. (10).

Past assessments summary: Spring Lake was assessed as fully supporting for both fishable and swimmable uses in 1992, and monitoring in 1990-92 found that the mean (averages) for Secchi depth, chlorophyll-a, total phosphorus, and total suspended solids were all better than overall means for the 116 significant publicly owned lakes of Iowa at that time. Despite being relatively shallow and not stratified, the water quality was well above average for Iowa's monitored lakes in 1992. However, the fishable and swimmable uses of this lake were assessed in 1994 as partially supporting at the recommendation of DNR Fisheries as a result of nuisance growths of rooted aquatic vegetation. In 1998, the Class A and Class B uses remained assessed as partially supporting due to the continuing problem of aquatic vegetation. With the control and elimination of the aquatic vegetation since then by Fisheries, the lake has shifted from a clear water phase with macrophyte growth, into a turbid lake with no macrophyte growth.

The State of Iowa does not have numeric water quality criteria for turbidity that apply to Spring Lake. However the turbidity impairment violates the narrative water quality standards stating that waters shall be free from asesthetically objectionable conditions. The aesthetically objectionable conditions present at Spring Lake are impairing the Class A1 use for primary contact recreation.

Data Sources

Water quality surveys have been conducted on Spring Lake in 1979, 1990, and 2000-2004 (1,2,5,6,7,8,9). Data from these surveys is available in Appendix A.

The ISU Lake Study data from 2000 to 2004 were evaluated for this TMDL. This study approximates a sampling scheme used by Dr. Roger Bachman (ISU) in earlier Iowa lake studies in 1979 and 1990 (1,2). Samples are collected three times per year in the early, middle, and late summer. A number of water quality parameters are measured including Secchi disk depth (SD), phosphorus series, nitrogen series, total suspended solids (TSS), inorganic suspended solids (ISS), and volatile suspended solids (VSS).

IDNR Fisheries conducted fish sampling and surveys of the fish population in the lake in 1995, 2000, and 2004. The 2004 survey was a more intensive survey in an effort to identify more precisely the number of fish in each species as part of a statewide in-depth survey of Iowa lakes. Information on age-growth parameters was collected in this study and will be incorporated into a statewide database. Fisheries will continue to survey Spring Lake every three years (13).

The 1979 data, as part of Iowa's lake classification survey, indicated better than average water quality, with TSI values of 55 for secchi disc and 48 for chlorophyll (n=1). Data collected in 1990 had TSI values of 52 and 49 respectively (n=1). However, in 1994 DNR Fisheries recommended the lake to be assessed as partially supporting because the fishable and swimmable uses were impaired by nuisance growths of rooted aquatic vegetation.

Biological background: Over-abundant macrophytes were a severe problem in Spring Lake in the decades earlier. A mat of coon-tail (*Ceratophyllum*) covered the surface of the lake, and was described as thick enough "to walk across". Once established, this aquatic vegetation can float freely in the water column, and can form dense mats just below the surface as evidenced in Spring Lake. The Park Ranger stated that the vegetation was raked at the beach area to provide clear water for swimming. At one point, a tractor was hooked to the vegetation in an effort to pull it from the water but it was unable to pull the heavy load. In 1979,Iowa DNR Fisheries began stocking the lake with grass carp (*Ctenopharyngodon idella*) in an effort to control the aquatic vegetation. Adult grass carp feed on a variety of aquatic plants, but they prefer submerged vegetation and were often used by fisheries managers as a biological method to control nuisance levels of submerged aquatic plants. Initially 350 grass carp were placed in the lake, followed each year with further stocking of 10 grass carp/acre of lake surface. Stocking continued at this rate until more recent years when it was reduced to one carp per acre. All stocking of grass carp ended about five years ago but large numbers continue to live in the lake. A County Conservation Park Board Member and the Park Ranger estimate that approximately 600 grass carp may have been added to the lake over the years. In addition to the stocking, an aquatic herbicide was used by the DNR to assist in reducing the vegetation. This resulted in die-off of the heavy mats of vegetation, and the residue settled as a dark organic matter layer on the lakebed. The residue continues to be present. Although distributed across the lake bottom, its depth may vary. When stirred by fish activity, this material disperses and adds to the turbidity of the water. The Park Ranger believes that this organic matter may also be responsible for the apparent sealing-off of some of the springs in the lakebed as evidenced by fewer reports by swimmers and staff in recent years of cold water under-currents in the lake.

Additionally, populations of the common carp (*Cyprinus carpio*), gizzard shad (*Dorosoma cepedianum),* catfish and bullheads *(Ictulurus)*, river carp sucker (*Carpiodes carpio*), buffalo (*Ictiobus cyrinellus*) and other river species (13) also contribute to the stirring of lake-bed sediments. These enter the lake from near-by West Buttrick Creek during periods of high water when the discharge gate on the lake is opened to lower the lake. The ditch that carries the discharge connects with West Buttrick Creek in two places, to the east ¼ mile and to the south about 1 mile. In either instance, rough fish leave the creek during high water, swim upstream via the ditch and enter the lake when the gate is open. Of the river species, the common carp and gizzard shad are the most numerous. IDNR Fisheries estimate that the common carp population has remained fairly constant over past survey periods, with fish normally greater than 20 inches in length. Sluggish rivers and soft-bottomed lakes such as Spring Lake are optimum habitat for gizzard shad and the other bottom dwelling species. Additionally, 2,000 – 3,000 catfish fingerlings are reared each year in cages by park staff and released to provide a catfish fishery for lake users. The present population of catfish in Spring Lake is thought to be underestimated because of the difficulty in accurate sampling methods for this species. Bluegill are the primary panfish species in the lake but are of less than optimum size and condition as they are out-competed by the gizzard shad.

All local contacts with the lake report that the water is turbid even during the winter as noted by ice-fishermen. The water's turbidity is significant and prevents the fishermen from seeing down into the water, even a short distance. These reports indicate that the lake continues to have reduced transparency because of turbidity even during the winter season when the lake is ice-covered and no rains, wave action or boating are occurring. Fish foraging activity would account for this year-round re-suspension and internal recycling of lakebed sediments. The west basin is visibly more turbid than the other two basins and is more shallow, maintaining a depth of only 1 or 2 feet. The carp tend to remain in this portion of the lake and the south end of the main basin as they prefer shallow areas.

The lake serves as a migration stop for >300 Canada Geese in October – November each year but very few remain throughout the year. Their contribution to turbidity is considered to be negligible.

None of the park’s grassy areas are fertilized. There is no inlet for surface runoff from the watershed. This suggests that excessive phosphorus does not enter the lake.

Interpreting Spring Lake Water Quality Data

Based on the mean values from the ISU lake study 2000-2004, the inorganic suspended solids is 10.1 mg/L, the volatile suspended solids is 10.7 mg/L, the phosphorus level is 66.1 ug/L, the chlorophyll level is 31.0 ug/L, and the Secchi disk depth is 0.6 meters. The median level of inorganic suspended solids in the 131 lakes sampled for the ISU lake study for 2000-2002 was 4.8 mg/L; the median level at Spring Lake was 6.6 mg/L. While earlier data showed an elevated level of inorganic suspended solids in Spring Lake compared to other Iowa lakes, the macrophyte die-off and resulting accumulation of organic residue increased the organic/non-inorganic component. The elevated total suspended solids is comprised now of nearly equal concentrations of inorganic suspended solids and volatile suspended solids. The total suspended solids account for the reductions in water transparency (Secchi disk depth) observed at this lake.

The ISU Iowa Lakes Study water column data indicate that turbidity increases more markedly near the lakebed. For most data from 2000 - 2004, turbidity significantly increases at the lower levels (5,6,7,8,9). This suggests that the fish activity by the large number of bottom-dwelling species in Spring Lake stirs the lakebed sediments and significantly contributes to the turbidity.

The data for volatile suspended solids (organic/algal particles) and inorganic suspended solids (non-organic/non-algal particles) for the 2000 - 2004 time period were compared. These data indicate that turbidity is caused both by inorganic material and organic material – each contributing similarly with slightly more impact by the volatile suspended solids/organic material. This is reflected in the mean values of inorganic suspended solids and volatile suspended solids, 10.1 mg/l and 10.7 mg/l respectively, and in correlation analyses of volatile and inorganic suspended solids with Secchi depth. There is a strong correlation of both volatile suspended solids and total suspended solids with Secchi depth (Figures 2 and 3), while there is considerably less correlation of inorganic suspended solids with Secchi depth (Figure 4). These data support that the volatile portion of the suspended solids comprise a greater portion of the total suspended solids than the inorganic portion, and subsequently, may contribute overall more significantly to the turbidity in the lake than the inorganic portion. Fish movement and foraging activity stirs-up the organic residue in addition to the sand of the lakebed and the organic portion appears to exceed that of the stirred-up sand more often.

Figure 2. Volatile Suspended Solids vs Transparency

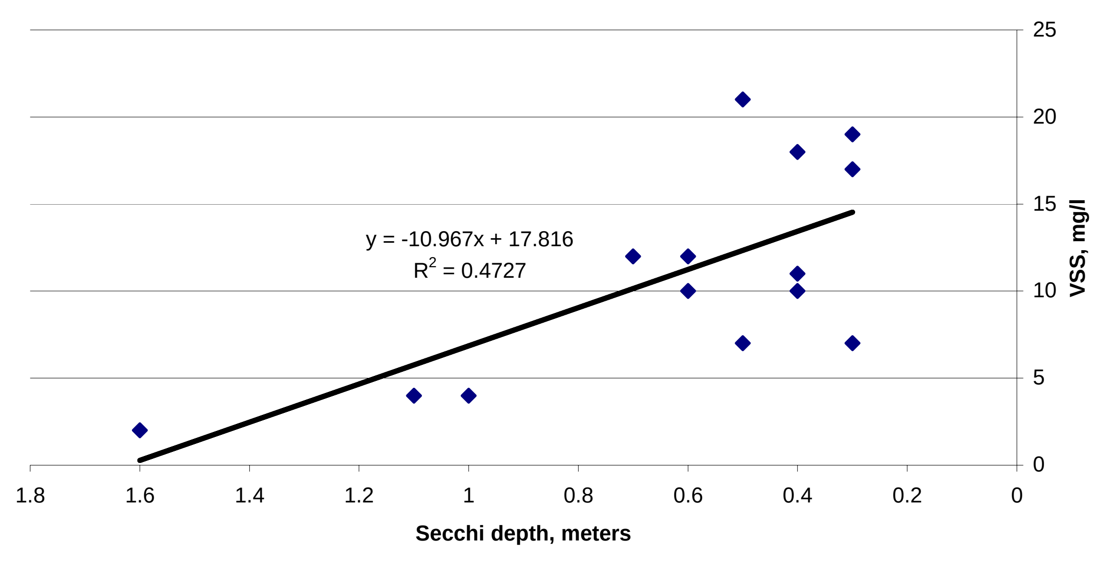
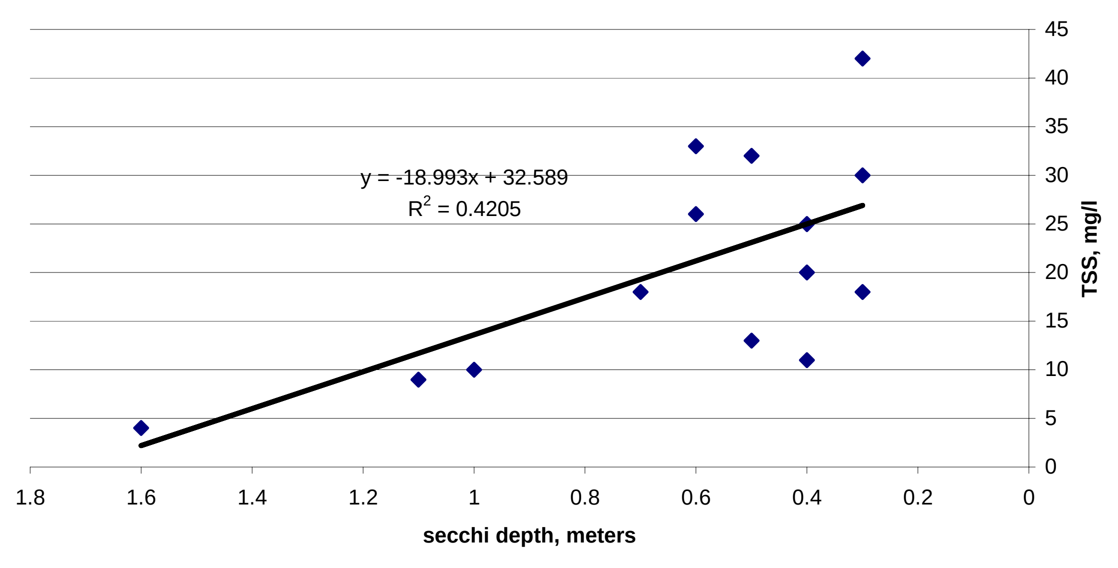


Figure 3. Total Suspended Solids vs Transparency



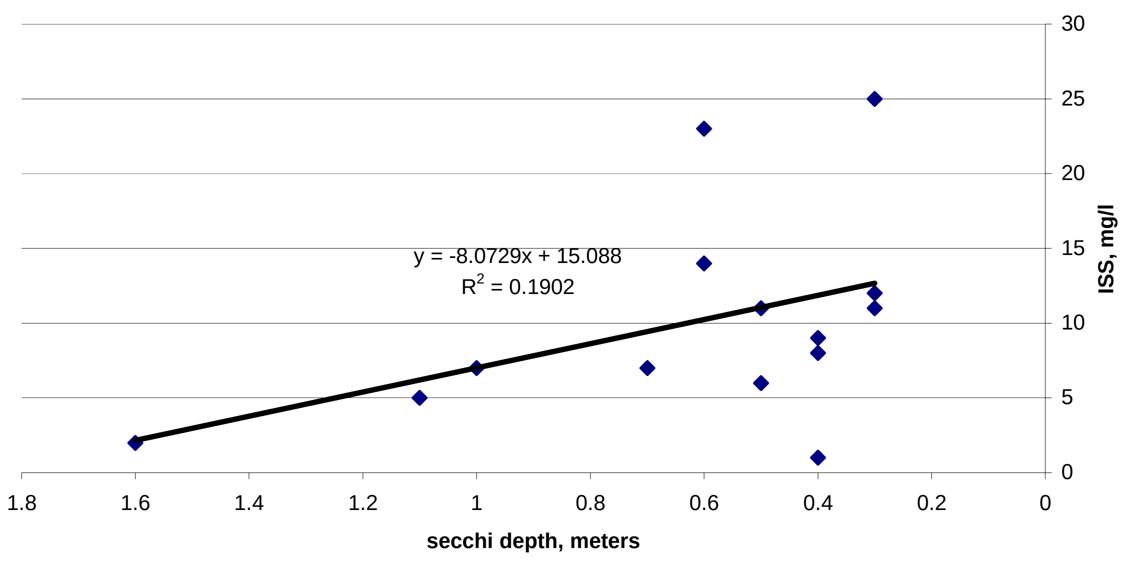


Figure 4. Inorganic Suspended Solids vs Transparency

DNR's 305(b) 2004 assessment report (12) stated that the chlorophyll-a (suspended algae) levels in Spring Lake are lower than would be expected in the conditions at Spring Lake. An evaluation of the Iowa Lake Study data shows only a moderate correlation between chlorophyll (algae) and Secchi depth whereas a stronger correlation exists between volatile suspended solids and total suspended solids with Secchi depth. Thus, the turbidity of the lake can be attributed to both inorganic and volatile suspended solids, with the organic residue from the decayed vegetation on the lakebed comprising a greater portion of the organic component of the turbidity in Spring Lake than algae. However, algae also contributes, as evidenced by the eutrophic designation of the TSI scores, but its role appears not to be as great as that of the organic residue.

In 2004 and in 2000, total phosphorus concentrations were independent of chlorophyll-a levels. At times when chlorophyll-a concentrations were moderately to significantly high, phosphorous remained moderately low, or the reverse occurred. Since algal increase is usually a response to increased nutrients, a rise in chlorophyll-a concentrations is expected when phosphorus concentrations increase, however, these relationships were not always present.

Further evidence that algae is not the leading contributor of the organic component is seen in the 2002 data. The mean volatile suspended solids for the three samples that year exceeded the mean inorganic suspended solids by 4 mg/L. If algae were the leading cause behind the elevated volatile suspended solids, it could be expected that total phosphorus levels would also be higher, but phosphorus concentrations were the 2nd lowest of the five years.

Comparisons of the Trophic State Index (TSI) (3) values for chlorophyll, Secchi depth, and total phosphorus for in-lake sampling from 2000 – 2004 found turbidity contributes to impairments of both primary contact recreation and aquatic life uses. The TSI values are lower for chlorophyll-a, while Secchi depth TSI values are higher, reflecting a water column that has reduced transparency and is turbid and yet does not have an extraordinary amount of algae (as measured by the chlorophyll-a). The occurrence of higher and similar TSI values for total phosphorus and Secchi depth compared to the TSI for chlorophyll-a suggests that non-algal particles may dominate light attenuation and limit the production of algae through light attenuation (4).

Some data showed an inverse relationship between turbidity and Secchi depth/transparency (turbidity poorer, SD better). In these instances, the volatile suspended solids were a larger contributor to total suspended solids than the inorganic suspended solids, however, chlorophyll-a concentrations were lower. These data suggest that the cause of this is the residual organic matter on the lakebed, and that while it contributes to turbidity, its relative contribution to overall transparency of the water is less. Fineness of particle size may explain this variation.

Interpretation of the data for this TMDL suggests that light attenuation occurs through a combination of inorganic suspended sediment, residual organic suspended sediment, and algae. Comparisons of the TSI values for Secchi depth, chlorophyll, and total phosphorus for 2000-2004 in-lake sampling are found in Figure 5.

Figure 5. Spring Lake 2000 – 2004 Mean TSI Multivariate Comparison Plots

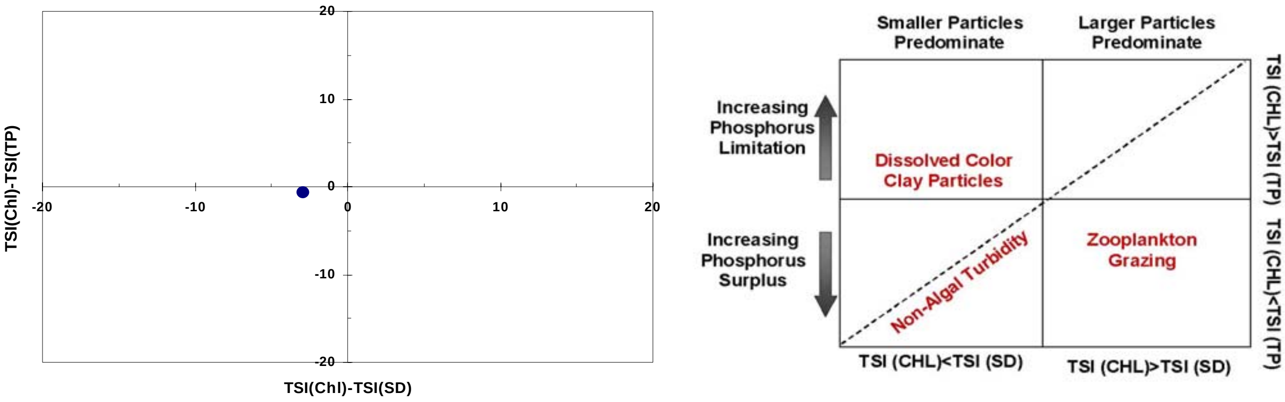


Figure 5 is a multivariate plot of mean TSI values. The dot on the left-hand graphic shows the relationship between TSI (SD), TSI (CHL), and TSI (TP) for Spring Lake on the graph area. The dot is near the border of the lower left-hand quadrant near the mid-graph area, indicating that the water column is dominated by smaller particles and is not limiting in phosphorus. However because of the nearness to the center these features are not as strong, and that there is some influence of other particle sizes and phosphorus variation. Also, being slightly above the diagonal line from the lower left to the upper right indicates the water body turbidity impairment has both algal and non-algal contributions.

TSI values for Secchi disk, chlorophyll, and total phosphorus for 2000-2004 are shown in Table 4 and graphed in Figure 6. The TSI values indicate that Spring Lake is eutrophic to hyper-eutrophic and has elevated Secchi depth values which reflects reduced transparency of the water. An explanation of Carlson's Trophic State Index is given in Appendix C. Table 5 lists selected parameters and their relationship to transparency.

Table 4. Spring Lake TSI Values (3,4)

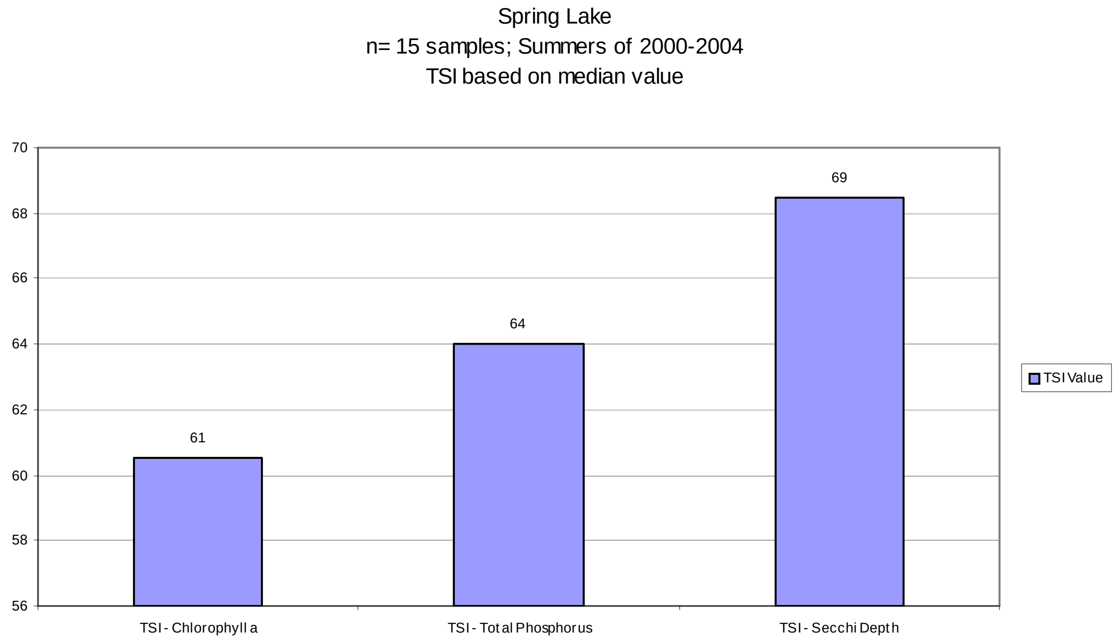
Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/23/2000	68	--	71
7/19/2000	71	51	64
8/9/2000	74	52	75
5/24/2001	53	38	43
6/20/2001	60	55	67
7/25/2001	66	66	69
5/30/2002	--	47	55
6/27/2002	72	55	63
7/31/2002	77	66	65
5/30/2003	59	51	52
6/24/2003	80	67	64
7/31/2003	73	66	64
5/27/2004	69	70	59
6/24/2004	76	76	63
Median	**69**	**61**	**64**
Mean	**68**	**59**	**63**

Table 5. Water Quality Parameters Related to Transparency

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 (SD, m)	Measures water column transparency and used as a translator for turbidity.
Total Suspended Solids (TSS, mg/L)	Solids residue captured on an 0.45 um filter and dried at 105 C.
Inorganic Suspended Solids (ISS, mg/L)	Solids residue remaining after heating at 550 C.
Volatile Suspended Solids (VSS, mg/L)	Weight lost after heating, VSS is the difference between TSS and ISS. This is the organic fraction found in the water.
Chlorophyll (CHL, ug/L)	Chlorophyll is a measure of the algae concentration in the water column. Usually chlorophyll will be correlated with VSS.
Total Phosphorous (TP, ug/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 lakes. It can be related to chlorophyll and Secchi depth with the trophic state index in the absence of other limiting conditions.

Neither nitrogen limitation nor zooplankton grazing appear to limit algal production at Spring Lake. Data (10) show relatively small populations of zooplankton species at this lake that graze on algae. Sampling in 2000 showed that Cladoceran taxa (e.g., *Daphnia*) were absent in the mid-July sample but increased to approximately 50% in the early August sample. However, the average 2000 summer mass of Cladoceran grazers (0.8 mg/l) was the 11th lowest of the 131 lakes sampled. At these population levels, grazing of algae by zooplankters likely does not affect algal production.

Figure 6. TSI median values for chlorophyll, total phosphorus, and Secchi depth.



Potential Pollution Sources

There are no point sources of pollution in the Spring Lake watershed. The inorganic and organic turbidity is caused by the internal re-suspension of sediment and residue from the lake bottom. There is a large population of lake bottom foraging fish, specifically grass and common carp and catfish. Since dikes run parallel along the east and west sides of the lake, surface runoff sediment from sheet and rill erosion from cropland does not occur. There are two tile outlets inside the park. One tile does not flow and is considered nonfunctioning. The other tile outlet is observed to flow only on a few occasions, and carries sediment-free water that filters through riparian vegetation. The baseball field and camping areas are grassed but not fertilized. Water quality data has shown that the phosphorus levels in the lake are not excessively high compared to other lakes in the Iowa Lakes Study. Algal growth appears to be largely limited by the excessive sediment/turbidity. The 305(b) report states that phosphorus, rather than nitrogen, appears to be the limiting nutrient.

Natural Background Conditions

Background levels of sediment were not separated from nonpoint sources of sediment.

3.2 TMDL Target

The Phase 1 target for this TMDL is an average water transparency level measured by Secchi depth greater than 0.7 meters. This target is equivalent to a TSI value of 65 which is the minimum depth considered to be fully supporting/threatened for the Section 305(b) use support category. This target requires an increase in transparency of 14.3%. Based on ISU sampling data for 2000-2004 the chlorophyll and total phosphorus targets are being met. The existing conditions and target values for Spring Lake are in Table 6.

Table 6. Spring Lake Existing vs. Target TSI Values

Parameter	2000-2004 Mean TSI	2000-2004 Mean Value	Target TSI	Target Value	In-lake Increase or Reduction Required
Cholorophyll	59.3	31.0 ug/l	<65	<33 ug/l	N/A
Secchi Depth	68.2	0.6 m	<65	>0.7 meters	14.3% Increase in Transparency
Total Phosphorus	62.8	66.1 ug/l	<65	<68 ug/l	N/A

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for turbidity. The turbidity impairment at Spring Lake is due to re-suspension of lake bottom sediment by common carp and other bottom-dwelling fish foraging activity, causing excessive turbidity and limiting the transparency of the water. The sediments are a combination of inorganic suspended solids (i.e., non-algal turbidity) and from volatile suspended solids (organic matter). The transparency objective is defined by a mean Secchi depth of 0.7 meters or a Trophic State Index of 65. The TSI is not a standard, but is used as a guideline to relate Secchi depth (transparency) to the turbidity impairment for TMDL development purposes and to describe water quality that will meet Iowa’s narrative water quality standards.

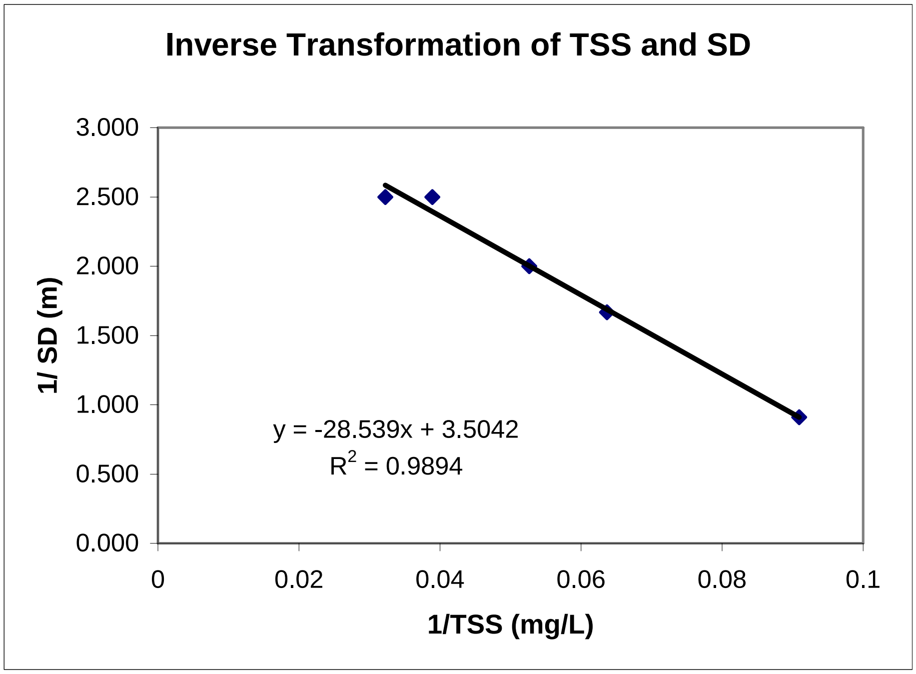
Selection of Environmental Conditions

The critical condition for the TMDL target transparency applies to the annual average transparency value. The existing and target values of Secchi depth are expressed as annual averages.

Waterbody Pollutant Loading Capacity

Excessive levels of total suspended solids (TSS) is causing the turbidity impairment. The loading capacity of the lake is determined by a Secchi depth TSI of 65, equivalent to a Secchi depth (SD) of 0.7 meters. The ISU Lake data collected from 2000-2004 were evaluated using an inverse transformation of the total suspended solids (TSS) and Secchi depth annual means to back-calculate the sediment load. Figure 7 shows the Inverse transformation of the TSS and SD.

Figure 7. Inverse Transformation of annual means of total suspended solids (TSS) and Secchi depth (SD).



Using the relationship between Secchi depth and TSS from Figure 7, the target total suspended solids concentration is:

InvTSS = (InvSD – 3.5042) / -28.539
InvTSS = (1/0.7 – 3.5042) / -28.539
InvTSS = 0.072729
TSS target = 13.7 mg/L

Based upon lake retention time, TSS concentration, and dam trapping efficiency this is equivalent to:

(179 ac-ft lake volume)(13.7 mg TSS/L)(365/204 day retention)(1,233,482 L/ac ft.)(2.204 lbs/10^6 mg)(1 ton/2000 lbs) = 5.96 tons sediment exiting the lake annually.

The Brune equation (14) was used to calculate the trap efficiency (TE) of Spring Lake based on volume and inflow.

Capacity-Inflow Method (Brune's Curve)
TE = 100*0.97^[0.19^(log C/I)]
C = Reservoir capacity, acre-ft = 179 acre-feet
I = Mean annual flow, acre-ft = 346 acre-feet

TE = 100*0.97^[0.19^(log 179/346)]
TE = 95.22%

Assuming a 95.2% trap efficiency of the lake, this results in a sediment load capacity of ([1-.952]x = 5.96 tons) => 124 tons of sediment per year.

3.3 Pollution Source Assessment

Existing Load

Turbidity levels in Spring Lake are created by an existing sediment load of 186 tons re-suspended in the lake. This is calculated using lake hydrology, measured TSS and dam trapping efficiency. The calculations are as follows:

(179 ac-ft lake volume)(20.48 mg TSS/L)(365 days/204 day retention)(1,233,482 L/ac ft)(2.204 lbs/10^6mg$^{)}$ (1 ton/2000lbs) = 8.92 tons sediment exiting the lake.

As discussed above, the Brune method was used to calculate trap efficiency of the lake based on volume and inflow.

Utilizing a trap efficiency of 95.2%, this results in an existing load of ([1-.952]x = 8.92 tons) => 186 tons of sediment to the lake.

Departure from Load Capacity

The turbidity load capacity is 124 tons of sediment. The existing turbidity load is 186 tons resulting in a departure from load capacity of 62 tons of sediment.

Identification of Pollutant Sources

There are no point sources of pollution in Spring Lake watershed and no input stream. Therefore, all of the turbidity is attributed to internal loading.

Linkages of Sources to Target

The load capacity of Spring Lake is 124 tons of sediment per year. The current sediment load is 186 tons per year. This load originates from internal lake re-suspension.

3.4 Pollutant Allocation

Wasteload Allocation

There are no known point sources of pollution in the watershed. Therefore, the wasteload allocation for this TMDL is set at zero.

Load Allocation

The load allocation for turbidity is 112 tons of sediment in the lake allocated to lake re-suspension.

Margin of Safety

An explicit margin of safety for turbidity is set at 10% of the load capacity, or 12 tons sediment (124 tons x 10%).

TMDL Summary

TMDL = WLA + LA + MOS
= 0 + 112 tons/yr + 12 tons/yr
TMDL = 124 tons/yr

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 offers the following implementation strategy to DNR staff, partners, and watershed stakeholders as a guide to improving water quality at Spring Lake.

Among the general mechanisms of re-suspension in lakes are bottom feeding rough fish such as carp, shad, and bullheads as well wind-driven waves and currents, and boat propellers. In Spring Lake, the lake's small size limits the amount of lakebed disturbance from boats, and the higher dikes and woods surrounding the lake reduces the amount of wind reaching the lake. Therefore, the stirring of sediment and re-suspension in the lake is nearly exclusively caused by fish activity.

The lake itself has characteristics that hinder improvement of water quality. The shallow nature of the lake prevents the upper levels of the water from clearing and returning to acceptable levels of transparency. Thus, if the lake had greater depth, stirring of bottom sediments would affect the upper reaches of the lake far less. The shallowness also lends itself to the preferred aquatic habitat by carp for spawning, loafing, and foraging. Additionally, since the lake is a mined sandpit, the sloughing-off of the sides and the shifting of loose sand creates natural turbidity that is difficult to control. The easily dispersed organic residue adds to the re-suspension of particles in the water column.

To date, no technique is available that would bind the organic residue nor artificially hold the bottom sediments in place. A method to reduce organic matter can be through increasing oxidation via aeration. However, the Greene County Conservation Board has already installed aerators that operate daily, primarily to improve the oxygen content of the water for the catfish. These have not eliminated the residue.

Dredging the lake to deepen is not an option. Dredging activity would loosen the sandy lake banks, resulting in the enlargement of the lake as banks break down and break away. In addition, even if dredging would be an option, to obtain the depth needed would be an extensive dredging operation and be cost prohibitive.

In reviewing the history of the lake, the water had significantly better transparency when the macrophytes (rooted aquatic vegetation) were present in the lake. Plants that are rooted in the lakebed hold the sediment in place, much like buffer and riparian vegetation reduces stream bank erosion by holding the soil in place. Thus, reestablishment of macrophytes is needed to hold the loose sand and organic residue. Careful placement and non-chemical control of the macrophytes would be necessary to prevent excessive growth. Establishing and controlling vegetation in the shallow south and west portions of the lake would be the most likely sites. Control of vegetation in beach, boat ramp, and other areas that need to be free of plants can be done in two ways: 1) placement of screening in the sediment which will keep plants from rooting, and 2) mechanical cutting of plants in strategic areas. Mechanical cutting units are reasonable in cost and are widely used in other states to cut out areas of vegetation in lakes. The vegetation can be composted and has been found to breakdown quickly.

Prior to the establishment of the macrophytes, biomanipulation is necessary of the fish population. Removal of the current fish population is needed to allow suspended particles to settle, and to allow for macrophyte vegetation to re-establish. Heavy fish activity would keep the water turbid, reducing the light available for plant growth, and would disrupt vegetation from rooting. Thus, for restoration steps to proceed, these conditions will need to be changed. Once fish activity has stopped, macrophyte growth re-occurs rather quickly and with accompanying improved water clarity. Following these improvements, DNR Fisheries will need to re-introduce appropriate fish species for a diverse and balanced fish population in the lake.

Further, a barrier to prevent rough fish from entering the lake at the discharge gate will need to be installed. This would prevent river carp sucker, common carp, gizzard shad, and other river-bottom fish from entering the lake when West Buttrick Creek is in flood stage and waters are backed-up into the connecting ditches.

These recommendations would involve the co-ordination of DNR Fisheries and the Greene County Conservation Board. The County Conservation Board is interested in improving the lake and is willing to contribute to the efforts that would result in long-term water quality improvement.

It is expected that reduction of the suspended sediment load and improvement in transparency can be obtained in a relatively short time period if the implementation recommendations of: a) biomanipulation of the fish population, b) establishment of macrophytes, and c) control measures at the discharge gate to prevent rough fish from entering the lake, are accomplished. Reduction of the 62 tons should be achievable by 2010.

5. Monitoring

Further monitoring is needed at Spring Lake to follow-up on the implementation of the TMDL. This monitoring will, at a minimum, meet the minimum 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. Spring Lake has been 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, a lake monitoring program will be continued by the DNR. IDNR Fisheries will also continue to monitor the fish population every three years. Monitoring of near-by West Buttrick Creek and Spring Lake occurs periodically through studies of Iowa State University students.

6. Public Participation

A public informational meeting was held May 11, 2005 with the Greene County Conservation Board (GCCB) at their monthly meeting at the Milwaukee Road Depot in Jefferson, Iowa. The meeting included describing the Spring Lake impairment and the steps that were being taken to develop a plan to address the impairment. TMDL staff met again with GCCB staff on August 5, 2005 to visit of the lake and watershed and acquire a greater understanding of the water quality at Spring Lake. The draft TMDL was made available for public review and comment and a public meeting was held on December 20, 2005 in Jefferson, Iowa to discuss the draft TMDL. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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8. Appendix A - Sampling Data

Table A-1. Data collected in 1979 by Iowa State University(n=3) (1)

Parameter	**1979**
Secchi Depth (m)	1.4
Chlorophyll (ug/L)	5.6
NO_3+NO_2-N (mg/L)	0.4
Total Phosphorus (ug/L as P)	-
Alkalinity (mg/L)	100.4

Data above is averaged over the upper 6 feet.

Table A-2. Data collected in 1990 by Iowa State University (2)

Parameter	**6/01/1990**	**7/01/1990**	**7/29/1990**
Secchi Depth (m)	2	1.7	1.4
Chlorophyll (ug/L)	2.6	7.1	10.5
Total Nitrogen (mg/L as N)	0.9	1.2	0.8
Total Phosphorus (ug/L as P)	43	33	33
Total Suspended Solids (mg/L)	9.5	11.7	7.3
Inorganic Suspended Solids (mg/L)	11.6	1.8	10.8

Data above is for surface depth.

Table A-3. Data collected in 2000 by Iowa State University (3)

Parameter	**6/23/2000**	**7/19/2000**	**8/09/2000**
Secchi Depth (m)	0.6	0.5	0.4
Chlorophyll (ug/L)	-	8.1	8.5
NH_3+NH_4^+ -N (ug/L)	-	-	-
NH_3 –N (un-ionized) (ug/L)	-	-	-
NO_3+NO_2-N (mg/L)	0.15	0.63	0.14
Total Nitrogen (mg/L as N)	1.13	1.48	1.55
Total Phosphorus (ug/L as P)	104	64	137
Silica (mg/L as SiO_2)	-	-	-
pH	7.8	8.3	7.9
Alkalinity (mg/L)	170	153	153
Total Suspended Solids (mg/L)	33	13	11
Inorganic Suspended Solids (mg/L)	23	6	1
Volatile Suspended Solids (mg/L)	10	7	10

Table A-4. Data collected in 2001 by Iowa State University (4)

Parameter	**5/24/2001**	**6/20/2001**	**7/25/2001**
Secchi Depth (m)	1.6	1	0.7
Chlorophyll (ug/L)	2.2	11.8	36.7
NH_3+NH_4^+ -N (ug/L)	-	-	-
NH_3 –N (un-ionized) (ug/L)	-	-	-
NO_3+NO_2-N (mg/L)	0.14	0.13	0.27
Total Nitrogen (mg/L as N)	0.96	1.05	1.19
Total Phosphorus (ug/L as P)	15	80	89
Silica (mg/L as SiO_2)	-	-	-
pH	7.9	8.3	8.4
Alkalinity (mg/L)	166	179	161
Total Suspended Solids (mg/L)	4	10	18
Inorganic Suspended Solids (mg/L)	2	7	7
Volatile Suspended Solids (mg/L)	2	4	12

Table A-5. Data collected in 2002 by Iowa State University (5)

Parameter	**5/30/2002**	**6/27/2002**	**7/31/2002**
Secchi Depth (m)	-	0.5	0.3
Chlorophyll (ug/L)	5.5	12	38.6
NH_3+NH_4^+ -N (ug/L)	367	278	326
NH_3 –N (un-ionized) (ug/L)	31	33	66
NO_3+NO_2-N (mg/L)	0.11	0.11	0.11
Total Nitrogen (mg/L as N)	0.73	1.08	1.25
Total Phosphorus (ug/L as P)	33	60	70
Silica (mg/L as SiO_2)	1.02	7.07	16.65
pH	8.2	8.3	8.5
Alkalinity (mg/L)	166	153	154
Total Suspended Solids (mg/L)	15	32	30
Inorganic Suspended Solids (mg/L)	10	11	12
Volatile Suspended Solids (mg/L)	6	21	19

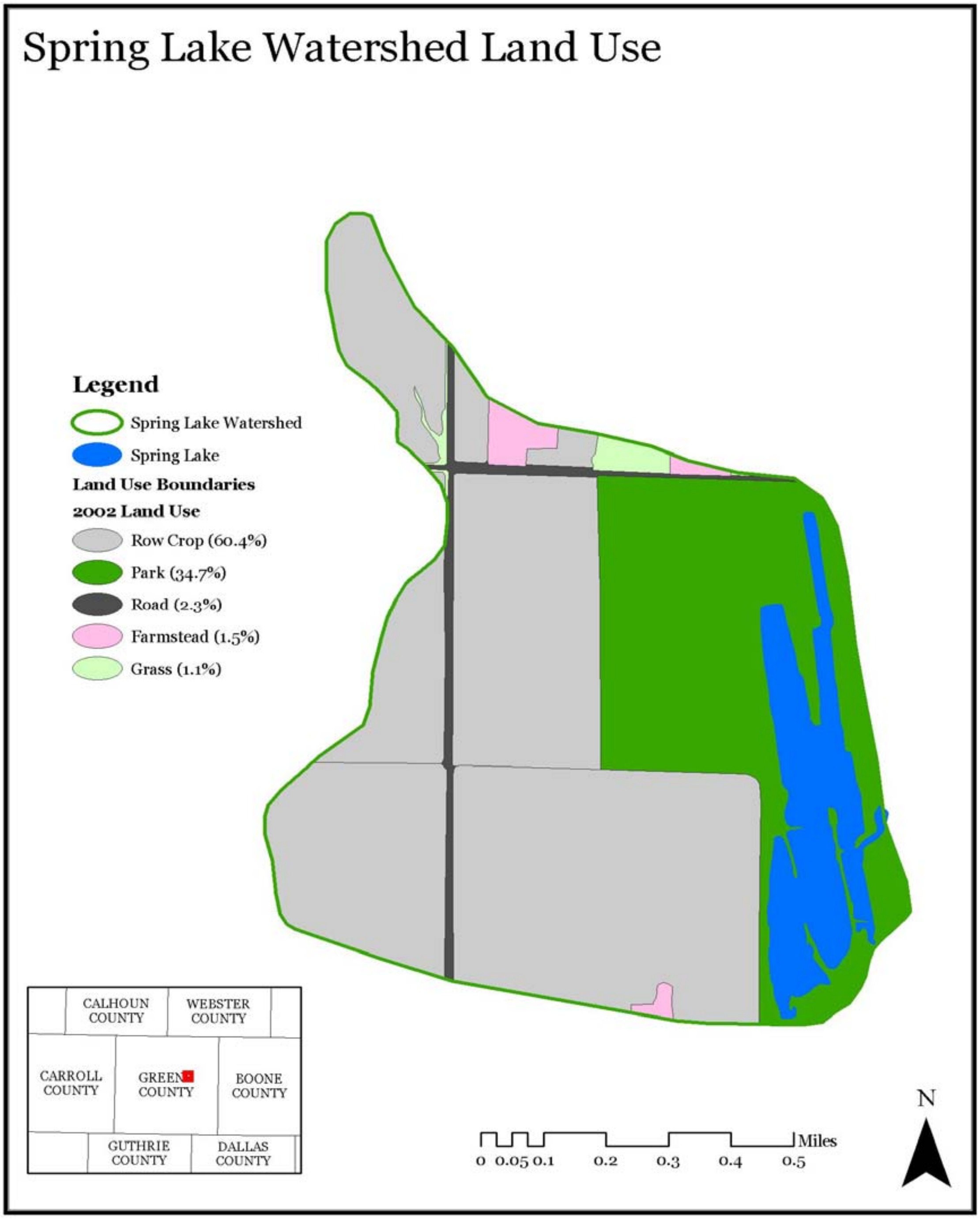
Table A-6. Data collected in 2003 by Iowa State University (6)

Parameter	**5/30/2003**	**6/26/2003**	**7/31/2003**
Secchi Depth (m)	1.1	0.3	0.4
Chlorophyll (ug/L)	7.7	40.9	37.4
NH_3+NH_4^+ -N (ug/L)	267	310	262
NH_3 –N (un-ionized) (ug/L)	22	34	20
NO_3+NO_2-N (mg/L)	0.16	0.11	8.4
Total Nitrogen (mg/L as N)	0.96	1.15	1.29
Total Phosphorus (ug/L as P)	29	64	65
Silica (mg/L as SiO_2)	3.97	5.36	12.31
pH	8.3	8.4	8.4
Alkalinity (mg/L)	141	120	118
Total Suspended Solids (mg/L)	9	18	20
Inorganic Suspended Solids (mg/L)	5	11	9
Volatile Suspended Solids (mg/L)	4	7	11

Table A-7. Data collected in 2004 by Iowa State University (6)

Parameter	**5/27/2003**	**6/24/2003**	**7/29/2003**
Secchi Depth (m)	0.6	0.3	0.4
Chlorophyll (ug/L)	55	99.7	55.5
NH_3+NH_4^+ -N (ug/L)	259	418	374
NH_3 –N (un-ionized) (ug/L)	43	33	111
NO_3+NO_2-N (mg/L)	0.11	0.12	0.11
Total Nitrogen (mg/L as N)	0.97	1.16	0.83
Total Phosphorus (ug/L as P)	45	61	76
Silica (mg/L as SiO_2)	1.74	3.82	7.56
pH	8.7	8.3	8.8
Alkalinity (mg/L)	139	144	164
Total Suspended Solids (mg/L)	26	42	25
Inorganic Suspended Solids (mg/L)	14	25	8
Volatile Suspended Solids (mg/L)	12	17	18

9. Appendix B – Spring Lake Land Use Map



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:

$$\text{TSI (TP)} = 14.42 \ln(\text{TP}) + 4.15$$

$$\text{TSI (CHL)} = 9.81 \ln(\text{CHL}) + 30.6$$

$$\text{TSI (SD)} = 60 - 14.41 \ln(\text{SD})$$

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 (7, 11).

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.

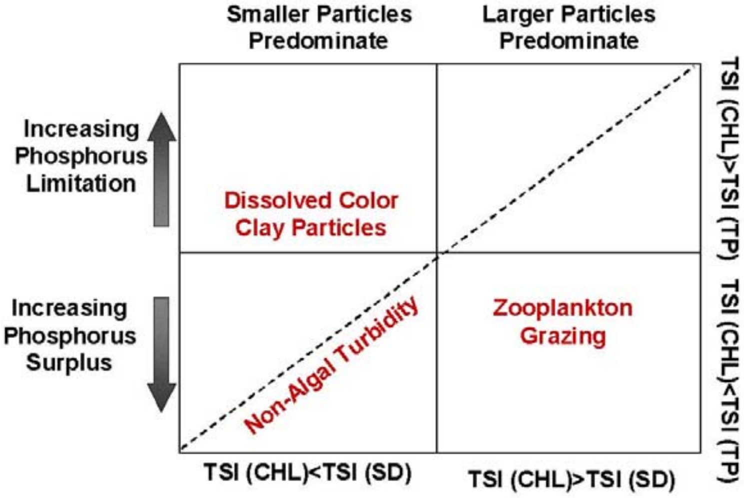
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for 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.

Figure C-1. Multivariate TSI Comparison Chart (Carlson)



11. Appendix D - 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 D-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 D-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 D-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 D-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 Spring Lake – Calculations

Table D-5. Spring lake Hydrology Calculations

Lake	Spring Lake	
Type	Impoundment	
Inlet(s)	none	
Outlet(s)	unnamed trib to Buttrick Creek	
Volume	179	acre-feet
Surface Area	49	acres
Watershed Area	519	acres
Mean Annual Precipitation	31.6	inches
Average Basin Slope	1.6	%
% Forest (2000 Land Cover)	13.4	
% Corn (2000 Land Cover)	34.6	
% Rowcrop (2002 Land Cover)	67.3	
Basin Soils Average % Sand	20.7	
Soil Permeability	1.3	inches/hour
Mean Annual Class A Pan Evaporation	52	inches
Evaporation Coefficient	0.74	
Optional User Input Inflow Estimate		acre-feet/year
Optional User Input Runoff Component		acre-feet/year
Optional User Input Baseflow Component		acre-feet/year
Mean Depth	3.6	Feet
Drainage Area	470	acres
Drainage Area	0.7	square miles
Drainage Area/Lake Area	9.5	
Mean Annual Lake Evaporation	38.5	inches
Mean Annual Lake Evaporation	158	acre-feet/year
Annual Average Inflow	0.5	cfs
Annual Average Inflow	346	acre-feet/year
Runoff Component	252	acre-feet/year
Baseflow Component	94	acre-feet/year
Direct Precipitation on Lake Surface	130	acre-feet/year
Inflow + Direct Precipitation	476	acre-feet/year
% Inflow	72.7	
% Direct Precipitation	27.3	
Outflow	318	acre-feet/year
HRT Based on Inflow + Direct Precipitation	0.38	year
HRT Based on Outflow	0.56	year