IOWA GREAT LAKES MANAGEMENT PLAN

DICKINSON COUNTY CLEAN WATER ALLIANCE

IOWA DEPARTMENT OF AGRICULTURE AND LAND STEWARDSHIP

Dickinson Soil & Water Conservation District

DNR

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Project Sponsors:
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Dickinson Soil and Water Conservation District

Photo courtesy of Steve Anderson.

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Inter-Lake Association
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Iowa Rural Water Association
Clean Water Alliance
Jackson County Conservation League
Okoboji Protective Association
Silver Lake Park Improvement Association
Spirit Lake Protective Association
Three Lakes Protective Association
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Iowa Lakeside Laboratory
Iowa Natural Heritage Foundation (INHF)
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University of Okoboji Foundation
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Local Governments and Commissions:
City of Arnolds Park
City of Lake Park
City of Milford
City of Okoboji
City of Orleans
City of Spirit Lake
City of Superior
City of Terril
City of Wahpeton
City of West Okoboji
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ABBREVIATIONS

AIS	Aquatic Invasive Species
BMP	Best Management Practices
CLAMP	Cooperative Lakes Area Monitoring Program
CRP	Conservation Reserve Program
CWA	Clean Water Alliance
DNR	Department of Natural Resources
FICMNEW	Federal Interagency Committee for the Management of Noxious & Exotic Weeds
GIS	Geographic Information System
GPS	Geographic Positioning System
HHW	Household Hazardous Waste
IA	Iowa
IDALS	Iowa Department of Agriculture Land Stewardship
IDED	Iowa Department of Economic Development
IGL	Iowa Great Lakes
ILL	Iowa Lakeside Laboratory
ISU	Iowa State University
LiDAR	Light Detection and Ranging
MN	Minnesota
NISC	National Invasive Species Council
NRCS	Natural Resource Conservation Service
SWAT	Strength Weaknesses Assets Threats
SWCD	Soil and Water Conservation Districts
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
USGS	United States Geological Society
WQC	Water Quality Commission

THE IOWA GREAT LAKES WATERSHED
Executive Summary

The Iowa Great Lakes (IGL) watershed is an area of about 87,600 acres (140 square miles) located in northwest Iowa and southwest Minnesota. Approximately 76 percent of the watershed lies within Dickinson County, Iowa and the remainder within Jackson County, Minnesota. The IGL are major recreational lakes for Iowa residents and visitors from adjacent states. Agricultural runoff containing sediment, fertilizers, pesticides, herbicides and feedlot waste negatively affect water quality. Urbanization contributes pollution from stormwater run-off and there are a number of private sewage disposal systems within the watershed area that are improperly installed or maintained.

Little Spirit Lake, Upper Gar Lake, Lower Gar Lake and Milford Creek are listed in Iowa's 1998 impaired waters list. Upper and Lower Gar Lakes, Little Spirit Lake and Milford Creek are listed in Iowa's 2004 list of impaired waters list. Total Maximum Daily Loads (TMDL) are written for Little Spirit Lake and Upper and Lower Gar Lakes. It is also proposed that Emerson Bay on West Okoboji Lake, Center Lake and Marble Beach on Big Spirit Lake be added to the DNR's 2008 Impaired Waters List.

Agricultural land, concentrated urban development, and natural areas characterize Dickinson County land use. There is increasing density of development and redevelopment on lakefront property. The county is also experiencing substantial growth along major transportation routes, and in unincorporated portions of Dickinson County and cities near the lakes.

WATER QUALITY

Surface water in Dickinson County is the single most important reason for the county's current economic prosperity and tourism industry. Dickinson County water resources are an important source of drinking water, recreation, wildlife habitat, and aesthetic enjoyment for residents and visitors. The primary threats to the water quality of the Iowa Great Lakes are sedimentation, excess nutrients, human and livestock waste, stormwater contaminants and loss of natural wetlands. Agricultural runoff contributes contaminants such as sediment, commercial fertilizers, pesticide, herbicides and feedlot effluent. Potential spills of hazardous waste and invasion of aquatic nuisance species are also a concern.

Increased urban development has presented stormwater quality and quantity problems. Urban stormwater runoff carries contaminants such as sediment, excess nutrients, pesticides and herbicides, heavy metals, and road salt. There is increasing pressure on drinking water supplies by the growing permanent population base and an expanding summer seasonal population.

Total phosphorous is considered to be the critical element in the IGL systems. It appears that there is a linear relationship between TP inputs and algal levels so that a halving of the TP input to a given lake might be expected to reduce the algal population by one-half. (Carlson, 2008) There is, of course, a lower limit to this relationship for if all inputs were removed, there would still be phosphorous recycled from the sediments. This appears, however, to be a small amount.

Water quality varies greatly among the lakes in the Iowa Great Lakes region and is affected by a number of different factors. Activities in the watershed dictate the quality of water reaching the lake. The size and depth of the lake also influence the water quality. Large lakes with large volumes of water can dilute nutrients from the watershed. Shallow lakes are susceptible to mixing and disturbance of the bottom sediments which allow nutrients to be released to the water column, while deep lakes don‘t experience as much mixing and stirring of the bottom sediments.

AQUATIC INVASIVE SPECIES (AIS)

Aquatic invasive species cost billions of dollars annually in damage and control measures. Zebra mussels alone are estimated to have cost the United States $750 million to $1 billion from 1989 to 2000. Because of the negative impacts to water quality, economies, and public health, both aquatic and terrestrial invasive species have gained new prominence in federal and state policy. There is increased cooperation among environmental nonprofits, government agencies, and trade organizations to halt or slow the spread of invasive species.

A successful AIS program must include:

- A comprehensive public outreach effort-including but not limited to, facilitated public meetings, distribution of fact sheets, public service announcements, newspaper advertisements, rest area displays, traveler information systems, and gas pump toppers
- Active local partnerships to assist with developing watershed AIS management plans
- Permanent DNR-AIS program staff to conduct public education and volunteer programs
- Seasonal officers to conduct watercraft inspections and on-site public education
- Support for research that identifies pathways to limit the spread of AIS and identifies new AIS control methods
- Education of recreational users (boaters and anglers)

CYANOBACTERIA

Cyanobacteria, sometimes called blue-green algae, are organisms that naturally occur in fresh, brackish, and marine water. Cyanobacteria have many characteristics of bacteria, but they also contain chlorophyll and can photosynthesize like algae and plants. Cyanobacteria often have a blue-green color, which is why they are also called blue-green algae. Cyanobacteria come in many sizes and shapes including microscopic single cells as well as filaments and colonies that are easily visible to the naked eye. Cyanobacteria cause problems in water bodies in several ways. The most severe problem with Cyanobacteria is the toxins the Cyanobacteria can produce. These toxins have been blamed for numerous fish kills, and even the illness and deaths of numerous land species. In addition Cyanobacteria cause a bad taste and odor to water, create a bad smell, and in general cause negative recreational use problems in a water body.

AGRICULTURAL LAND

It has been estimated that an average of 0.91 tons sheet and rill erosion per acre per year of soil occurs in the Iowa Great Lakes watershed using the Revised Universal Soil Loss Equation (RUSLE). Using this model the Iowa Great Lakes Watershed realizes a total average erosion rate of 65,302 tons of sediment per year on the 71,761 land area acres within the watershed of sheet and rill erosion. Each ton of sediment carries with it, nutrients, pesticides, and many other pollutants. The primary concern with sediment, beyond the sediment itself, is the phosphorous it carries.

URBAN

The Iowa Great Lakes pre-historic hydrology was such that up to 50% of the annual precipitation would have infiltrated, and 40% evaporating or transpired by plants and 10% run off into water bodies. Typically, the 10% runoff that has been estimated on the historic landscapes occurred while the ground was frozen. On the other hand, urbanized landscapes generally have runoff rates of up to 50% of any rainfall event and infiltrate only about 15% with the rest evaporating.

In the urban area, the principal concern comes first from construction sites. Those sites typically provide more sediment and pollutants per acre than any other pollutant source in Iowa. After construction is complete, storm water management is key in controlling the amount and type of water that is entering the Iowa Great Lakes nearly directly. Shoreline stabilization and revegetation should be completed where feasible to reduce the potential for shoreline erosion, increase the amount of native aquatic vegetation in the IGL, and decrease the amount of free nutrients that are present in the water bodies. Improperly maintained septic tanks and drain fields offer a significant source of pollution in three areas of the Iowa Great Lakes. The three areas, which offer a significant source of pollution for the Iowa Great Lakes, are Little Spirit Lake, Center Lake, and an area near Emerson Bay State Park. Finally, There are areas where urban storm water is concentrating in areas and creating gullies, in some instances 20 feet deep or more and 40 feet wide. These gullies have formed over years of constant erosion but are a significant source of pollution to the lakes especially in localized areas near the gullies.

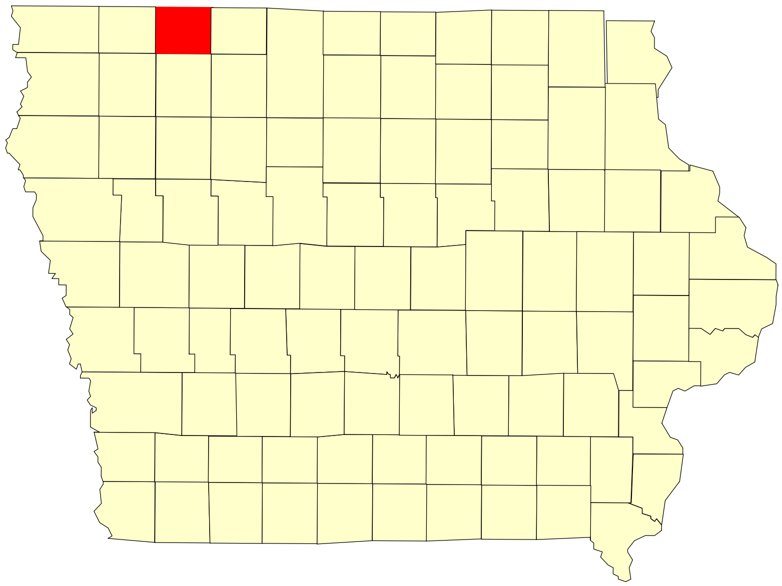
PHOSPHOROUS

Throughout the Iowa Great Lakes Watershed Assessment and Management Plan, a theme will emerge vilifying phosphorous. The primary reason for this is the significance phosphorous plays in producing Cyanobacteria and other single celled algae‘s. It is significant to note that ―one pound of phosphorous can grow up to 1000 pounds of algae and concentrations as low a 0.03 parts per million of total phosphorous will support an algae bloom". (Carlson, 2008) When looking at an additional 378,751 pounds of phosphorous each year into the lake we can assume, using accepted multipliers, that an additional 379 million pounds of algae could be produced in Iowa Great Lakes each year due to the influx of additional phosphorous if none of the phosphorous leaves the lakes. This growth of algae does not include the phosphorous that is already in the Iowa Great Lakes but is rather the ―newly added" phosphorous.

MANAGEMENT PLAN

The IGL are a diverse landscape with many facets that make the area a tough area to manage. The IGL should be managed with the idea that no one management method is the best but rather multiple methods are the desired way. Many conservation measures can and should be employed in protecting the IGL. Those methods should be used on a project by project basis. The key ingredient to success in reducing the pollutant load into the IGL is the use of the practices that reduce pollutants the most in the area they are built or used.

INTRODUCTION



Map 1.1: The Iowa Great Lakes in Dickinson County highlighted in red.

The watershed resources of Dickinson County, Iowa and Jackson County, Minnesota provide an important source of recreation, drinking water and aesthetic enjoyment for residents and visitors. Good water quality is vital to the region's economy and enhances the quality of life for those who live within and visit the area.

Agricultural nutrients, soil erosion, human and livestock waste, stormwater contaminants, urban development and the loss of natural wetlands threaten the water quality of the Iowa Great Lakes. Preventing the potential spread of aquatic invasive species (AIS) into the Great Lakes is a major concern. Other threats include potential spills of hazardous materials.

THE IOWA GREAT LAKES WATERSHED

The Iowa Great Lakes watershed is an area of about 88,167 acres (140 square miles) located in northwest Iowa and southwest Minnesota. Approximately 76 percent of the watershed lies within Dickinson County, Iowa and the remainder within Jackson County, Minnesota. The Iowa Great Lakes are major recreational lakes for Iowa residents and visitors from adjacent states. Agricultural runoff containing sediment, fertilizers, pesticides, herbicides and feedlot waste negatively affect water quality. Urbanization contributes pollution from stormwater run-off and as well as a number of private sewage disposal systems within the watershed area that are improperly installed.

The largest lake within the Iowa portion of the watershed is Big Spirit Lake (5,684 acres), the longest is East Okoboji (approximately 5 miles) and the deepest is West Okoboji (136 feet deep). The watershed also includes several smaller Minnesota lakes, in addition to Little Spirit Lake, Upper Gar Lake, Minnewashta Lake and Lower Gar Lake in Iowa.

The lakes are interconnected and water flows from Spirit Lake and West Okoboji into East Okoboji Lake, and then through Upper Gar, Minnewashta, and Lower Gar into Milford Creek. Milford Creek flows into the Little Sioux River and is the only surface outlet from the Iowa Great Lakes. Little Spirit Lake, Upper Gar Lake, Lower Gar Lake and Milford Creek are listed in Iowa's 1998 impaired waters list. In addition, Little Spirit Lake and Milford Creek are listed in Iowa's 2004 list of impaired waters list. Total Maximum Daily Loads (TMDL) is written for Little Spirit Lake, Upper, and Lower Gar Lakes. It is also proposed that Emerson Bay on West Okoboji Lake will be added to the DNR's impaired waters list.

The center of the watershed lies at the intersection of the principal north-south route through both counties (U.S. Highway 71) and the principal east-west route through Dickinson County (Iowa Highway 9). The two routes meet in the City of Spirit Lake. Dickinson County cities and towns within the watershed include Arnolds Park, Lake Park, Milford, Okoboji, Orleans, Spirit Lake, Superior, Terrill, Wahpeton and West Okoboji.

The Great Lakes Trail system connects communities in the Iowa Great Lakes Region, including Spirit Lake, Okoboji, Arnolds Park and Milford. Residents and visitors use the multi-use trail extensively for nature viewing, hiking, biking and cross-country skiing. Snowmobiling is allowed on some segments of the trail. The Great Lakes Trail currently loops around most of Spirit Lake and there are plans to expand it around the entire lake. There are 60 miles of connecting biking routes, including the Kenue Park Trail, Arnolds Park City Trail and Spirit Lake City trail. In the spring of 2009, the trail will extend to the Minnesota state border, Mini-Wakan State Park, and connect with the trail system in Jackson County, Minnesota.

The lakes within the Minnesota portion of the watershed include Clear Lake, Rush Lake, Pearl Lake, Loon Lake, Chandler Lake, Grover's Lake, and Little Spirit Lake. Little Spirit Lake is listed in Minnesota's 2004 impaired waters list. Loon Lake has been assessed as ―not supporting" recreational or fishing uses.

Interstate 90 passes through Jackson County approximately ten miles north of the Iowa border. The major cities within Jackson County and the watershed include Alpha, Heron Lake, Jackson, Lakefield, Okabena and Wilders. In addition, there are several townships with significant populations.

<u>WATERSHED CHARACTERISTICS</u>

Land Use

The total Great Lakes watershed area encompasses 88,167 acres. Within the watershed, land is used for a number of purposes.

2003 Land use	Acres	%
Row Crop	43,710	49.5
Water (Lakes)	15,381	17.4
Grassland, Grassed Waterways	11,104	12.5
Urban/Residential	5,597	6.3
Hay/Pasture	2,943	3.4
Wetlands	2,422	2.8
Roadways	2,202	2.5
Trees and Tree Plantings	1,808	2.0
Farmsteads	1,712	1.9
Golf Courses	772	.9
Streams or Waterways	256	.3
Salvage yard, Landfill, Quarry	199	.2
Animal Feeding Operations	61	.1

2007 Land use	Acres	%
Row Crop	42,663	47.6
Water (Lakes)	15,392	17.2
Grassland, Grassed Waterways	13,095	14.6
Urban/Residential	5,999	6.7
Hay/Pasture	2,564	2.9
Wetlands	2,538	2.8
Roadways	2,262	2.5
Trees and Tree Plantings	2,220	2.5
Farmsteads	1,658	1.8
Golf Courses	766	.8
Streams or Waterways	243	.3
Salvage yard, Landfill, Quarry	199	.2
Animal Feeding Operations	73	.1

Table 1.1: Land use data for the years 2003 & 2007 as verified by NRCS field office personnel.

Concentrated urban development in the Iowa Great Lakes region and rural areas in the remainder of the county characterize Dickinson County land use. There is increasing density of development and redevelopment on lakefront property. The county is also experiencing substantial growth along major transportation routes, and in unincorporated portions of Dickinson County and cities near the lakes.

In addition to the parks and recreational facilities within the county, one of the state‘s largest publicly owned land tracts is located just east of East Okoboji Lake. The Spring Run Complex is a public wildlife and recreation area that encompasses 3,577 acres. The area is the primary watershed for Lower Gar Lake. The Iowa Department of Natural Resources owns and operates 38 public areas, including Spring Run, encompassing 19,911 acres within Dickinson County.

The county encompasses 243,904 acres, of which 203,000 acres (83 percent) are farmland. According to the 2002 Census of Agriculture, there are 492 farms in Dickinson County. The average farm size is 413 acres, compared to the state average of 350. Agricultural trends indicate the county is moving toward larger farm corporations and fewer family farms. As urbanization continues, more agricultural lands are taken out of production. (US Census Bureau, 2000)

According to the Dickinson County Land Use Development Plan Summary, the County's land use objectives are to ―establish a pattern of land uses that will maximize the safety and welfare of the residents, while considering the protection, preservation, and mitigation of sensitive environmental areas and critical natural habitats." (Dickinson County Comprehensive Planning and Development Plan, 2006)

In Jackson County, significant lakeshore development has occurred around Clear Lake, Loon Lake and Little Spirit Lake. In 1993, Jackson County adopted new shoreline regulations regarding vegetation removal, soil erosion, upgrading of sewage systems, the operation of feedlots, and established a shoreline classification on rivers and streams. There has been some local conflict over establishing acceptable water levels for Clear Lake and Loon Lake.

Land use in Jackson County is expected to remain predominantly agriculture. The county encompasses 458,880 acres, of which 398,068 acres (95 percent) is cropland and pasture. The remainder is urban and recreational development, or wildlife habitat. There is a trend towards larger and more intensive farming in both livestock and grains. Much of the livestock expansion is total confinement operations with storage of manure in concrete pits. Jackson County reviews feedlot permits for location from water bodies and recharge areas, slope, and sites to be used for manure disposal, in order to avoid contamination of surface and ground water. (US Census Bureau, 2000)

Demographics

As of the census of 2000, in Dickinson County, Iowa there were 16,424 people, 7,103 households and 4,759 families residing in the county. The median income for a household in the county was $39,020 and the median income for a family was $47,739. The per capita income for the county was $21,929; 6 percent of the population and 4 percent of families were below the poverty line including, 6 percent of those under the age of 18 and 7 percent of those age 65 and older.

As of the census of 2000, in Jackson County, Minnesota there were 11,268 people, 4,556 households and 3,116 families residing in the county. The median income for a household in the county was $36,746, and the median income for a family was $43,426. The per capita income for the county was $17,499. About 5 percent of families and 9 percent of the population were below the poverty line, including 11 percent of those under age 18 and 8 percent of age 65 or over. (US Census Bureau, 2000)

Climate
The climate of the Great Lakes region is classified as humid-continental. Seasonal temperatures range from highs of 110 degrees Fahrenheit to lows of -40 F, while daily variations may be as much as 50 F. The area receives 28 inches of rain per year. The US average is 37. Snowfall is 33 inches. The average US city gets 25 inches of snow per year. The number of days with any measurable precipitation is 84.

On average, there are 208 sunny days per year in Dickinson County, IA. The July high is around 84 degrees. The January low is four. Our comfort index, which is based on humidity during the hot months, is a 45 out of 100, where higher is more comfortable. The US average on the comfort index is 44. (Sperlings Best Places, 2008)

Two-thirds of the precipitation falls between May and September. Summer precipitation ranges from severe storms to occasional drought. High summer temperatures produce evaporation levels typical of the prairies.

The average frost-free season is approximately 150 days, with a maximum growing season of 225 days from March 29 to November 9. The climate is dry enough to have aided the development of the prairie soils and humid enough to support a highly productive agricultural economy.

Geology
A geological drama occurred 14,000 years ago when the Des Moines lobe of the Wisconsin glacier retreated across the upper Midwest - created a glacial phenomenon that sculpted the earth with unimaginable power and beauty, fashioning the landscape now known as the Iowa Great Lakes Region. With more lakes, wetlands, public land and state parks than any county in Iowa, Dickinson County is arguably the most environmentally diverse in the state.

The geological resources (lakes) of the area are a reason the IGL region has developed as a tourist and recreational area. The geologic history of the area has affected the surface contours of the land; the formation of soil types; location of minerals; groundwater; lake basins; and stream channels. During the ice ages, massive glaciers moved across the region, carrying with them boulders, gravel, sand and clay and organic remains. As the glaciers melted, millions of tons of debris were deposited (glacial drift). The glacial drift forms a 200-to 300-foot cover over the region‘s bedrock.

The glacial drift in the Iowa Great Lakes area was deposited in the Wisconsin Age of the Pleistocene Epoch. The Wisconsin glacier was the last of at least three major ice sheets to cover the area. The Des Moines lobe of the Wisconsin glacier, which originated in the Keewatin District west of Hudson Bay in Canada, pushed down into north-central Iowa across an area 70 to 80 miles wide. As the glaciers receded, the glaciers occasionally left large blocks of ice, which melted and formed basins for future lakes. The rugged bottom of West Okoboji Lake suggests it may have been formed in this manner.

Water from the melting glaciers also cut new drainage patterns in the deposits below the ice. Outwashes of sand and gravel were carried by streams that drained glacial melt and deposited it in the valleys, which the glaciers had formed. The Milford Gravel Flat and Spirit Lake appear to have been formed by a buildup of glacial outwash.

Underlying the glacial drift are shale‘s and sandstone created in the Cretaceous Age. The shale varies in thickness and is several hundred feet thick just north of the northern boundary of the watershed. The sandstones vary in thickness but generally do not exceed the thickness of the shale.

Below the Cretaceous units, data regarding the age of the soil is limited. However, it appears that Ordovician and Cambrian Age sediment underlie the Cretaceous units in the southeastern half of the watershed. A few miles north of the northern boundary there also exists a buried northwest-southeast trending quartzite ridge of Pre-Cambrian Age.

Soils

Heavier textured glacial soils occur within the Great Lakes watershed. The soils are not as erosive as the predominantly lighter textured loess soils found 50 miles to the southwest, but the soils do erode–especially during periods of abnormal rainfall or excessively high winds. Water erosion takes a toll on the steeper lands that are being row-cropped. The flatter land is more subject to wind erosion when it is left over winter without a cover of crop residue.

There are four major soil associations within the watershed. The major and minor soils are listed in order of importance below. Two associations may contain the same soils, but in a different pattern.

Wadena - Estherville

The Wadena – Estherville association consists of soils that are medium to moderately coarse textured, gently sloping (2 to 5 percent). The association developed from glacial outwash is shallow to deep gravel and is calcareous in nature. The soils are prone to drought when sand and gravel are within 15 to 30 inches of the surface. Minimum tillage is an excellent conservation practice to use here, since it retains moisture in the surface soil and slows wind erosion.

Webster - Clarion – Nicollet

These soils occur in a small portion of the watershed; one area is at the northern tip and one at the southern edge. The area is typified by level to gently undulating (0-5 percent slopes) medium and moderately fine textured soils that are developed from glacial till. There may be pond spots and high lime areas.

This has low potential as a sediment producing area because of its gentle slopes. Simple conservation practices such as contouring, strip cropping and minimum tillage are all that maybe needed to keep erosion in check. Occasionally, terraces maybe recommended on steeper slopes.

Clarion – Nicollet - Webster
This association is characterized by gently undulating to gently rolling (2 to 9 percent) slopes. The soils are developed from glacial till and are medium and moderately fine textured. This area is used extensively as farmland. Some steeper slopes and wet areas are in permanent pasture. Conservation measures would include contouring, contour stripping, stubble mulching, and minimum tillage with modified terraces on steeper slopes.

Clarion - Storden – Okoboji
The Clarion soils occupy the greater portion of this association. They are dark brown, loamy, well-drained soils occupying an upland position on gently undulating to steep slopes. The Storden soils occur on the steeper slopes and knobs, usually above the Clarion soils on the landscape. Most of the larger permanent pastures are in the areas of predominately Storden soils, since they are not as well suited to faming operations, as is Clarion. The Okoboji soils are dark, deep and poorly drained. They occupy potholes or small depressions within the association and ordinarily require artificial drainage to be productive farmland.

Conservation measures on this association, principally Clarion and Storden, consist of mulch tillage and terraces. Terracing is usually difficult because of short, irregular slopes. The steeper the slopes the higher the importance is of being converted to permanent pasture. (Dickinson County Soil Survey, 1974)

Topography
The topography of the watershed can be characterized as gently rolling. Lakes and marshlands lie within the hollows of the terrain. Runoff from precipitation drains into the lakes, evaporates, or percolates into the soil where it recharges the groundwater. Water draining into the lakes and streams carry contaminants from the land, which affect the water quality of the lakes.

The watershed area of the Iowa Great Lakes can be divided into five major sub-watersheds, which define the drainage areas for each of the three major lakes plus an extensive area that drains into Lower Gar Lake from the east. Each of the major sub-watersheds is made up of smaller watersheds. Although most of the runoff from the watersheds reaches the lakes due to natural drainage, some runoff is diverted to the lakes by manmade features or modifications of the natural system. Examples are constructed storm sewer outlets, tile lines and drainage ditches throughout the watershed.

Physical Characteristics
Dickinson County is home to 20 natural lakes covering more than 16,000 acres, all of which are public use resources. Although most of the lakeshore acres on these lakes are held in private ownership, there are ten lakeside state parks. The lakes are noted fisheries for game species such as walleyes, northern pike, largemouth and smallmouth bass, yellow perch, crappies and bluegills. Large numbers of anglers from throughout the Midwest travel to Dickinson County each year to sample the fishing. Walleye Weekend,

for example, held annually on the walleye opener in early May, attracts thousands of anglers.

In addition to the natural lakes, Dickinson County has more than 15,000 acres of public land managed by the Department of Natural Resources or about 15 percent of the total land area in the county. These areas consist of shallow natural lakes, natural or restored prairie wetlands, prairie grass uplands, woodlands and meadows. Enjoyed by hunters, anglers, bird watchers, kayakers, canoeists and nature lovers, these public acres add to the environmental allure of the area. About half of the land in Dickinson County remains agricultural cropland, 12% grassland and about 2% woodland. Work continues throughout the lakes watersheds to restore wetlands and other buffers to reduce runoff pollution.

Surface Water

Surface waters consist of tributaries, rivers and lakes that make up the Little Sioux River drainage basin; the Little Sioux River and several tributary streams flow year-round. Most creeks are intermittent and carry water only in periods of heavy rainfall or spring thaw. Runoff corresponds to the annual precipitation rate. The large lakes, small lakes and wetlands make up a unique lake district. The lakes provide municipal drinking water supplies for communities within both Dickinson and Jackson counties.

Dickinson County-Spirit Lake

Spirit Lake is located about one mile north of the center of the City of Spirit Lake, and is the largest of Iowa‘s natural lakes. The lake encompasses 5,684 acres, and is approximately six miles long and three miles wide. Shoreline length is 15.25 miles and average depth is 17 feet, with a maximum recorded of 24 feet. The northern edge of Spirit Lake borders the Minnesota state line and the majority of its watershed lies in Minnesota. There are three state parks—Templar Park, Marble Beach and Minnewashta—and 8 public areas—Trickles, Hales, Anglers, Orleans (two), Orleans Beach, Pump House and Grade—with lake access bordering the shoreline. Forty species of fish, including 13 species of sport fish sought after by fishing enthusiasts, are located within Big Spirit Lake.

Little Spirit Lake

Little Spirit Lake lies on the Iowa-Minnesota border, with approximately 40 percent of the lake located in Iowa. The lake is 618 surface acres in size with an average depth of six feet and a maximum of 10 feet. Since Little Spirit Lake is a border lake, anglers must comply with Minnesota bag limits and fishing seasons as well as Iowa‘s fishing regulations. The lake is on both state‘s impaired waters lists and has an aeration system. There is one public access in both Iowa and Minnesota.

Center Lake

Center Lake is located between the northern halves of West and East Okoboji Lakes, within the City of Spirit Lake. The lake encompasses 272 surface acres with an average depth of 14 feet and a maximum of 17 feet. The entire northeastern shoreline is developed, but public access to the lake remains good, with approximately 25 percent of its 4.7-mile shoreline in timber and wetlands.

This watershed may be protected by using conservation and land retirement programs in the agricultural part of the watershed. In the urban portion, using low impact development practices will protect the lake from urban runoff. Center Lake also has the highest ratio of urban area to agricultural land for its watershed.

West Okoboji

West Okoboji Lake is located southwest of the city of Okoboji and northwest of the city of Arnolds Park. West Lake is the largest of the six interconnected lakes in the Iowa Great Lakes chain, reaching over 3,847 surface acres with an average depth of 38 feet and maximum depth of 138 feet. The lake has 19.8 miles of shoreline. The natural drainage area, or watershed, around the lake encompasses about 13,668 acres.

Public access is provided at Emerson Bay, Triboji, Givens Point, Pillsbury Point, Gull Point, and Pikes Point. West Okoboji Lake was formed as glaciers retreated north. More than 47 species of fish are found in the lake, including 11 species of popular sport fish.

East Okoboji

The City of Okoboji is located on the Western shores of East Lake Okoboji. The lake includes 1,835 surface acres with an average depth of 10 feet and a maximum of 22 feet. Only 6 percent of the 16.8 miles of shoreline is publicly owned; 85 percent of the shoreline is developed. Eleanor Bedell State Park offers access to fishing, camping, picnicking and playground facilities. Additionally, North Park, Iowa DNR Fish Hatchery, East Okoboji Beach, Claire Wilson Park and Hattie Elston Park are public parks in the watershed. The lake‘s watershed encompasses 12,212 acres.

Upper Gar Lake

Upper Gar Lake connects the south bay of East Okoboji Lake to Minnewashta Lake. Upper Gar covers 37 surface acres and is the smallest of the Iowa Great Lakes chain. The lake is essentially a shallow channel connecting two larger bodies of water. The average depth of Upper Gar Lake is only 3.5 feet; it has the smallest watershed with, one boat ramp, and warrants 5-miles per hour speed limit on the lake.

Minnewashta Lake

Minnewashta Lake is the second in a string of the small-interconnected lakes south of East Okoboji Lake. The lake is located within the city of Arnolds Park. The lake is 126 surface acres in size with 2.3 miles of shoreline. Average depth of the lake is 10 feet with a maximum of 16.5 feet. Most anglers fishing Minnewashta are in search of bass and pan fish populations. It is also a small watershed with one boat ramp and two state parks.

Lower Gar Lake

Lower Gar Lake is the southernmost lake in the Iowa Great Lakes chain, but has the largest watershed percentage. The lake is shallow and discharges into Milford Creek at the southwest corner of the lake. Lower Gar encompasses 273 surface acres, but the average depth is only 3.6 feet. There are four public areas on the lake. A dam on the lake holds back water to enable a higher water level.

Minnesota Lakes

Clear Lake

Clear Lake is located 3 miles west of the City of Jackson, Minnesota and is noted as one of the reference lakes for this region. This 451-acre lake has a relatively small watershed of under 1200 acres. Clear Lake has a maximum depth of approximately 10 feet and a 6-helixor aeration unit was installed in 1976. The OHW for Clear Lake is 1503.5 feet and the highest recorded lake level was 1504.3 in July of 1993. The lake is managed for walleye, which are stocked. The lake also has a healthy supply of perch, crappie, and bullhead. Clear Lake has a public access on the north and south side of the lake as well as some county parkland on the west side. Clear Lake is proposed to be on the 2008 MPCA, TMDL list for total phosphorous. (Jackson County Planning and Environmental Services. November 28, 2007)

Loon Lake

Loon Lake is located just one mile north of Big Spirit Lake. This 725-acre lake has a watershed of nearly 20,000 acres or a watershed ratio of 27:1. Loon Lake has a maximum depth of approximately 7 feet and a 9-helixor aeration unit was installed in 1982. The majority of the water drains into Loon Lake by way of either the drainage ditch on the north side or the creek which comes from Pearl Lake into Loon Lake on the west side of the lake. The OHW for Loon Lake is 1406.8 feet. The highest water level was in June of 1993.

Loon Lake is managed for walleye and secondarily for perch and northern pike. Loon Lake has a county park on the east and west side of the lake as well as a large USFWS property on its east side. A residential development, as well as a golf course is located on the north side of the lake. Loon Lake is proposed to be on the 2008 MPCA, TMDL list for total phosphorous. (Jackson County Planning and Environmental Services. November 28, 2007)

Pearl Lake

Located adjacent to the west shore of Loon Lake; this 155 acre lake has a watershed of approximately 7000 acres. Pearl Lake has a maximum depth of approximately 6 feet and a 3-helixor aeration unit was installed in 1987. Pearl Lake does not have an established OHW at this time. The lake is presently managed for northern pike as a primary species while walleye, yellow perch, and black crappie are managed secondarily. Pearl Lake has a county park on its east and west side with very little residential development around the lake. (Jackson County Planning and Environmental Services. November 28, 2007)

Rush Lake

Rush Lake is located immediately to the west of Pearl Lake and serves as a filter for much of the water that enters Pearl and Loon Lake from the west. This 293 acre lake is very shallow with a maximum depth of approximately 3‘. There is very little development around this lake and the only public access is from the Federal Waterfowl

Production Area on the east side of the lake. Rush Lake does not have an established OHW at this time. A 1988 survey indicated populations of perch, northern pike, buffalo, bullhead, carp and suckers were all present in the lake. (Jackson County Planning and Environmental Services. November 28, 2007)

Groundwater Resources

The Dakota sandstone and the Ordovician and Cambrian Age sandstones are the most important of the deep flow systems. The well source in the watershed is mainly from the Dakota sandstone aquifer. The wells in the region average 130-500 feet in depth. The gradient of the groundwater is generally south but local high water levels are found throughout the area following land surface contours. Ground water highs are found below the hills east and west of West Okoboji Lake and east of East Okoboji Lake. Topographic high areas are recharge areas and low-lying marshes and wetlands are discharge areas.

The flow system having direct bearing on the lakes and streams of the area is the shallow system found in the glacial drift. The gradient of the ground water in the drift generally is to the south, but local ground water highs are found throughout the area. The piezometric levels generally follow topographic highs and lows, and ground water highs are found below the hills east and west of West Okoboji Lake and east of East Okoboji Lake. The topographic high areas are recharge areas and the low-lying swamps and lakes are discharge areas. In the areas adjacent to the Little Sioux River, the contour configuration indicates that the river is receiving ground water discharge. The lakes are also receiving base flow from ground water.

The quality of ground water varies throughout the area depending upon location and well depth penetration. The Dakota sandstone and Ordovician and Cambrian Age sandstones typically contain highly mineralized waters. Dissolved solids are found in concentrations exceeding 1000 parts per million (ppm). The water is also very hard with concentrations of more than 700 ppm of total hardness. High sulfates are characteristic of the Dakota sandstone.

Water Use-Dickinson County

Water in Dickinson County is primarily used for public and private water supplies. Public water supplies provide 900 million gallons per year to Dickinson County residents and visitors. Other water usage consists of private use, and farms that accounts for 62 million gallons per year. Irrigation and mining combined account for 83 million gallons per year.

Visitors to the region increase the summer population within the county from approximately 16,424 to more than 100,000 people. The tourist population presents challenges to dealing with public wastewater systems, and raised concerns as early as the 1930s about a need to maintain a pollution-free environment. Currently, the Iowa Great Lakes Sanitary District consists of 95 miles of sanitary sewers, 63 pump stations, and 1 central wastewater treatment facility. The sanitary district has expanded to include more than 23,450 acres, 11,550 acres of which are water.

Partnerships
There are several partnerships, lake associations, local governments, commissions and conservation organizations at work in the county to preserve and enhance the natural resources. Two specific groups coordinate the efforts of all of these groups. They are:

Water Quality Commission (WQC) was established in 2001 to provide a steady funding source, using local money as a match to state and federal revenues for water quality projects for lakes in Dickinson County. This one-of-a-kind organization in the state is comprised of 18 commissioners who represent the county and its ten municipalities. Among the many objectives of the WQC are to bring a minimum of $3 in federal, state and private matching funds for every 1 dollar the local communities contribute to improve water quality. In the first year of operation in 2001, the WQC had a pool of $100,000 to grant to water quality projects to improve lakes in Dickinson County. In each subsequent year, the WQC has administered $200,000 in water quality projects. The 28-E agreement that created the WQC is in effect until 2009, and automatically renews for a two-year period thereafter.

Dickinson Clean Water Alliance (CWA) coordinates the efforts of governmental agencies, non-profit and private organizations through the help of a branch of the Dickinson County Soil and Water Conservation District (SWCD). Its slogan is, "united to keep our lakes alive." The CWA is an uncommon federation of 61 groups working in harmony to protect the water resources of the area. The Dickinson County SWCD and the Iowa Natural Heritage Foundation, the area lake protective associations and the Iowa DNR, formed the CWA in 1990. It continues to coordinate activities for water quality.

Lake protective associations cover all the major lakes in the county with similar missions to protect and enhance water quality for the lake in which they were formed. The oldest of these is the Okoboji Protective Association, which celebrated its 100th anniversary in the summer of 2005.

The Iowa Great Lakes Water Safety Council (WSC) is unique among the non-profit public service organizations because it concerns itself with both water safety and clean water issues. In its short history, the WSC played a large role, for instance, in the passage of a state law raising boat registration fees, providing funds for water safety, and the prevention of invasive species projects.

Iowa Lakeside Laboratory (ILL) is a year-round environmental education facility with over 40 buildings on a 143-acre campus on West Lake Okoboji. Classes held at the lab serve numerous students from various universities throughout the Midwest. University of Iowa botany professor, Thomas MacBride, founded ILL in 1908. He wanted to establish an onsite scientific research facility in the lakes area, which he said supported the most diverse environmental habitats in Iowa.

The Iowa DNR Northwest Regional Headquarters houses the Spirit Lake Fish Hatchery, and is the only cool water hatchery in the state. This hatchery is noted for its walleye, northern pike, and muskellunge production, which help to sustain healthy game fish populations in the lakes, streams, and reservoirs of Iowa. The DNR regional headquarters also has offices dedicated to the management of fisheries and wildlife resources in NW Iowa and the research of Iowa‘s natural lakes.

The area continues to urbanize with construction of larger summer homes and condominiums and the associated recreational and service facilities, such as golf courses, strip malls, and restaurants. The long-range strategic plan developed by the Alliance has identified four main watershed goals for the Great Lakes area:

- Native biological diversity is respected and encouraged
- Infiltration practices are promoted throughout the watershed
- Impaired waters are protected and improved
- High quality waters are maintained and improved

The Alliance recognizes that a successful watershed approach to protecting and enhancing the water quality in the Great Lakes region requires clearly identifying needs and goals, selection of management alternatives based on good science, and a genuine stakeholder partnership. The Alliance promotes a voluntary conservation program driven by landowners, lake and park users, and public and private organizations that will reduce or prevent negative impacts to water, land, and economic resources within Dickinson County.

TOURISM

For more than 100 years, the Iowa Great Lakes area has been the ideal destination for family vacations. Truly, a recreational haven, the Iowa Great Lakes are rich in heritage and abundant in leisure activities. Visitors of all ages are drawn to the blue lakes, the sunshine and the fun times of Okoboji. (Vacation Okoboji, accessed May 4, 2007)

Dickinson County, with a population of 16,424 is known as a growing, progressive area in Iowa. During the summer, the population often swells to over 100,000 people especially on the weekend. There are typically over one million visitors to the IGL each year. It offers a wonderful place to live and work, but for many a vacation destination. There are more people here in the summer months than other times of the year, but many locals will tell you how much they love the quiet beauty of the off-season. In addition, some perceptive visitors are just beginning to appreciate the area's natural beauty year around. Many vacationers have ended their status as 'area visitors,' deciding not to fight Okoboji fever any longer and simply move here! (Vacation Okoboji, accessed May 4, 2007)

Regardless, tourism has proven itself as a major component of Iowa‘s economy, in the last decade. In 2006, it generated an impressive $5.4 billion in direct spending, while improving the quality of life for our citizens. The Iowa Great Lakes are a major piece of the tourism puzzle especially for Northwest Iowa.

The Iowa Great Lakes serve as the major recreational lakes for Iowa Residents and visitors from adjacent states. The main attractions of the Okoboji area are the glacier-carved lakes. This beautiful chain of lakes extends from the Minnesota border southwest several miles and covers about fifteen thousand acres. The Iowa Great Lakes include Iowa‘s largest natural lake, Spirit Lake and five interconnected lakes: West Okoboji, East Okoboji, Upper Gar, Lower Gar and Minnewashta. Spring-fed West Lake Okoboji is a beautiful shade of blue and 134' deep. It is the centerpiece of the five chain lakes, and the surrounding communities provide the backdrop for Okoboji‘s year around playground. (Vacation Okoboji, accessed May 4, 2007)

The total Great Lakes watershed area encompasses 88,167 acres, two percent of which is primarily used for recreational/tourist activities. (See Map 2.1)

Photos 2.1 & 2.2: Trails at the Iowa Great Lakes.
Photo courtesy of Vacation Okoboji Magazine, 2007.

Recreational possibilities for tourists include the 20-mile long Great Lakes Trail that connects communities in the Iowa Great Lakes Region, including Spirit Lake, Okoboji, Arnolds Park and Milford. This is the only independent county trails commission in Iowa. The multi-use trail is extensively utilized for nature viewing, hiking, biking and cross-country skiing. Snowmobiling is allowed on some segments of the trail.

Photo 2.3: Trails at the Iowa Great Lakes.
Photo courtesy of Vacation Okoboji Magazine, 2007.

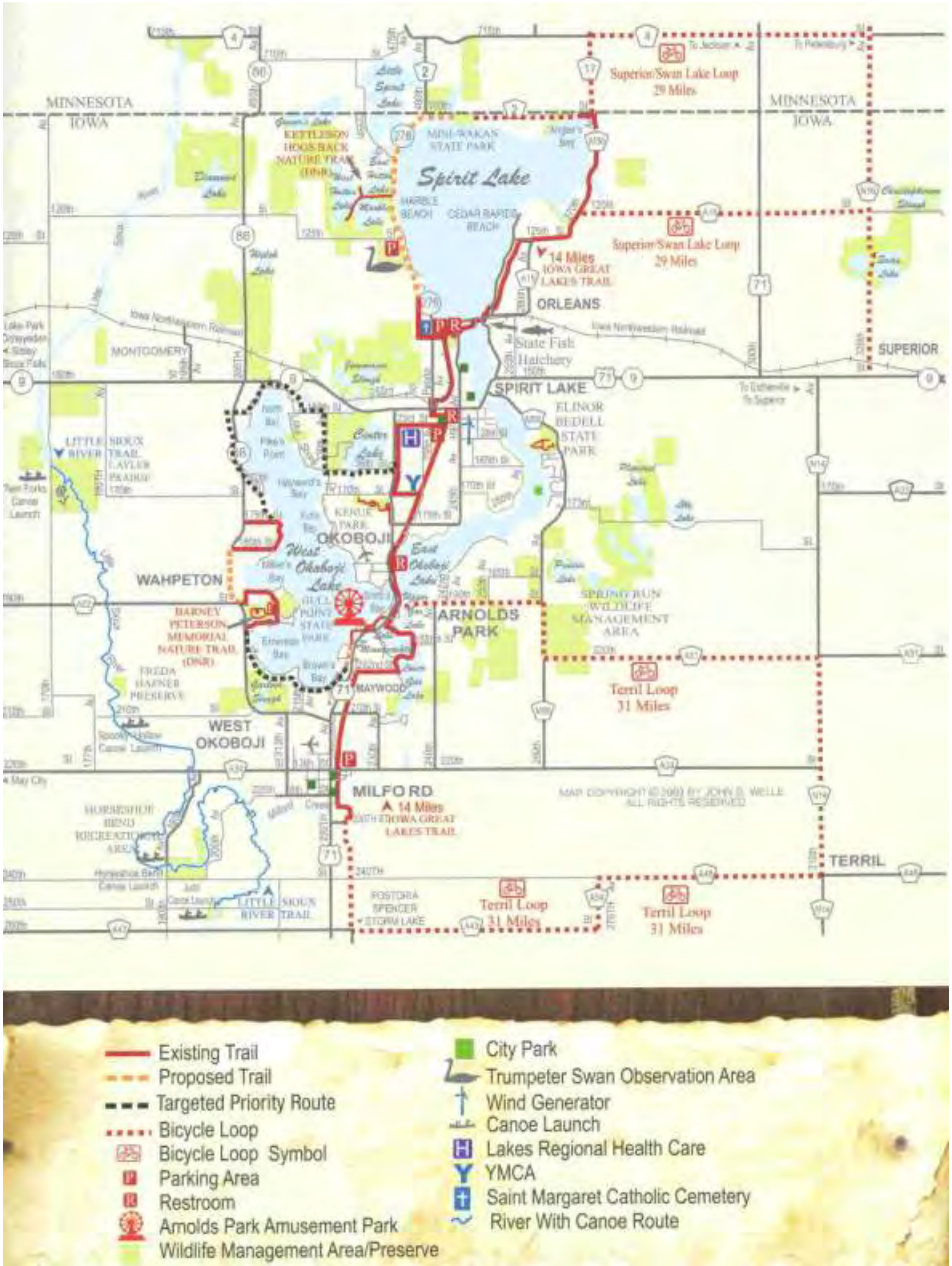
The Great Lakes Trail currently loops around the east side of Spirit Lake, and plans are to continue the expansion so the trail provides access to the entire lake. There are 60 miles of connecting biking routes, including the Kenue Park Trail, Arnolds Park City Trail and Spirit Lake City trail. In the spring of 2007, the trail will extend to the Minnesota state border and Mini-Wakan State Park. Construction has continued on the west side of West Lake Okoboji. Plans are to connect over 200 miles of trails in the lakes region.

Dickinson County tourism activities include:

- Iowa Rock N Roll Hall of Fame
- Iowa Great Lakes Maritime Museum
- Higgins Museum of Banking
- Okoboji Yacht Club Sailing School
- Grand National Walleye Cup (GNWC) Fishing Tournament
- Iowa State Fish Hatchery
- Iowa Lakeside Laboratories
- The Queen II Excursion Boat
- The Abbie-Gardner-Sharp Cabin and Spirit Lake Massacre Monument
- Dickinson County Museum
- The Annual Okoboji Winter Games
- Arnolds Park Amusement Park
- The Ranch Amusement Park
- Okoboji Summer Theater (50 years old)
- Treasure Theater (children's theater)
- Lakes Art Center
- Bridges Bay (indoor water park)
- Emerald Hills Golf Club
- Brooks Golf Club
- Inn Golf Course
- Okoboji View Golf Course
- Woodlyn Hills Golf Course
- Indian Hills Golf Course

Furthermore, located within Dickinson County are the following tourism related businesses, according to information obtained from the Okoboji Tourism Committee:

- 37 resorts or lodging facilities
- 15 campgrounds or camping facilities
- 11 recreation/tourism based businesses
- 45 restaurants or eateries



Map 2.1: Courtesy of Vacation Okoboji Magazine, 2007, p 45.

Photo 2.4: The Queen. Photo courtesy of David Thoreson, Blue Water Studios and Okoboji Tourism Committee

The Iowa Great Lakes Chamber of Commerce and Okoboji Tourism Committee work together to create an atmosphere in support of the businesses and professionals necessary to stimulate a growing and prosperous lakes region. Specifically, Okoboji Tourism Committee is responsible for organizing annual tourism generating events such as the Walleye Weekend (1st weekend of May), Okoboji Winter Games, the Memorial Day ―Wing Ding” and the Couples Golf Event. Each of these events and many more, are intended to and successfully draw in millions of tourism dollars through increased visitors to the area. Furthermore, the Iowa Great Lakes Chamber of Commerce and Okoboji Tourism also assist the Okoboji Foundation with some of their fundraising and recreational events in Dickinson County. Other popular ‗night-life‘ activities include stopping at one of eateries on the lake, which includes the Barefoot Bar, Ritz, Wharf, and the Emporium. Additional information regarding other benefits and programs offered through the Great Lakes Chamber of Commerce can be obtained through the chamber‘s website (www.vacationokoboji.com).

Photo 2.5: Fireworks over Lake Okoboji. Photo courtesy of David Thoreson, Blue Water Studios and Okoboji Tourism Committee

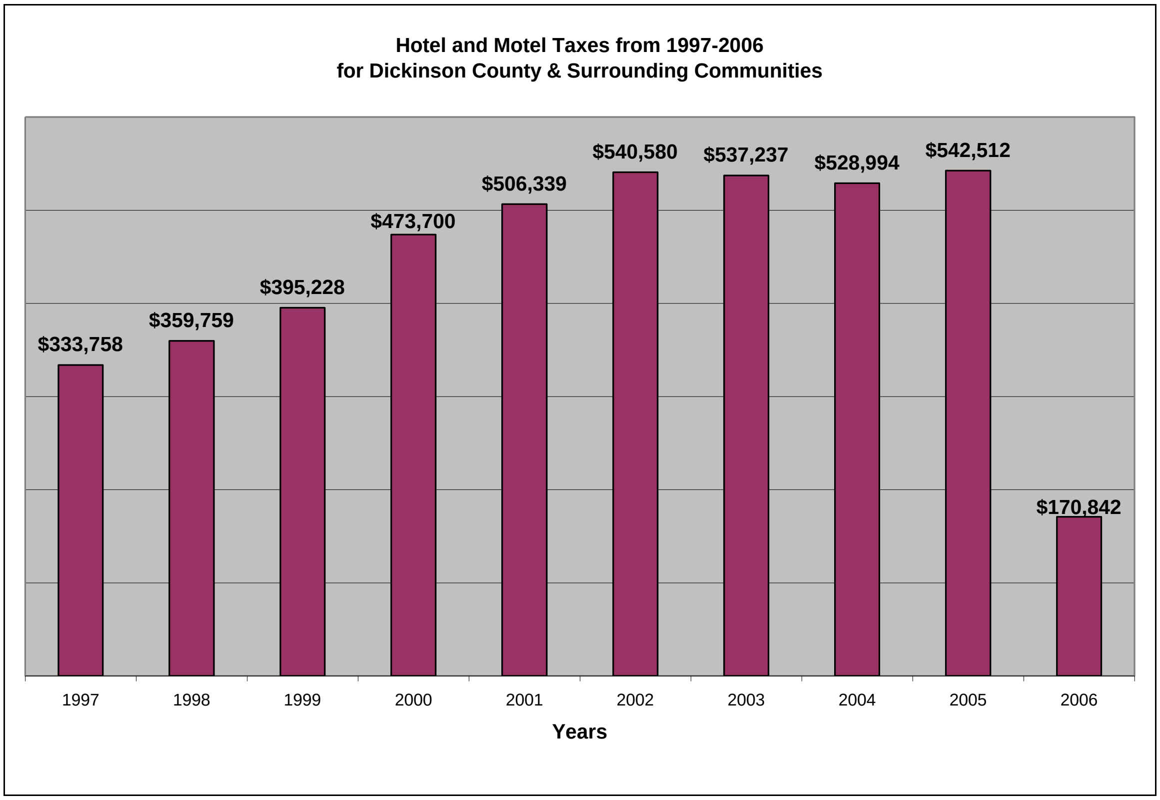
Aside from the natural lakes themselves, probably the most widely recognized and visited destination in Dickinson County is the Arnolds Park Amusement Park complex, including the Maritime Museum, Queen II excursion boat, and the Iowa Rock N Roll Hall of Fame. The amusement park itself is a collection of 17 unique rides, including the legendary wooden roller coaster. There is a miniature golf course, a go-kart track, many games, souvenir stands, food vendors, the Tipsy House, mirror maze, caricature artist, and many other fun and eclectic activities to entertain the young and adventurous.

Photo 2.6: Fillenwarth Beach, circa 1950. Photo courtesy of www.fillenwarthbeach.com.

Also as part of the Arnolds Park Amusement Park campus, visitors and patrons will be entertained through the numerous concerts held at the Roof Garden venue or at the State Pier on the green space or ―preservation plaza." In addition to visiting the maritime Museum, the Iowa Rock N Roll Hall of Fame or catching a ride on the Queen II excursion boat, one can shop at the Queen's Court or enjoy an afternoon of relaxation at the Arnolds Park public beach.

Photo 2.7: Fillenwarth Beach, Okoboji. Photo courtesy of www.fillenwarthbeach.com.

Research compiled by the Travel Industry Association of America indicates tourism was a $173.18 million dollar industry in Dickinson County in 2005. The tourism industry creates $25.38 million dollars in payroll affecting 1,770 employees throughout the county. It also creates $10.41 million dollars in state tax receipts and $3.6 million dollars in local taxes. Since 1997, according to the hotel/motel taxes collected, the Lakes-area tourism has experienced steady growth (See G 2.1).



Graph 2.1: shows the change in hotel & motel taxes in the past ten years. (Note 2006 reflects the first and second quarters only.) Spirit Lake Main Sail, Chamber of Commerce.

While it is interesting to know what tourist spend in a year or even in a decade, we should also know in which venue the tourism dollar is spent. With this information, we can better cater the tourism industry to what tourist need, want, and require for a fulfilling vacation.

Visitors to the region increase the summer population within the county from approximately 20,000 to more than 100,000 persons. The tourist population presents challenges in dealing with public wastewater systems. These concerns were raised as early as the 1930's with a need to maintain a pollution free environment. The increase in tourism has created a demand on water resources for recreational purposes and housing development.

2005 Average Daily Spending by Travelers in Iowa		
Lodging	$	59.97
Food	$	47.36
Transportation	$	48.90
Entertainment	$	27.32
Retail	$	25.00
TOTAL	**$**	**208.55**
The average travel party in Iowa spends a total of $208.55 daily		
Source: 2005 Welcome Center Survey, IDED, Tourism Office		
Average Travel Party is 2.6 people		

Table 2.1: 2005 Average Daily Spending in Iowa

While tourism is a prosperous industry for the lakes, the increase of boat traffic also carries an immediate affect and the potential for degraded water quality increases due to four factors.

In dealing with boat fuel, we realize that resort owners are very careful when they fill up boats at their on lake fuel pumps, however many people bring fuel from other sources to avoid the marine tax. There is a need to educate boat owners on how fuel spills could be harmful to water quality. The insurance companies who insure the resorts have very tough standards on shut offs from the tanks to the hoses in case of emergency. The resort owners who sell fuel on our lakes say they are inspected yearly on the conditions of the tanks, hoses, and all shut offs.

Human waste in the Iowa Great Lakes is a major factor and one of the greatest achievements was the construction of the IGL Sanitary Sewer District. Direct input of human waste will have a negative effect on the quality of our lakes. As the size of boats increase in size, it leads to more people per boat for an increased amount of time enjoying the water. While these increases may seem insignificant, the result is an increase of waste to the lake.

Many new boats have sealed toilet systems where wastes is collected and then can be dumped at several of the marine businesses who offer the service of pumping human waste directly into the sanitary sewer. However, there are boats that do not have this type of sanitary system. For the owners of these boats, education is necessary! The owners of these boats need to be informed of the sanitary systems available to them. Their waste needs to be dumped into the sanitary system when they get on shore, not in the lake water.

With increased tourism and boat traffic, boats and personal watercraft are traveling along the shoreline. What may seem like fun to a boater actually has the potential to degrade water quality. When boaters travel fast in the shallow areas of the lakes the prop tends to stir up the bottom of the lakes resulting in sediment being suspend in the water. Further education and more strict boat laws will aid in a reducing this third factor.

The increasing size of large resorts and condominiums has the potential to cause severe problems in the future. The loss of smaller (family owned) resorts to large resorts and condominium development has increased the number of boat docks and increased the number of permanent boats with access to the lake. This increase in the number of permanent boats has allowed more boating traffic easier access for greater lengths of time.

The current threat of Aquatic Invasive Species (AIS) such as Eurasian Water milfoil, zebra mussel, Asian carp, and other AIS is a major factor, which is influence heavily by tourism. AIS are brought to new locations on boat trailers, in bilge pumps, and other hidden locations of boats. AIS is easily controlled as long as those people who are traveling clean their boats and trailers prior to going to a new lake.

While there are positive aspects of a tourist-based industry it is important to understand and realize what the impacts are on the environment and the lakes. The increase in new and bigger houses has resulted in an increase in density of development and redevelopment on lakefront property. The housing boom is one of the largest impacts that the Lakes have experienced as a tourist community. Other possible negative aspects of tourism include,

1. increase in litter and waste
2. overall use of the lakes
3. overall use of parks
4. increase in noise and pollution

Change should not be feared but we should become more prepared to accept the changes that come. An analogy of how our tourism season has changed is a summer porch that is remodeled into a three season porch and finally into a year-round family room. Tourism will be spread out over a much more extended time and we will not see quite the congestion that we have now. That will be good for our economy and possibly for the ecology of our lakes.

If we have learned anything from our past, it should be known that changes and setbacks are inevitable. As long as our beautiful lakes draw people here, the area will be a vacation destination in the future. Tourism is the key to the economic sustainability of the Iowa Great Lakes area and could be a key in the lakes protection. Protection of the Iowa Great Lakes takes a strong financial commitment and with money coming in it is easier to find money to protect these lakes. The Iowa Great Lakes must be protected in so they may be enjoyed now and in the future.

WATER QUALITY

INTRODUCTION

Surface water in Dickinson County is the single most important reason for the county's current economic prosperity and tourism industry. Dickinson County water resources are an important source of drinking water, recreation, wildlife habitat, and aesthetic enjoyment for residents and visitors. Because of the importance of surface water to the county and its residents, there are many individuals, groups and organizations currently working to educate residents and businesses in the area about protecting water quality.

Dickinson County encompasses some of Iowa's most unique natural resources and environmentally sensitive areas. One of Iowa's largest publicly owned tracts of land is located just to the east of East Okoboji Lake, Minnewashta Lake, and Upper and Lower Gar Lakes. The Spring Run Complex is a public wildlife and recreation area of more than 1,600 acres and serves as the primary watershed for the lakes listed above.

Photo 3.1: Body of water at the Iowa Great Lakes. Courtesy of the Dickinson County 2006 Comprehensive Land Use Plan.

The prairie potholes and marshes adjacent to the lakes are ground water recharge areas, and serve as a natural filtration system for the Iowa Great Lakes (IGL) by filtering and capturing contaminants carried in stormwater runoff, and infiltrating runoff from surrounding developed land. In the past, wetlands have been drained in favor of agriculture and urban developments, but it has more recently been recognized that wetlands are an integral part of a complex ecological system. In addition to the parks and recreation activities within Dickinson County, the wildlife and natural areas provide wildlife habitat and opportunities for walking, hiking, and bird watching.

The primary threats to the water quality of the Iowa Great Lakes are sedimentation, excess nutrients, human and livestock waste, stormwater contaminants and loss of natural wetlands. Agricultural runoff contributes contaminants such as sediment, commercial fertilizers, pesticide, herbicides and feedlot effluent. Potential spills of hazardous waste and invasion of aquatic Invasive species are also a concern.

Increased urban development has presented stormwater quality and quantity problems. Urban stormwater runoff carries contaminants such as sediment, excess nutrients, pesticides and herbicides, heavy metals, and road salt. There is increasing pressure on drinking water supplies by the growing permanent population base and an expanding summer seasonal population. Good water quality is vital to the region‘s economy and quality of life for those who visit or live within the area.

The 2006 Dickinson County Comprehensive Land Use Plan identifies several goals and objectives regarding protecting water quality and other valuable natural resources. The following Natural Resource/Conservation Land Use Policies are to be used when considerations are given toward environmentally sensitive areas in Dickinson County:

1) Recognize that Dickinson County contains many natural areas that must be protected from urban development, and provide measures within the zoning ordinance to accomplish this task.

2) Recognize that urban development is acceptable when adjacent to some environmental areas, but at the same time establish construction provisions to preserve environmental features.

3) Preserve flood plains and wetlands that are typically not suited for urban development. This would also include protection and preservation of those sensitive natural areas that include hydric soils.

4) The best preservation of environmentally sensitive areas lies with public ownership, but in the best interest of the county tax structure, preservation through limited agricultural zoning districts that leave these lands in private ownership may be advisable.

5) Encourage the conversion of all abandoned waste disposal sites and excavation areas to recreational areas or other available alternatives.

6) Guide urban development to areas where soil characteristics are compatible with such development and consider construction techniques to overcome soil limitations.

7) Develop a stormwater management control agency/a storm water district, which would be responsible for the control and management of storm water runoff through the county and implement a countywide management plan.

8) Update silt control ordinances in zoning and subdivision ordinances.

9) The County should weigh the benefits versus the effects of establishing a dredging program for specifically Minnewashta and Lower Gar Lakes for enhancement of all lake resources. Direct consultation and oversight from the IDNR is mandated in this endeavor.

10) Establish policies or ordinances to promote the capture or recycling of storm water.
11) Explore the potential and feasibility of designating –environmental zones" to outline and subsequently protect naturally sensitive environmental areas.

12) A plan and program should be incorporated to map and identify all sensitive natural resource areas within the Iowa Great Lakes watershed and throughout Dickinson County.

(Dickinson County Comprehensive Planning and Development Plan, 2006)

<u>WATER QUALITY STUDIES</u>

An overview of water and nutrient budget information for the IGL obtained during three publicly funded water quality investigations is presented in the following paragraphs. The information is intended to provide a summary of the purpose and scope of the projects, and a general discussion of the results and findings. Content is credited to the appropriate authors.

"A Management Plan for Water Quality of Iowa Great Lakes"

Background

In 1970, three IGL lake associations began a comprehensive study of water quality in the lakes and their watersheds. The lake associations and primary businesses and industries in the area contributed financing. Many local volunteers agreed to contribute services to the program.

The Dickinson County Board of Supervisors subsequently received a federal grant from the Water Quality Office of the Environmental Protection Agency in 1971, and hired Hickok and Associates to coordinate the activities of the many agencies involved in the study and evaluate the data being collected. The Board of Supervisors also appointed a seven-person committee to administer the program, which included representatives from the Okoboji Protective Association, East Okoboji Lakes Improvement Corporation, Spirit Lake Protective Association, Dickinson County Extension Service, Dickinson County Regional Planning Commission, Dickinson County Soil Conservation District, and Jackson Planning Commission.

The study was conducted from March 1, 1971 to December 31, 1972 in order to evaluate long-term trends, identify sources of pollution, and provides the basis for developing an overall pollution abatement and water quality improvement plan. Potential issues included urban drainage, agricultural runoff, land use, sanitary sewage, and institutional and financial difficulties. For a complete review of data collection, data analysis, and results and findings see *Management Plan for Water Quality in Iowa Great Lakes,* submitted by Hickok and Associates to the Dickinson Board of Supervisors, February 1974. (Hickok and Associates, 1974)

Hydrologic Budget

Available hydrologic data in the IGL watershed were adequate only for an approximate, generalized hydrologic budget determination. Long-term precipitation records were available from the Iowa Lakeside Lab Station on West Okoboji Lake. Lake level records for Spirit Lake and Lower Gar Lake were initiated in 1971. However, approximate flows were determined for these areas by extrapolating from lake stage records and existing stream flows.

Hydrologic budget year calculations were related to the IGL region water year, which begins on October 1 and ends on September 30. This was done to recognize the effect snow and frost have on the precipitation - runoff relationship. For the IGL area, a water year starting about December 1 would more nearly approach the desired objective of reducing carry-over of substantial quantities of stored water from one water year to the next. A water year coinciding with the calendar year was chosen for this study for ease of understanding and with due recognition that runoff observed in the spring may occasionally contain precipitation that occurred during the previous year and was stored in the form of snow during the winter.

Hydrologic Budget Summary
Based on the 1971 stream flow measurements and corresponding lake level stages, a stage discharge correlation was established. In general, a rise in the lake level and eventual overflow at the outlet of the respective basins correlated with greater than average precipitation. However, the correlation is not a direct ratio since temperature, precipitation rates, intensities and antecedent moisture conditions play an important role in determining distribution of water in the hydrologic cycle.

Nutrient Budgets
A sampling program was established to estimate the annual inputs of phosphorous and nitrogen into the IGL. Beginning March 1, 1971, tributary streams were sampled about once a week if there was measurable flow. Orthophosphate phosphorous, nitrate nitrogen nitrite nitrogen, and ammonia nitrogen levels were determined. Beginning in September of 1971, total phosphorous concentration was also analyzed. This entire report is based on concentration of total phosphorous or TP. Volume of flow was estimated by determining the average width and depth of each stream to find the cross-sectional area. The average velocity was estimated by timing a small float over a measured distance, and the two values were multiplied together to obtain flow in cubic meters per second.

The analysis covered by this report is separated into two periods: March 1, 1971 to February 29, 1972, and March 1, 1972 to December 31, 1972. Since spring runoff usually does not start until after March 1, and most of the annual runoff occurs before December, these two periods are good approximations of the annual nutrient inputs for the calendar years 1971 and 1972. Total phosphorous, nitrate-N, and ammonia-N concentrations in mg/l were determined for 750 stream samples.

The total of each of the nutrients delivered by each of the streams was calculated by multiplying the concentration of the nutrient by the volume of flow. This was repeated for the next sampling date, and the average value for the two dates was multiplied by the number of days between samples. Since flows were in cubic meters per second, the result was multiplied by the number of seconds in a day. This was done for each of the two years, and the increments were then totaled to arrive at an annual input of TP, nitrate-N, and ammonia-N.

In the watersheds of each lake, the metered streams covered only a portion of the total watershed area. In order to estimate inputs from the non-metered area, the total input from the metered areas was multiplied by the area of the un-metered portion and divided by the area of the metered portion. The sum of the metered and un-metered watershed inputs represented the total annual input of the respective lakes. Since USGS had not released the flow data for the stream that flows from Loon Lake to Spirit Lake, it was not possible to complete the 1972 calculations for that lake. For the same reason, it was not possible to calculate the loss from Spirit Lake into East Okoboji Lake, nor the loss from Lower Gar Lake into Milford Creek.

Rural septic tanks, feedlot runoff, soil erosion, and soil nutrient leachates were contributors to the results and analysis of the monitoring studies of the metered watersheds. The exact quantities contributed by each of these factors was not determined because it was beyond the project scope, however, correlation analysis of the results with the various parameters was conducted. Total phosphorous in urban stormwater runoff from developed areas were determined from the results of monitoring stormwater runoff during several storms at several points in the system (Table 1). Urban inputs were analyzed separately and as a component of the other sources (Tables 2, 3, 4 and 5).

Since Upper Gar and Lake Minnewashta are connected to East Okoboji and have no tributary streams flowing into them, they were combined with East Okoboji Lake. Lower Gar is connected to this system but is being treated separately using only inputs from its own watershed. In general, the inputs of TP and ammonia-N were greatest in 1971, which was also a year of high stream flows. The nitrate-N concentrations were about the same for both years.

The nutrient budget includes groundwater contributions, stormwater contributions, and rainfall contributions. Groundwater input is based on an estimated inflow of three inches per year over the lake surface with a TP concentration of 0.02 mg/l. Between August of 1971 and October of 1972, analyses were made of 17 rainwater samples. They had the following average concentrations: 0.05 mg/l TP, 0.29 mg/l nitrate-N, and 0.56 mg/l ammonia-N.

Lake	Total Phosphorous (kg)
Big Spirit Lake	249
West Okoboji Lake	1,058
East Okoboji Lake, Lake Minnewashta, Upper Gar Lake	826
Lower Gar Lake	28

Table 3.1. Estimated TP Input from Urban Stormwater Runoff

Source	Total Phosphorous (kg)		Nitrate-N (kg)		Ammonia-N (kg)	
	1972	1971	1971	1972	1971	1972
Metered Watersheds	2,781	1,804	31,564	24,188	9.777	2,370
Un-metered Watersheds	1,534	995	17,406	13,338	5,392	1,307
Subtotal	4,315	2,799	48,970	37,523	15,169	3,677
*Other Sources	1,142	1,116	3,263	3,113	6,953	6,662
Total	5,457	3,915	52,233	40,636	22,122	10,339

Table 3.2. Nutrient Inputs to East Okoboji Lake, Upper Gar Lake, and Lake Minnewashta *Includes urban runoff, groundwater and nutrients from precipitation.

Source	Total Phosphorous (kg)		Nitrate-N (kg)		Ammonia-N (kg)	
	1972	1971	1971	1972	1971	1972
Metered Watersheds	630	680	6,140	9,349	1,072	1,948
Un-metered Watersheds	100	108	976	1,486	329	310
Subtotal	730	788	7,116	10,835	5,401	2,258
*Other Sources	74	70	416	395	579	537
Total	804	858	7,532	11,230	5,980	2,785

Table 3.3. Nutrient Inputs to Lower Gar Lake
*Includes urban runoff, groundwater and nutrients from precipitation.

Source	Total Phosphorous (kg)		Nitrate-N (kg)		Ammonia-N (kg)	
	1971	1972	1971	1972	1971	1972
Metered Watersheds	1,472	736	22,555	23,609	3,052	1,569
Un-metered Watersheds	1,709	854	26,183	27,407	3,543	1,821
Loon Lake Outlet	2,011		15,206		13,525	
Subtotal	5,192		48,738		20,120	
*Other Sources	1,153	1,079	8,027	7,599	9,992	9,166
Total	6,345		56,765		30,112	

Table 3.4. Nutrient Inputs to Big Spirit Lake *Includes urban runoff, groundwater and nutrients from precipitation.

Source	Total Phosphorous (kg)		Nitrate-N (kg)		Ammonia-N (kg)	
	1972	1971	1971	1972	1971	1972
Metered Watersheds	1,441	497	14,716	13,324	3,743	1,452
Un-metered Watersheds	566	195	5,782	5,235	1,471	570
Subtotal	2,007	692	20,498	18,559	5,214	2,022
*Other Sources	1,700	1,648	6,235	5,931	11,210	10,609
Total	3,707	2,340	26,733	24,490	16,428	12,631

Table 3.5. Nutrient Inputs to West Okoboji Lake. *Includes urban runoff, groundwater and nutrients from precipitation.

Critical Nutrients
The hypothesis that the annual input of plant nutrients is a major factor in determining the standing summer crop of plankton algae in the IGL was tested. The summer standing crop for each lake in each year was estimated as the average chlorophyll a value for samples taken June through September. The nutrient input was taken as the total amount of TP and inorganic nitrogen entering the lakes divided by the volume of the respective lakes to yield a potential concentration.

The period for each year extended from March 1 through July 31 on the assumption that nutrients entering after that time would not contribute to summer bloom. In 1971 about 95%, and in 1972 about 68% of the measured flow of the tributary streams occurred in the above period. These percentages were applied to annual inputs of TP and nitrogen for each year to arrive at the nutrient incomes for those periods (Table 7).

Several things were noted. First, the order of the lakes with respect to summer chlorophyll a concentrations is the same as the order of the potential concentrations of TP and inorganic nitrogen (Table 6). Second, the concentrations of both the plant pigments and nutrients were higher in 1971 than 1972. There was a highly significant correlation between the concentrations of chlorophyll a and the potential concentration of TP. A similar calculation using inorganic nitrogen also produced a highly significant relationship. The ratio of nitrogen to TP in the inputs to the lakes ranges from 13.3:1 to 25.3:1, which is similar to the ratio in which these elements are found in planktonic algae (about 15:1).

Lake	**Chlorophyll a** mg/m^3	**Potential TP** mg/l	**Potential Inorganic N** mg/l
1971			
West Okoboji Lake	5.70	0.010	0.133
Spirit Lake	57.89	0.046	0.616
East Okoboji Lake	169.84	0.184	2.73
Upper Gar Lake	135.06	0.184	2.73
Lake Minnewashta	160.86	0.184	2.73
Lower Gar Lake	338.54	0.439	7.51
1972			
West Okoboji Lake	3.42	0.003	0.076
Spirit Lake	9.44	*	*
East Okoboji Lake	107.50	0.085	1.25
Upper Gar Lake	93.31	0.085	1.25
Lake Minnewashta	74.85	0.085	1.25
Lower Gar Lake	123.41	0.339	5.63

Table 3.6. Average summer concentrations of chlorophyll a for the IGL. Potential concentrations of TP and inorganic N calculated from total amounts added up to July 31, divided by the volumes of the respective lakes. *Flow records not available at time of analysis

Total phosphorous is considered the critical element in the IGL systems. It appears that there is a linear relationship between TP inputs and algal levels so that a halving of the TP input to a given lake might be expected to reduce the algal population by one-half. There is, of course, a lower limit to this relationship for if all inputs were removed, there would still be phosphorous recycled from the sediments. This appears, however, to be a small amount.

Watershed Factors Associated with Nutrient Inputs

It was noted in the study that there were differences in the nutrient concentrations between streams. A statistical procedure was conducted to determine if the differences were due to differences in land use practices in the respective watersheds. In setting up the analyses, it was assumed that the amount of a particular nutrient would be proportional to the size of that watershed. It was further assumed that the quantity of each nutrient delivered per unit area in kilograms per hectare (kg/ha) could be expressed in a linear relationship. A positive value would indicate an increase in nutrient loss from that land use, and a negative value would indicate a decrease in nutrient loss.

Land use categories included row crops, pasture, urban uses, marshlands, and animal units. For TP, the only watershed factor that could be correlated with differences between streams was the number of animal units per hectare. A highly significant relationship indicated that animal units were associated with the major fraction of TP inputs.

The results for nitrate-N concentrations were less clear-cut. There was a significant negative correlation for the percent of watersheds in marshlands and a positive correlation for animal units. However, when the two factors were combined in a multiple regression analysis, no significant correlation was found for animal units. An earlier analysis of 1971 data produced a significant relationship between nitrate-N and percent of watersheds in row crops and a negative relationship with percentage of watersheds in marshland. No significant relationship was found between ammonia-N and any of the watershed land uses.

The only consistent, strong relationship was between animal units and TP. Animals and row crops may have had some role in the delivery of inorganic nitrogen to streams, but the evidence was not conclusive.

Relationship Between Livestock and Phosphorous Inputs

In this analysis, emphasis was placed on the 15 largest sub watersheds with areas greater than 100 hectares. These watersheds had flowing streams for longer periods and were considered to yield the most reliable data on flows and nutrient concentrations. The periodic measurements of flow and phosphorous concentrations were integrated over time to yield annual outputs of phosphorous for each watershed. These were divided by the respective watershed areas to yield the annual outputs in kilograms per hectare. Average concentrations for each stream were determined by dividing the annual output of phosphorous by the annual output of water.

The land use in each watershed was inventoried. The categories included the percentages of each watershed in row crops, pasture, woodlands, marshes and urban uses. The livestock numbers in each watershed was determined. The USEPA guidelines were utilized to convert the numbers into animal units (one animal unit = one beef animal). The animal units were divided by the areas of the watersheds to establish animal units per hectare. The number of animals in feedlots and in pastures, and whether or not runoff drained to a stream or tile intake also was determined.

The years 1971 and 1972 differed in several respects. Due largely to a heavy snow pack there was exceptionally high runoff in 1971, which resulted in an annual runoff in 1971 that was 50% higher than that recorded in 1972. The concentration of TP in the 1971 runoff was also higher than in 1972, so that a result was a higher output of TP from the watersheds in 1971. Each of the six lakes in the system had higher levels of plankton algae in the summer of 1971.

If correlations between TP inputs or concentration and animal units represent a cause and effect relationship rather than an experimental artifact, then it is not surprising that the strongest relationship was found in 1971 when the runoff was greatest. Under these conditions, animal waste would be most efficiently transported to the streams. Other studies in Iowa rivers have shown that under conditions of high flow there is a significant rise in biological oxygen demand that can be attributed to animal wastes. Sewage effluents on the other hand tend to become more dilute under higher flows.

Summary

In comparing the years 1971 and 1972 it was found that 1971 had the largest surface runoff, the highest phosphorous concentration in the streams, and the greatest input of phosphorous to the lakes and highest levels of summer algal blooms in the lakes. Of all the variables tested only the number of animal units in a watershed showed any significant correlation with the amount of phosphorous delivered by that watershed. The highest correlation was found with the numbers of animals in a feedlot that drained into streams or tiles. The study proposed that livestock are a significant source of phosphorous to the IGL.

Findings

Briefly stated, the following elements were recommended by Hickok and Associates for adoption and implementation to ensure that the water quality of the IGL is preserved and protected as one of the most important natural resources in the State of Iowa:

1) Formation of a regional inter-governmental agency with broad power to implement a water quality management plan.

2) Construction of feedlot and barn lot runoff collection facilities. The waste collected should be disposed of on the land according to specific guidelines.

3) Management of livestock so they are not allowed in a stream, watercourse or drainage path within 1,000 feet of a lake. For our purposes, the first 1,000 from a lake is considered shoreline. Include the addition of low berms to prevent direct runoff from pasture to the drainage ways are recommended for areas outside the 1,000-foot area.

4) Construction of required erosion control structures, terraces, and waterways.

5) Preparation of a municipal plan for each municipality for management and transportation of surface water resulting from urban development. Each municipality should identify in their land development plan guides and drainage plans the swamps and marshes to be preserved in their natural states. Direct surface drainage to the IGL and other public waters should be avoided. Where runoff from urban or suburban lands are contributing the pollution of the waters, a suitable system of catch basins, filters and settling ponds shall be cleaned and maintained by the local municipalities.

6) Adoption of stormwater policies and guidelines pertaining to the development of municipal and private drainage systems, including specific additions to existing facilities.

7) Adoption of zoning ordinances that require minimum setbacks from the lakes, stormwater management, and adequate septic system or sanitary sewer availability as a prerequisite for development.

8) Sanitary sewer service provided to all developed areas as soon as possible.

9) Development of a coordinated land and water management program to assist with retention of open space lands and wildlife habitat, marshes, wetlands, and drainage ways within the watershed.

Data from Minnesota
Loon Lake and Clear Lake Results
2003-2007

37 tests
Turbidity: 3-8 NTU

Loon Lake	32.30
Clear Lake	19.27

Fecal: 200 f.c/100 mg/L

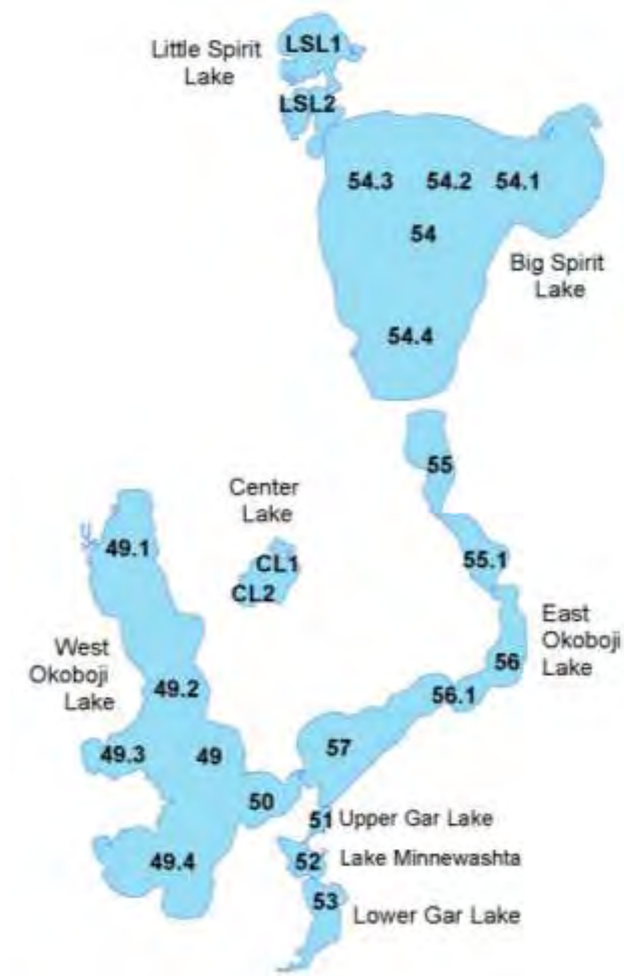
Loon Lake	150.30
Clear Lake	28.11

Phosphorous: .06-.15 mg/L		
	Loon Lake	0.36
	Clear Lake	0.08
Nitrogen – TKL: 1.3-2.7 mg/L		
	Loon Lake	2.28
	Clear Lake	2.25
34 tests		
Chlorophyll: 30-80 mg/cubic m		
	Loon Lake	78.84
	Clear Lake	42.49
Secchi:		
	Loon Lake	1.84
	Clear Lake	1.83

Table 3.7: *Courtesy of* Ardis Hotzler, GIS Specialist, Jackson County Planning & Environmental Services

"Cooperative Lakes Area Monitoring Project"
Background
The Cooperative Lakes Area Monitoring Project (CLAMP) began in 1999 as a partnership between Iowa Lakeside Laboratory and Friends of Lakeside Laboratory to take advantage of a rich tradition of volunteer involvement in the Iowa Great Lakes region. A group of volunteers was organized and trained to monitor water quality on 10 lakes in northwest Iowa. CLAMP focuses on monitoring nutrient levels (nitrogen and phosphorous) as well as chlorophyll *a* (an index of algal abundance) and Secchi depth (an index of water clarity). By monitoring these parameters, CLAMP volunteers provide an integrated measure of each lake's water quality.

Since its inception in 1999, over 100 volunteers have participated in CLAMP. These volunteers have taken over 3500 samples on nine lakes in Dickinson County: Big Spirit Lake, Center Lake, East Okoboji Lake, Little Spirit Lake, Lower Gar Lake, Lake Minnewashta, Silver Lake, Upper Gar Lake, and West Okoboji Lake. By volunteering their time, CLAMP volunteers are providing a long-term data set that will be useful in protecting these prized resources. CLAMP volunteers also provide information on the variation in water quality within a lake by sampling multiple sites on each lake. At the same time, volunteers have an opportunity to learn more about water quality issues and the ecology of their lakes. (Limnology Laboratory, 2007)



Map 3.1: CLAMP Lakes and Sampling Locations. (Limnology Laboratory, 2007)

Water Quality in the Iowa Great Lakes

Water quality varies greatly among the lakes in the Iowa Great Lakes region. Activities in the watershed dictate the quality of water reaching the lake. The size and depth of the lake also influence the water quality. Large lakes with large volumes of water can dilute nutrients from the watershed. Shallow lakes are susceptible to mixing and disturbance of the bottom sediments which allow nutrients to be released to the water column, while deep lakes don't experience as much mixing and stirring of the bottom sediments.

Lake	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)		Nitrate (mg/L)	Chlorophyll *a* (µg/L)
Big Spirit Lake	1.5	0.06	1.13	0.07	20
East Okoboji Lake	1	0.13	1.33	0.11	26
West Okoboji Lake	3.7	0.02	0.83	0.06	5
Upper Gar	0.7	0.13	1.59	0.12	43

Lake					
Lake Minnewashta	0.9	0.12	1.75	0.14	40
Lower Gar Lake	0.4	0.15	2.01	0.19	41
Little Spirit Lake	0.4	0.29	3.03	0.24	83
Center Lake	0.9	0.15	2.54	0.18	78
Silver Lake	0.7	0.16	2.81	0.62	39
All Natural Lakes*	0.5	0.11	1.81	0.31	34

Table 3.8: Median Values sites at the deepest location CLAMP data (1999-2006)

- All natural lakes monitored by the ambient lake monitoring program.

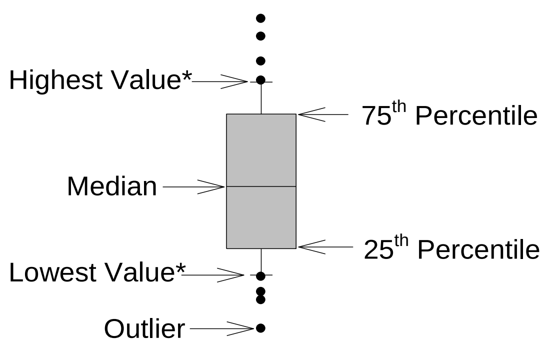


Figure 3.1: Reading a box plot. The median is the middle value in a group of numbers arranged in increasing order. If the median line is not in the center of the box, then the data are skewed. The length of the box represents the spread of the data (the larger the box, the greater the spread). An outlier is an unusual case.

Highest Value* Lowest Value* Median Outlier 75th Percentile 25th Percentile

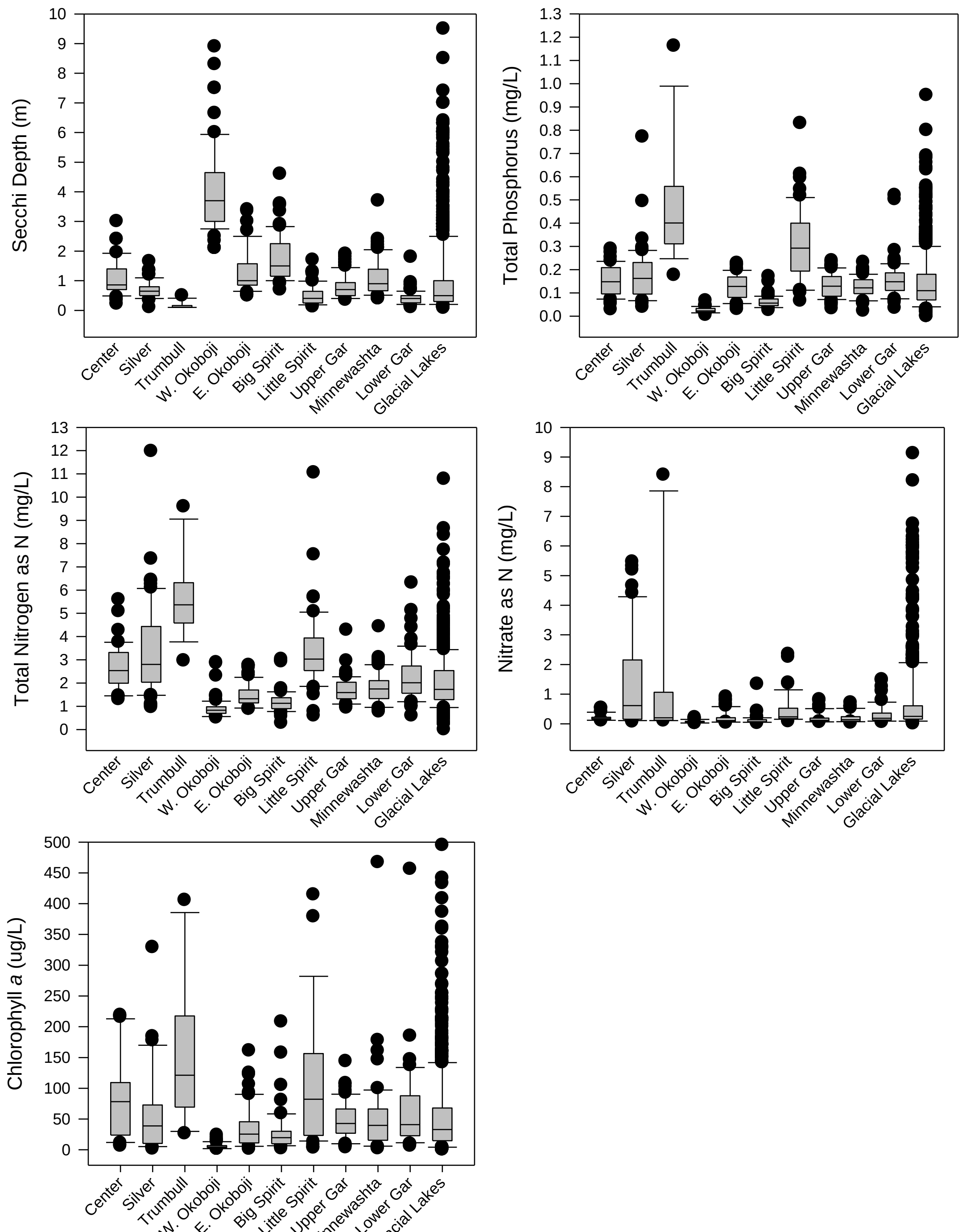


Figure 3.2: CLAMP data 1999-2006. (Limnology Laboratory, 2007)

Big Spirit Lake

Secchi depth ranged from 0.7 m on 8/25/2005 to 4.6 m on 6/8/2001, with the deepest Secchi depths occurring in spring, when algal productivity is the lowest, and the shallowest in late summer, when algal productivity is greatest. Overall, the median Secchi depth in Big Spirit was deeper than all other CLAMP lakes with the exception of

West Okoboji and deeper than the median of all monitored, glacial lakes in Iowa (Figure 3.2).

Total phosphorous and total nitrogen concentrations were low in Big Spirit compared to other CLAMP lakes. With the exception of West Okoboji, Big Spirit had the lowest median total phosphorous (0.06 milligrams per liter [mg/L]) and total nitrogen (1.1 mg/L) as well as a lower median concentration than all monitored, glacial lakes (Figure 3.2). Total phosphorous ranged from 0.025 mg/L to 0.171 mg/L. Total nitrogen ranged from 0.28 mg/L to 3.03 mg/L.

Chlorophyll *a* concentrations ranged from 2 micrograms per liter (µg/L) (6/8/01) to 208 µg/L (8/22/04). The median chlorophyll *a* concentration was less than all other CLAMP lakes with the exception of West Okoboji and less than the median for all monitored, glacial lakes (Figure 3.2).

East Okoboji Lake
Secchi depth ranged from 0.5 m to 3.4 m in East Okoboji Lake, with the deepest Secchi depths occurring in the spring, and the shallowest in late summer. Overall, Secchi depths in East Okoboji were in the middle of the range when compared to other CLAMP lakes and were deeper than the median for all monitored, glacial lakes in Iowa (Figure 3.2). Total phosphorous and total nitrogen concentrations in East Okoboji were in the middle of the range when compared to other CLAMP lakes. East Okoboji had the fifth highest median total phosphorous concentration (0.13 mg/L) and the seventh highest median total nitrogen (1.3 mg/L) out of 10 lakes. East Okoboji had slightly higher median total phosphorous and slightly lower median total nitrogen compared to all monitored, glacial lakes (Figure 3.2).

Chlorophyll *a* concentrations ranged from one µg/L (6/8/2005) to 161 µg/L (9/16/2004). East Okoboji had the third lowest median chlorophyll *a* concentration behind West Okoboji and Big Spirit and a lower concentration than all monitored, glacial lakes (Figure 3.2).

West Okoboji Lake
Secchi depth ranged from 2.1 m to 8.3 m, with the deepest Secchi depths occurring in the spring, and the shallowest in late summer. Overall, Secchi depths in West Okoboji were deeper than all other CLAMP lakes and all monitored, glacial lakes in Iowa (Figure 3.2). Total phosphorous ranged from 0.01 mg/L to 0.07 mg/L. Total nitrogen ranged from 0.6 mg/L to 2.9 mg/L. Both total phosphorous and total nitrogen concentrations were lowest when compared to other CLAMP lakes and all monitored, glacial lakes in Iowa (Figure 3.2).

Chlorophyll *a* concentrations ranged from one µg/L to 24 µg/L. The median chlorophyll *a* concentration in West Okoboji Lake was less than all other CLAMP lakes and all monitored, glacial lakes.

Upper Gar Lake
Secchi Depth ranged from 0.4 m to 1.9 m with the deepest Secchi depths occurring in the spring, and the shallowest in late summer. Overall Secchi depths in Upper Gar were shallower than many other CLAMP lakes and slightly deeper than the median for all monitored, glacial lakes (Figure 3.2).

Total phosphorous concentrations ranged from 0.03 mg/L to 0.3 mg/L. The median total phosphorous concentration (0.13 mg/L) was similar to Lower Gar, Minnewashta, and East Okoboji and slightly higher than the median for all monitored, glacial lakes. Total nitrogen concentrations ranged from 1.0 mg/L to 4.3 mg/L. Total nitrogen concentrations in Upper Gar were similar to other CLAMP lakes and similar to all monitored, glacial lakes (Figure 3.2).

Chlorophyll *a* concentrations ranged from four µg/L to 144 µg/L. Chlorophyll *a* concentrations in Upper Gar were similar to other CLAMP lakes and the median of all monitored, glacial lakes (Figure 3.2).

Lake Minnewashta
Secchi depth ranged from 0.4 m (8/12/2002) to 2.4 m (6/8/2005) with the deepest Secchi depths occurring in the spring, and the shallowest in late summer. Overall, Secchi depths in Minnewashta were in the middle of the range of CLAMP lakes and deeper then the median for all monitored, glacial lakes (Figure 3.2).

Total phosphorous ranged from 0.02 mg/L to 0.23 mg/L with the highest concentrations occurring in the late summer and the lowest occurring in spring. Total phosphorous concentrations in Minnewashta were similar to Upper Gar, Lower Gar and East Okoboji and were slightly higher than the median for all monitored, glacial lakes. Total nitrogen ranged from 0.8 mg/L to 3.1 mg/L and was similar to Upper Gar and Lower Gar as well as the median for all monitored, glacial lakes (Figure 3.2).

Chlorophyll *a* concentrations ranged from three µg/L on 5/20/2000 to 467 µg/L on 6/28/2004. The median chlorophyll *a* concentration was in the middle of the range for CLAMP lakes and was slightly higher when compared to all monitored, glacial lakes (Figure 3.2).

Lower Gar Lake
Secchi depth ranged from 0.1 m to 1.8 m with a median value of 0.4 m. Overall, Secchi depths in Lower Gar were shallower than other CLAMP lakes with the exception of Trumbull and Little Spirit and near the median for all monitored, glacial lakes in Iowa (Figure 3.2).

Total phosphorous concentrations ranged from 0.04 mg/L to 0.50 mg/L with a median of 0.15 mg/L. With the exception of Trumbull and Little Spirit, Lower Gar had the highest median total phosphorous among CLAMP lakes and was higher than the median for all monitored, glacial lakes. Lower Gar‘s median total nitrogen concentration (2.0 mg/L) was also higher than all monitored, glacial lakes and higher than many other CLAMP lakes (Figure 3.2).

Chlorophyll *a* concentrations ranged from 7μg/L (6/3/2006) to 456 μg/L (6/28/2004). Lower Gar's median chlorophyll *a* concentration was similar to Upper Gar and Minnewashta and was the median for all monitored, glacial lakes (Figure 3.2). Only Center, Trumbull, and Little Spirit had higher median chlorophyll *a* concentrations.

Little Spirit Lake
Secchi Depth ranged from 0.1 m to 1.7 m, with the deepest Secchi depths occurring in the spring, and the shallowest in late summer. Overall, Secchi depths in Little Spirit were shallower than other CLAMP lakes and near the median for all monitored, glacial lakes in Iowa (Figure 3.2).

Total phosphorous and total nitrogen concentrations were high in Little Spirit compared to other CLAMP lakes. With the exception of Trumbull, Little Spirit had the highest median total phosphorous (0.29 milligrams per liter (mg/L)) and total nitrogen (3.1 mg/L) as well as a higher median concentration compared to all monitored, glacial lakes (Figure 3).
Chlorophyll *a* concentrations ranged from 3 μg/L (6/5/2002) to 4217 μg/L (8/2/2005). Chlorophyll *a* concentrations varied greatly in Little Spirit between 1999 and 2006. The median chlorophyll *a* concentration for Little Spirit was greater than other CLAMP lakes with the exception of Trumbull, and was greater when compared to all monitored, glacial lakes (Figure 3.2).

Center Lake
Secchi depth ranged from 0.2 m on 7/11/2002 to 3.0 m on 6/15/2003, with the deepest Secchi depths occurring in the spring, and the shallowest in late summer. Overall, Secchi depths in Center Lake were in the middle of the range of other CLAMP lakes and slightly deeper than the median for all monitored, glacial lakes (Figure 3.2).

Total phosphorous and total nitrogen concentrations were slightly higher than other CLAMP lakes as well as being higher than the median value for all monitored, glacial lakes. Center Lake had median total phosphorous of 0.15 mg/L and median total nitrogen of 2.54 mg/L. Only Trumbull, Little Spirit and Silver Lake had greater median total phosphorous and total nitrogen values (Figure 3.2).

Chlorophyll *a* concentrations ranged from six μg/L (9/4/2006) to 218 μg/L (8/5/2001). The median chlorophyll *a* concentration (78μg/L) was greater than all other CLAMP lakes with the exception of Trumbull and Little Spirit and greater then the median for all monitored, glacial lakes (Figure 3.2).

Silver Lake
Secchi depth ranged from 0.1 m to 1.7 m, with the deepest Secchi depths occurring in the spring, and the shallowest in late summer. Overall, Secchi depths in Silver Lake were

shallower than most other CLAMP lakes and similar to the median for all monitored, glacial lakes in Iowa (Figure 3.2).

Total phosphorous concentrations ranged form 0.03 mg/L to 0.3 mg/L. The median total phosphorous concentration for Silver Lake was higher than all other CLAMP lakes with the exception of Trumbull and Little Spirit and higher than the median for all monitored, glacial lakes. Total nitrogen concentrations in Silver Lake were also higher than most other CLAMP lakes and the median for all monitored, glacial lakes (Figure 3.2).

Chlorophyll *a* concentrations ranged from 3 μg/L to 753 μg/L. The median chlorophyll *a* concentration for Silver Lake was similar to Upper Gar, Minnewashta, and Lower Gar as well as the median for all monitored, glacial lakes (Figure 3.2).

Trophic State

The large amount of water quality data collected by CLAMP can be difficult to evaluate. In order to analyze all of the data collected it is helpful to use a trophic state index (TSI). A TSI condenses large amounts of water quality data into a single, numerical index. Different values of the index are assigned to different concentrations or values of water quality parameters.

The most widely used and accepted TSI, called the Carlson TSI, was developed by Bob Carlson (1977). Carlson‘s TSI is a set of mathematical equations created from relationships between summertime total phosphorous, chlorophyll *a*, and Secchi disk transparency for numerous lakes. Using this method a TSI score can be generated by just one of the three measurements. Carlson TSI values range from 0 to 100. Each increase of 10 TSI points (10, 20, 30, etc.) represents a doubling in algal biomass. Data for one parameter can also be used to predict the value of another.

The Carlson TSI is divided into four main lake productivity categories: *oligotrophic* (least productive), *mesotrophic* (moderately productive), *eutrophic* (very productive), and *hypereutrophic* (extremely productive). The productivity of a lake can therefore be assessed with ease using the TSI score for one or more parameters. Mesotrophic lakes, for example, generally have a good balance between water quality and algae/fish production. Eutrophic lakes have less desirable water quality and an overabundance of algae or fish. Hypereutrophic lakes have poor water quality and experience frequent algal blooms and hypolimnetic anoxia.

Carlson‘s TSI can be used to classify the CLAMP lakes. West Okoboji and Big Spirit have the lowest TSI scores indicating they are the least productive (Figure 3.3). Little Spirit Lake and Silver Lake have the highest TSI scores indicating they are the most productive (Figure 3.3). Most lakes are in the *eutrophic* category based on Carlson‘s TSI (Figure 3.3). West Okoboji generally is in the *mesotrophic* category. Little Spirit Lake and Center Lake are generally in the *hypereutrophic* category.

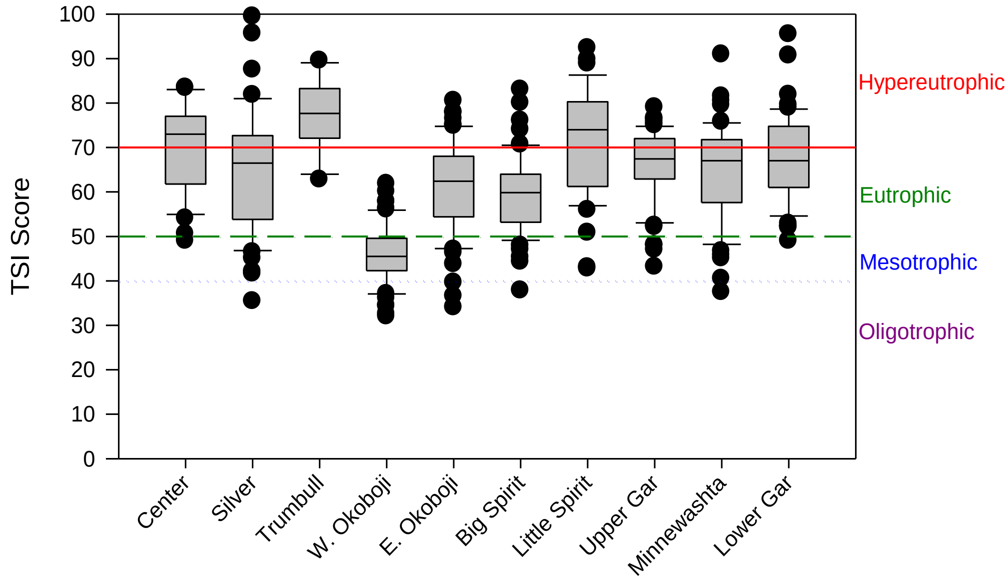


Figure 3.3: Chlorophyll *a* trophic state value (TSI) by lake: 1999-2006 CLAMP data. (Limnology Laboratory, 2007)

Trends

Seasonal

The data can also be used to learn about seasonal trends in water quality. The data show that nitrate concentrations are highest in the spring and early summer months before declining in the summer. This time coincides with spring applications of fertilizers as well as high amounts of rain. Nitrate is a water-soluble compound and thus is transported easily by runoff from spring rains. The data also show that water clarity is greatest in the spring before water temperatures increase and algal populations increase. Figure 3.4 shows that Secchi depths are generally deepest in June and shallowest in August and September for the lakes.

Spatial

The CLAMP program monitors multiple sites on many of the lakes, which is useful in understanding how water quality varies in different areas of the lakes. East Okoboji has the deepest Secchi depths at Site 57, which is in the deepest part of the lake, and the shallowest Secchi depths at Sites 55 and 55.1, which are at the shallow end of the lake

(Figure 3.3). In Big Spirit Lake, Secchi depths are deepest at Site 54 and shallowest at Site 54.1, which is in a shallow area of the lake (Figure 3.4).

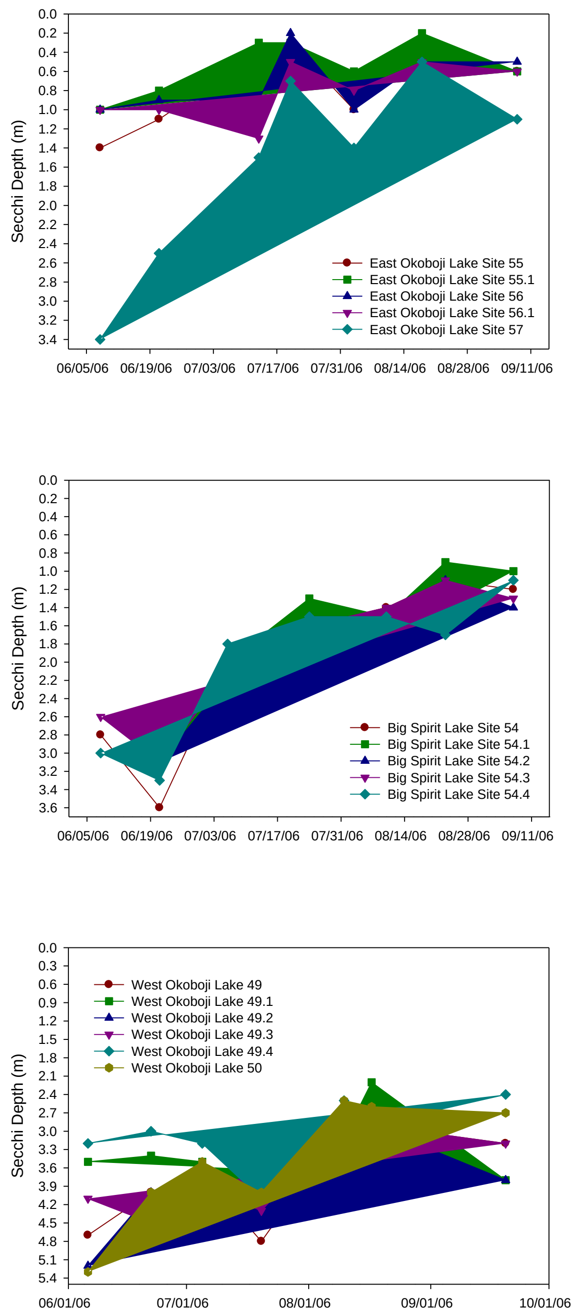


Figure 3.4: Variation in Secchi depth among sites for East Okoboji, Big Spirit, and West Okoboji in 2006. (Limnology Laboratory, 2007)

Long-term

CLAMP data has now been collected for 7 years on many of the lakes. This can show how these lakes have changed during that time. While it is a relatively short period, the data can be used to track any major changes in water clarity or nutrient levels. Over time, this data can be used to evaluate the effectiveness of lake restoration programs, track how changes in watersheds affect lake water quality, and provide a long-term reliable data set to show how the lakes are changing over time.

CLAMP data can also be combined with data from previous lake assessments to track how the lakes have changed. A survey of Iowa's lakes by Roger Bachmann in the 1970's provides historical data to help determine long-term trends. Figure 3.5 is an example of the trend line for West Okoboji Lake. In general, East Okoboji, West Okoboji, Big Spirit, and Lower Gar have small decreasing Secchi depth trends, based on visual assessment, while Secchi depths in Upper Gar and Minnewashta have not changed over time.

"Ambient Lake Monitoring Program"

The Iowa Department of Natural Resource's ambient lake monitoring program began in 2000. One hundred thirty-one lakes located throughout the state are monitored between 3 and 5 times during the summer by Iowa State University (2000-2007) and University of Iowa Hygienic Laboratory (2005-2007). Big Spirit, Little Spirit, East Okoboji, West Okoboji, Lower Gar, Upper Gar, Minnewashta, Center, and Silver Lake are all monitored as part of this program. Through the ambient lake-monitoring program, the lakes are monitored for a number of physical, chemical, and biological parameters. Physical parameters include temperature, dissolved oxygen, specific conductivity, pH, Secchi depth, turbidity, total suspended solids, total fixed suspended solids, and total volatile suspended solids. Chemical parameters include total nitrogen, nitrate + nitrite, ammonia, total phosphorous, soluble reactive phosphorous, silica, alkalinity, total organic carbon, and total dissolved solids. Biological parameters include chlorophyll *a*, phytoplankton biomass and composition, and zooplankton biomass and composition. The ambient monitoring program characterizes current water quality in the monitored lakes and tracks the trends in lake water quality.

The ambient lake monitoring program differs from the CLAMP program in that professionals collect the samples. The ambient program however only samples the lakes three to five times throughout the summer, while the CLAMP program is able to sample the lakes more frequently. The ambient program also only samples one location on the lake (deep spot) so that the data from each lake can be compared to other lakes in the state. The CLAMP program samples multiple locations on each lake, which allows for a more complete spatial characterization of the lakes.

The ambient program tests for more parameters than are feasible through the CLAMP program. This allows for a greater understanding of the characteristics of each of the lakes. The CLAMP program includes Secchi depth, total phosphorous, total nitrogen, nitrate plus nitrite nitrogen, and chlorophyll *a*, which are all explained above. The additional parameters monitored by the ambient lake monitoring program are explained below. Table 2 contains the median values (2000-2006) for some of the parameters measured by the ambient lake monitoring program. (Downing, 2008)

Physical Parameters

Temperature and Dissolved Oxygen (DO) profiles are measured at the sampling location. A probe is lowered in the water column and a reading is taken at regular intervals to determine if the lake is thermally stratified. Thermal stratification occurs when surface waters warm and the density difference between the cooler, deeper water and the warm surface water prevents mixing. One potential consequence of thermal stratification is anoxia (or low oxygen conditions) in the hypolimnion (the deep cold-water area) due to respiration. Hypolimnetic anoxia can lead to release of phosphorous from the sediment, which can lead to algae blooms. The extent of thermal stratification depends on several factors including depth, wind fetch, wind exposure, and spring temperatures. West Okoboji is the only lake in the Iowa Great Lakes that stratifies regularly. The other lakes are too shallow and are susceptible to mixing by the windy conditions in that area of the state.

Turbidity is a reduction in clarity that results from the presence of suspended particles. Turbidity usually consists of inorganic particles, such as sediment, and organic particles, such as algae. In general, the lakes in the Iowa Great Lakes region have lower turbidities than other natural lakes in the state with the exception of Little Spirit, Lower Gar, Upper Gar and Silver.

Total Suspended Solids (TSS) includes all suspended particles in water that will not pass through a filter. Big Spirit (6 mg/L) and West Okoboji (2.3 mg/L) have low concentrations of TSS when compared to other natural lakes. Lower Gar (21.1 mg/L) and Silver (17.1 mg/L) have the highest TSS concentrations of the Iowa Great Lakes.

Total Fixed Suspended Solids (TFSS) is a measure of the inorganic fraction (sediment) of suspended solids. Big Spirit, Center, East Okoboji, Minnewashta and West Okoboji all have relatively low median TFSS concentrations (below the 25th percentile for all monitored, natural lakes).

Total Volatile Suspended Solids (TVSS) is a measure of the organic fraction of suspended solids. Big Spirit, East Okoboji, Minnewashta, Upper Gar and West Okoboji all have relatively low median TVSS concentrations (below the 25th percentile for all monitored, natural lakes).

Total Organic Carbon (TOC) is the sum of all organic carbon from decaying organic material, bacterial growth, metabolic activities of living organisms, and chemicals. (Humic acid, fulvic acid, amines, and urea are types of natural organic matter. Detergents, pesticides, fertilizers, herbicides, industrial chemicals, and chlorinated organics are examples of synthetic sources of organic carbon.) TOC can be used as a measure of organic contamination. Little Spirit (18.5 mg/L) and Center (14.6 mg/L) have relatively high levels of TOC (above the 75th percentile for all monitored, natural lakes). All other lakes in the Iowa Great Lakes with the exception of Silver fall below the 25th percentile for all monitored natural lakes.

Specific Conductivity is a measure of the ability of a solution to electrical flow. Specific conductivity is an indirect measure of the presence of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron, and can be used as an indicator of water pollution. The higher the specific conductivity, the higher the amount of dissolved ions in the water. Silver (629 µS/cm) and Center (571 µS/cm) have the highest median specific conductance among the Iowa Great Lakes, which was above the 75^{th} percentile for all monitored, natural lakes. Big Spirit (480 µS/cm) and West Okoboji (466 µS/cm) had the lowest median specific conductance among the Iowa Great Lakes.

Chemical Parameters

Soluble Reactive Phosphorous (SRP) is the form of phosphorous used by algae and therefore constitutes the fraction of total phosphorous that is available to be used by algae. In phosphorous-limited situations, this form should be low to undetectable, as is the case in Big Spirit (0.003 mg/L) and West Okoboji (0.003 mg/L). As SRP increases, it implies that phosphorous is either not needed by algae or it is being supplied at a rate that is faster than the rate of biologic uptake. Little Spirit (0.09 mg/L), Silver (0.04 mg/L) and East Okoboji (0.04 mg/L) have relatively high SRP levels when compared to other monitored, natural lakes in Iowa (greater than the 75^{th} percentile).

Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen and ammonia in water. High concentrations of TKN in a water body are generally from organic pollution, such as sewage or manure discharges. Little Spirit (2.6 mg/L) and Center (2.0 mg/L) have TKN concentrations above the median for other monitored, natural lakes in Iowa (1.7 mg/L).

Ammonia is a soluble form of nitrogen that is found in water. Ammonia can be toxic to fish and invertebrate populations when at high levels. Ammonia is commonly used as an agricultural fertilizer. Little Spirit, Minnewashta, Center, and Lower Gar have the highest median ammonia concentrations, while Big Spirit and West Okoboji have the lowest (Table 3.9).

Biological Parameters

Phytoplankton wet mass and composition are measured to get a better understanding of the biological dynamics of each lake. Phytoplankton or algae are the photosynthetic organisms that form the base of the food chain in lakes. The median phytoplankton wet mass ranged from 9.1 mg/L in West Okoboji to 36.0 mg/L in Upper Gar. All lakes in the Iowa Great Lakes had a lower median concentration than the median for all monitored, natural lakes in Iowa (39.7 mg/L). Most phytoplankton samples were dominated by Cyanobacteria, which often dominate summer plankton in productive lakes.

Zooplankton wet mass and composition are measured to get a better understanding of the biological dynamics of each lake. Zooplankton is the microscopic and macroscopic animals that float, drift, or swim weakly in the water column. Zooplankton is the primary consumers of algae and many fish rely on them as a food source. The median zooplankton wet mass ranged from 94.1 mg/L in West Okoboji to 288.5 mg/L in Lower Gar. Zooplankton samples were composed mainly of cladocerans, copepods, protozoa and rotifers.

Lake Name	Secchi Depth (m)	Total Phosphorous (mg/L)	Soluble Reactive Phosphorous (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia (mg/L)	Nitrate +Nitrite (mg/L)	Chlorophyll *a* (ug/L)	Dissolved Oxygen (mg/L)
Big Spirit	2.0	0.046	0.003	1.0	0.044	0.205	11	8.8
Center	1.0	0.107	0.032	2.0	0.149	0.255	25	9.4
East Okoboji	1.2	0.082	0.041	1.2	0.070	0.243	15	8.6
Minnewashta	1.3	0.081	0.036	1.3	0.160	0.211	14	8.5
Little Spirit	0.6	0.220	0.090	2.6	0.167	0.429	38	8.7
Lower Gar	0.5	0.100	0.023	1.4	0.136	0.379	28	8.5
Upper Gar	1	0.867	0.027	1.3	0.090	0.194	27	8.7
West Okoboji	5.8	0.021	0.003	0.8	0.051	0.166	3	9.4
Silver	0.6	0.114	0.043	1.4	0.111	2.183	14	8.7

Lake Name	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Organic Carbon (mg/L)	Total Fixed Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)	pH	Alkalinity (mg/L)	Specific Conductivity (uS/cm)
Big Spirit	7.3	6	8.5	3	4.0	8.7	172.5	480
Center	17.1	10.2	14.6	4.3	6.0	8.8	170.0	571
East Okoboji	11.3	7.5	8.6	3.0	3.4	8.6	199.5	508
Minnewashta	16.7	8.4	8.5	4.3	4.6	8.5	190.0	505
Little Spirit	36	18	18.5	9	8.5	8.9	200.0	489
Lower Gar	30.7	21.1	8.0	12.9	8.1	8.5	200.0	514

Upper Gar	21	13.1	8.1	7.7	5.2	8.6	193.8	501
West Okoboji	1.5	2.3	7.5	1.5	1.6	8.5	192.0	466
Silver	33.9	17.1	9.4	11.4	6.1	8.4	151	629

Lake Name	Phytoplankton Wet Mass (mg/L)	Zooplankton Wet Mass (mg/L)	Carlson Trophic State Index (Secchi)	Carlson Trophic State Index (Total Phosphorous)	Carlson Trophic State Index (Chlorophyll)
Big Spirit	23.0	121.9	50	60	54
Center	20.3	206.1	61	72	62
East Okoboji	15.1	101.5	57	68	57
Minnewashta	9.9	182.7	56	67	57
Little Spirit	24.5	274.7	69	82	66
Lower Gar	28.0	288.5	71	71	63
Upper Gar	36.0	170.1	60	68	63
West Okoboji	9.1	94.1	35	48	41
Silver	21.1	169.5	68	72	56

Table 3.9: Median values for ambient lake monitoring program data (2000-2006). (Downing, 2008)

"Quantification of Nutrient Inputs into the Iowa Great Lakes"
Background

This study examined water and nutrient budgets for West Okoboji Lake, East Okoboji Lake, and Lower Gar Lake. The three lakes, along with Upper Gar Lake and Minnewashta Lake, form a series of interconnected lakes within the IGL system. The only surface outflow from these lakes is over a low-head dam at the south end of Lower Gar Lake. The purpose of the study was to better understand and quantify how water and nutrients move into, among, and out of the lake system. For a complete review of data collection, data analysis, and results see *Quantification of Nutrient Inputs into the Iowa Great Lakes,* submitted by Stenback, Crumpton, and van der Valk to the U.S. Environmental Protection Agency, December 2005. (Quantification of Nutrient Inputs into the Iowa Great Lakes, 2005)

In order to develop water and nutrient budgets, three additional types of monitoring were initiated to fill data gaps, including 1) inputs of nutrients in wet and dry depositions, 2) collection of lake and inflowing surface water samples for nutrient analyses, and 3) evaporation rates.

A thirteen-year numerical water budget model based on local daily rainfall data, watershed input from the nearby Ocheyedan River water yield and lake to watershed area, lake-to-lake water flow, and local pan evaporation data was developed for the period of January 1, 1992 to December 31, 2004. For each lake, total phosphorous (TP) and total nitrogen (TN) budgets were estimated each year from 1999-2004, using measured lake concentration data, modeled watershed inputs estimated from inflowing stream data, and wet/dry depositions.

The flow of nutrients into, among, and out of the lake system was estimated using the water budget model and nutrient concentration data. For each lake‘s nutrient budget, lakebed sediment was treated as a nutrient source or sink to maintain water column nutrient concentrations after accounting for all other inputs and outputs.

Spirit Lake, which was not a direct focus of this study, was modeled separately to obtain an estimate of lake discharge into East Okoboji Lake. The lake water budget model was developed as a component of a separate study to look at phosphorous cycling in portions of the lake system. Existing water monitoring programs provided much of the data needed to develop the water and nutrient budgets. Data on water and nutrient yields from different kinds of watersheds were used to estimate water and nutrient loads from each lake‘s watershed. In order to complete mass balance budgets for the lakes, additional monitoring was conducted to obtain inputs of nutrients in wet and dry deposition, nutrients in lake water and inflowing surface water samples, and evaporation rates.

Model Input and Data Sources

Watershed inputs to each lake include:

1) Watershed input was modeled as the product of watershed area and water yield based on data from the Ocheyedan River near Spencer, IA (USGS Station 06605000).

2) Rainfall directly to the lake surface using rain data Milford, IA (NOAA NNDC Climate Online Data Online, Station 135493).

3) Spirit Lake model outflow was used as a water input into East Okoboji.

Watershed exports to each lake include:

1) Evaporation from the lake surface, based on the product of a pan evaporation coefficient and pan evaporation data obtained online from University of Minnesota, Southwest Research and Outreach Center, Lamberton, MN (Station 23669). Lamberton is 50 miles north of the Iowa Great Lakes area. Pan

evaporation data was also collected at the Lakeside Laboratory in 2003 and 2004. The Lakeside Laboratory data were significantly less variable ($p<0.0001$) than the Lamberton data and had a significantly lower mean than the Lamberton data (about 23% lower, $p<0.0001$) for the 180 days when both stations had measurements. The Lamberton data were used because they have a more complete record for the time of the study. The difference in average values between Lakeside and Lamberton data is compensated for by the application of the pan evaporation coefficient in the numerical model.

2) Discharge from the lake outflow structure to Milford Creek and or into adjacent lakes.

Groundwater inputs to and exports from the lake system are assumed to be negligible. Five stream monitoring sites were chosen for streambed stability and approximately U-shaped channels (see figure 3.6 on page 52). American Sigma 900 Max auto-samplers equipped with depth/velocity probes were used at each site to record average depth and water velocity at five-minute intervals. Stream cross-section profiles were completed at each probe location and an area versus stream water depth relationship was developed corresponding to one millimeter depth interval changes. Five-minute stream discharges were calculated as the product of the average velocity and the area associated with the average stream depth over each five-minute period. Daily stream discharges were calculated by summing the five-minute discharges for a 24-hour period.

Evaporation and rainfall was identical for each day and each lake in the model. Rainfall and evaporation were applied directly to the lake surface area so that rainfall and evaporation affected change in the lake surface elevation identically for each lake. Because of this, rainfall and evaporation generally have no effect on modeled water movement between the lakes. One exception to this occurs if rainfall inputs raises lake surface elevation enough to cause discharge over the Lower Gar spillway at a sufficiently high rate to stop any upstream flow that might be occurring, and start downstream flow. The major effect of rain for the purpose of nutrient balance is as a source of nutrients, while the effect of evaporation is to concentrate nutrients already in the lake.

East Okoboji Lake

During relatively wet years, lake-to-lake flow accounts for more than 60 or 70 percent of the East Okoboji water budget. The quantity of water delivered to East Okoboji from both rain and watershed input are generally similar. Water input from West Okoboji to East Okoboji was always less (except in the 1993-flood year) than surface water input to East Okoboji from its watershed, and in relatively dry years, net flow was into West Okoboji from East Okoboji. Water input from Spirit Lake to East Okoboji may exceed surface water input during wet years, but during relatively dry years, Spirit Lake provides little or no flow to East Okoboji.

Water output to Upper Gar exceeds water input to East Okoboji from its watershed during wet years, but during the very dry years (2000, 2002, and 2003); Upper Gar was a net source of water to East Okoboji. While flow through East Okoboji varied considerably from year to year, and in some years more water flows into the lake than out of it, the outflow to Upper Gar indicates that sufficient water flows in and out of East Okoboji to completely replace the lake water every few years, except during extended dry periods such as 2002 and 2004. During the 1993 flood year, sufficient water flowed through East Okoboji to replace its volume nearly eight times.

Upper Gar Lake

During wet years, lake-to-lake flow accounts for more than 60 or 70 percent of the Lower Gar water budget. During 1992-2004, surface water flow from the watershed into Lower Gar exceeded the lake volume each year of the study. However, during three dry years (2000, 2002, and 2003), there was little or no outflow and net flow was upstream out of Lower Gar into Minnewashta.

During the dry years, watershed input and lake-to-lake flow dominated the water budget. With the exception of the dry years and 1998, sufficient water flowed in and out of Lower Gar to replace the entire lake volume more than ten times each year. During the 1993 flood year, approximately 200 lake volumes flowed out of Lower Gar to Milford Creek.

Water Budget Summary

While small lake elevation differences produce alternating flow direction between lakes, there is a net long-term flow of water from the upper to lower Iowa Great Lakes, with significant annual variability between wet and dry years. During wet periods, water flows from West Okoboji to East Okoboji and downstream through the lower lakes and out the overflow structure below Lower Gar Lake.

During relatively dry years, outflow from the upstream lakes may cease for periods lasting months to more than a year. During the dry periods, the water level in Lower Gar, which has a large watershed to lake ratio, rises at a greater rate than the upstream lakes. This causes reversed or up-lake flow.
Therefore, during dry periods nutrients from the smaller, shallower and more nutrient-rich Lower Gar, Minnewashta, and Upper Gar Lakes may flow up lake into East Okoboji Lake. In addition, during the dry periods East Okoboji Lake may exchange water with West Okoboji Lake. West Okoboji Lake is the largest, deepest and least nutrient enriched of the Iowa Great Lakes chain. Because East Okoboji has greater TP and TN concentrations, it can be a significant source of nutrients to West Okoboji during periods of up lake water flow.

During wet periods when a lake volume is overturned multiple times, particularly for Lower Gar and occasionally East Okoboji, the nutrient load of primary concern is that of the last lake volume because all of the preceding volumes have flowed through and out of the lake. Understanding water inputs and outputs is a first step towards understanding how nutrients that are dissolved or suspended in the water column move into, within, and out of the lake system.

2004 Nutrient Budget Model

Mass balance nutrient budgets were developed for TP and TN for 2004. The nutrient budget inputs to the lake water column include direct rain and atmospheric deposition, inflowing stream water, flux from the sediment, and input from adjacent lakes. Nutrients may be exported from a lake along with water flowing between lakes or discharged to Milford Creek from Lower Gar. Nutrients may be stored within the lake in lakebed sediments, elevated aqueous concentration or associated with suspended solids. Nutrient flux from the water column to lakebed sediment is considered an export from the lake water column even though the nutrients are stored within the lake system.

Mass balance models were constructed for nutrients using a daily time step for 2004. Initial conditions include the lake water volume determined from the water budget model and a lake water column nutrient mass determined from an initial lake nutrient concentration and water volume. The model assumes that once nutrients enter a lake, they are completely mixed within the lake. The mass of nutrients entering and exiting are determined at each daily time step and the resulting model lake nutrient concentration is determined.

When all non-sediment related nutrient inputs and outputs are accounted for, the model lake nutrient concentration is compared to the measured lake nutrient concentration. If the model lake concentration is greater than the measured lake concentration, nutrients are forced into the sediment to make up the difference. If the model lake concentration is less than the measured lake concentration, nutrients are taken from the sediment to make up the difference. Since daily measured lake nutrient concentrations are not available, a linear interpolation generated by ModelMaker was used to estimate a daily concentration value between each measured value.

Water samples were collected from inflowing streams from April 6 to October 4 during 2004 and analyzed for TP and TN. Stream discharge at these locations was measured daily, although occasional equipment failures occurred resulting in several data gaps. The data were evaluated using ModelMaker to estimate flow-weighted average (FWA) concentrations; however, because the data encompass less than a full year and the FWA concentrations are dependent on the particular flow events during this period of record, they may not be appropriate for use outside of this particular period. These data were utilized to estimate concentrations in inflowing water from surface runoff to the lakes.

The TP concentration data showed some tendency to increase with increasing discharge, although there is considerable scatter in the data. Differences in mean TP concentration and variation among sites at low discharge are minimal and concentrations at all sites show a similar tendency to increase with increasing discharge as would be expected for phosphorous concentrations associated with water carrying suspended particulate matter. Accordingly, the linear relationship between increasing total phosphorous concentration with increasing discharge was used to estimate a phosphorous concentration associated with discharge estimated from the product of the Ocheyedan water yield and the sub watershed area for watersheds within the main watershed for each of the lakes in this study.

There is a non-linear relationship between FWA TN concentration and percentage of the watershed area in row crop. The FWA TN concentrations were determined as the total TN mass load divided by the total water volume for the five sub watershed sites over the approximately six-month data collection period from early April to early October of 2004. The non-linear relationship between FWA TN and percent cropland was used to generate daily TN concentrations for surface water input in the nutrient budget models.

Watersheds were delineated using a D8 directional flow algorithm described by O'Callaghan & Mark (1984). One arc second elevation data was obtained from the USGS National Elevation Dataset (USGS). Percent row crop was derived by zonal statistics of each watershed based on a 2003 land cover dataset. Land cover information was obtained from the USDA National Agricultural Statistics Service.

An Aerochem Metrics Inc. Automatic Sensing Wet/Dry Precipitation Collector was used to collect wet-dry samples to estimate TP and TN inputs from both rainwater and dry deposition. Rainwater samples were collected during August to October 2003 and all of 2004. Lake TP and TN concentrations were available from the ongoing lake water quality-monitoring program, Cooperative Lakes Area Monitoring Program (CLAMP), a partnership between the local community and Iowa Lakeside Laboratory. The CLAMP data were used to estimate lake water nutrient concentrations for the nutrient budget. Initial lake (January 1, 2004) concentrations were determined by linear interpolation between the concentration determined for the last sampling event in 2003 and the first event in 2004. Final December 31, 2004 lake concentrations were set equal to the initial concentration.

West Okoboji Lake 2004 TP and TN Budgets

The model indicates that net TP inputs to West Okoboji for 2004 total 3.3 metric tons (t) with 22% from rain, 25% from dry deposition, 41% from surface runoff, and 12% from East Okoboji. The net input from East Okoboji is interesting because the net water movement during 2004 was primarily from East Okoboji to West Okoboji. This occurred because water flow was primarily from East Okoboji to West Okoboji during the early part 2004, while late in the year water generally moved downstream from west to east.

Because the TP concentration is greater in East Okoboji than in West Okoboji, the net flux of TP was from east to west even though the net flux of water was from west to east. Approximately 2.8 t TP was stored in the lake sediment (about 86% of the net TP input) and 0.5 t was stored in the water column (about 14% of the net TP input).

The model results indicate that net TN inputs to West Okoboji for 2004 total 35.5 t with 22% from rain, 14% from dry deposition, 59% from surface runoff, and 4% from East Okoboji. About 29 t TN (83% of the input TN) was deposited to the lakebed sediment and approximately 6 t TN was stored in the water column (about 17% of the net TN input).

East Okoboji Lake 2004 TP and TN Budgets
The model results indicate that net TP inputs to East Okoboji for 2004 total 21 t with 16% from rain, 18% from dry deposition, and 65% from watershed runoff. Spirit Lake did not overtop its outflow structure during 2004 so no TP phosphorous was contributed from that potential source. About 0.4 t TP (19% of the input TP) was output from East Okoboji to West Okoboji and 0.7 t TP (34%) of the net TP input was output to Lower Gar during 2004. Approximately 0.3 t TP (15% of the net TP input) was deposited to the lake sediment and 0.7 t TP (33% of the net TP input) was stored in the water column.

The model results indicate that net TN inputs to East Okoboji for 2004 total 38.5 t with 10% from rain, 6% from dry deposition, and 84% from surface runoff. About 2.8 t (7% of the input of TN) was output to West Okoboji and 5.5 t (14% of the input TN) was output to Upper Gar Lake. About 24 t of TN (63% of the input TN) was deposited to the lakebed sediment and approximately 6.1 t of TN was stored in the water column (about 16% of the net TN input).

Lower Gar Lake 2004 TP and TN Budget
The model results indicate that net TP inputs to Lower Gar for 2004 total 2.9 t with 2% from rain, 2% from dry deposition, 52% from surface runoff, 4% from Minnewashta Lake, and 41% released from the lakebed sediment to the water column. About 2.8 t TP (97% of the input TP) was output to Milford Creek and approximately 0.8 t TP (about 3% of the net TP input) was stored in the water column.

The model results indicate that net TN inputs to Lower Gar for 2004 total 42 t with 1% from rain, 1% from dry deposition, 52% from surface runoff, and 46% from lakebed sediment. About 33 t (79% of the input TN) was output to Milford Creek and 8 t of TN (18% of the input TN) was exported to Minnewashta Lake. Approximately 1 t of TN (about 3% of the net TN input) was stored in the water column.

2004 TP Budgets on a Mass per Lake Area and Mass per Lake Volume Basis
Because the lake areas and volumes vary, expressing the TP nutrient budget in terms of mass per lake area and mass per lake volume provides a different perspective on TP source load to the lakes and on between lake comparisons. The rain and dry deposition inputs are the same for each lake when evaluated on a per lake area basis.
However, on a per lake volume basis, the rain and dry deposition inputs are lowest for West Okoboji and highest for Lower Gar, which is the opposite of the order of actual mass input to these lakes. While the actual watershed input mass is similar for each lake, the per lake area watershed input is lowest for West Okoboji and highest for Lower Gar, and because of the relative lake depths, this effect is even more pronounced on a per lake volume basis.

1999 to 2004 Six-Year Annual Nutrient Budget Model
A temporal assessment of the nutrient budget was developed using CLAMP lake concentration data available from 1999 to 2004. Lake samples were collected on seven to ten days each year in each lake from 1999 to 2004. Spirit Lake did not contribute to the 2004 nutrient budget because there was no outflow from Spirit Lake that year. However,

Spirit Lake did contribute water and nutrients to East Okoboji during 1999 and 2001. Adequate lake concentration data is not available for the years between 1992 and 1999 so the lake budget model could not be extended to years prior to 1999. Wet deposition for the six-year nutrient budget is based on 2004 wet/dry average TP and TN rain concentrations applied to daily ran data as described in the water budget model. The average 2004 dry deposition rate was used for the six-year modeling period. The TP and TN watershed inputs were based on the 2004 sampling data, the relative proportions of water inputs to each lake (watershed runoff, precipitation, and lake-to-lake flow) described for the thirteen-year water budget model, and TP estimated as a function of discharge coupled with estimated surface runoff from Ocheyedan water yield (R^2=0.379). Otherwise, watershed and from adjacent lake nutrient budgets were modeled as previously described. The resulting nutrient budgets are given in Tables 3.10-3.14.

Lake	Inputs					Outputs		Storage	Total Mass In Lake
	Rain	Dry Dep.	Watershed	Adjacent Lakes	Sediment Flux	Adjacent Lakes or Milford Creek	Sediment Flux	Stored in the Water Column*	Nutrient Mass in Lake Water Column at End of 2004
West Okoboji	0.047	0.052	0.086	0.026			0.18	0.030	0.35
East Okoboji	0.047	0.052	0.19			0.055 (WOL) 0.096 (UGL)	0.042	0.092	0.64
Lower Gar†	0.047	0.052	1.5	0.41	0.95	2.9 (Milford Cr.)		0.084	0.20

* End of 2004 minus beginning of 2004 mass of TP in the lake water column.

† One outlier TP concentration of 0.52 mg/L collected on August 2, 2004 was set to 0.2 mg/L to better match temporally adjacent measurements.

Table 3.10: Lake TP nutrient flux model budget summary for 2004 in mass per lake area (g/m2).

Lake	Inputs					Outputs		Storage	Total Mass In Lake
	Rain	Dry Dep.	Watershed	Adjacent Lakes	Sediment Flux	Adjacent Lakes or Milford Creek	Sediment Flux	Stored in the Water Column*	Nutrient Mass in Lake Water Column at End of 2004
West Okoboji	0.0041	0.0046	0.0075	0.0023			0.016	0.0026	0.031
East Okoboji	0.015	0.017	0.059			0.017 (WOL) 0.030 (UGL)	0.013	0.029	0.20
Lower Gar†	0.043	0.048	1.4	0.38	0.88	2.6 (Milford Cr.)		0.077	0.19

* End of 2004 minus beginning of 2004 mass of TP in the lake water column.

† One outlier TP concentration of 0.52 mg/L collected on August 2, 2004 was set to 0.2 mg/L to better match temporally adjacent measurements.

Table 3.11: Lake TP nutrient flux model budget summary for 2004 in mass per full lake volume (g/m3).

Nutrient	Inputs: Rain	Inputs: Dry Dep.	Inputs: Watershed	Inputs: Adjacent Lake (EOL)	Inputs: Sediment to Lake Flux	Outputs: Adjacent Lake (EOL)	Outputs: Lake to Sediment Flux	Annual Water Column Storage*	Nutrient Mass In Lake Water Column at End of Year
TP									
1999	0.5 (20)	0.8 (35)	1.0 (45)			0.1 (5)	1.2 (53)	1.0 (43)	5.9
2000	0.5 (30)	0.8 (47)	0.2 (12)	0.2 (11)			0.2 (10)	1.6 (90)	7.5
2001	0.6 (15)	0.8 (22)	2.2 (60)	0.1 (3)			4.1 (111)	-0.4 (-11)	7.1
2002	0.5 (26)	0.8 (44)	0.3 (18)	0.2 (12)			3.8 (205)	-1.9 (-105)	5.1
2003	0.4 (20)	0.8 (41)	0.4 (22)	0.3 (17)			2.2 (108)	-0.2 (-8)	5.0
2004	0.7 (22)	0.8 (25)	1.3 (41)	0.4 (12)			2.8 (86)	0.5 (14)	5.5
TN									
1999	5 (8)	5 (8)	17 (28)		34 (55)	6 (10)		55 (90)	213
2000	6 (32)	5 (28)	4 (21)	3 (19)			83 (463)	-65 (-363)	148
2001	6 (14)	5 (12)	31 (73)	0.5 (1)			57 (134)	-14 (-34)	133
2002	5 (15)	5 (14)	6 (17)	3 (9)	16 (46)			36 (100)	169
2003	4 (19)	5 (22)	8 (35)	6 (25)			24 (107)	-2 (-7)	167
2004	8 (22)	5 (14)	21 (59)	2 (4)			29 (83)	6 (17)	174

* End of year minus beginning of year mass of TP in the lake water column.

Table 3.12: Model lake nutrient budget summary for West Okoboji Lake (metric tons, (% of Total Inputs)).

Nutrient	Inputs: Rain	Inputs: Dry Dep.	Inputs: Watershed	Inputs: Adjacent Lake (WOL)	Inputs: Spirit Lake	Inputs: Adjacent Lake (UGL)	Inputs: Sediment to Lake Flux	Outputs: Adjacent Lake (WOL)	Outputs: Adjacent Lake (UGL)	Outputs: Lake to Sediment Flux	Annual Water Column Storage*	Nutrient Mass In Lake Water Column at End of Year
TP												
1999	0.22 (10)	0.39 (17)	1.0 (45)	0.11 (5)	0.48 (21)		0.08 (3)		1.7 (75)		0.58 (25)	2.96
2000	0.25 (21)	0.39 (32)	0.21 (17)			0.36 (30)		0.19 (16)		0.69 (57)	0.33 (28)	3.29
2001	0.27 (8)	0.39 (11)	2.42 (71)		0.33 (10)			0.12 (4)	1.7 (48)	2.7 (78)	-1.02 (-30)	2.27
2002	0.23 (13)	0.39 (22)	0.32 (18)			0.26 (15)	0.58 (33)	0.22 (12)			1.56 (88)	3.83
2003	0.19 (15)	0.39 (31)	0.44 (36)			0.22 (18)		0.34 (28)		0.67 (54)	0.23 (19)	4.06
2004	0.3 (16)	0.4 (18)	1.4 (65)					0.4 (19)	0.7 (34)	0.3 (15)	0.7 (33)	4.75
TN												
1999	2.4 (5)	2.4 (5)	27 (53)	6.2 (12)	11 (22)		1.5 (3)		49 (98)		1.0 (2)	49
2000	2.7 (16)	2.4 (14)	5.8 (35)			5.8 (35)		3.4 (20)		21 (125)	-7.5 (-45)	41
2001	2.9 (5)	2.4 (4)	48 (80)		6.8 (11)			0.5 (1)	28.7 (48)	41 (68)	-9.8 (-16)	31
2002	2.5 (10)	2.4 (10)	9.0 (38)			4.2 (17)	6.0 (25)	3.1 (13)			20.9 (87)	52
2003	2.0 (10)	2.4 (11)	12 (57)			4.7 (22)		5.7 (27)		32 (153)	-16.9 (-80)	35
2004	3.8 (10)	2.4 (6)	32 (84)					2.8 (7)	5.5 (14)	24 (63)	6.1 (16)	41

* End of year minus beginning of year mass of TP in the lake water column.

Table 3.13: Model lake nutrient budget summary for East Okoboji Lake (metric tons, (% of Total Inputs).

	Inputs					Outputs			Annual	Nutrient Mass In
Nutrient	Rain	Dry Dep.	Watershed	Adjacent Lake (Minn. L)	Sediment to Lake Flux	Adjacent Lake (Minn. L)	Lake to Sediment Flux	Milford Creek	Water Column Storage*	Lake Water Column at End of Year
TP										
1999	0.03 (1)	0.05 (1)	1.06 (22)	2.04 (42)	1.70 (35)			4.95 (101)	-0.07 (-1)	0.11
2000	0.03 (10)	0.05 (16)	0.19 (58)		0.05 (16)	0.36 (110)		0.00 (0)	-0.03 (-10)	0.07
2001	0.04 (1)	0.05 (1)	2.94 (83)	0.50 (14)			0.49 (14)	2.99 (85)	0.04 (1)	0.12
2002	0.03 (2)	0.05 (4)	0.29 (23)		0.88 (70)	1.24 (100)		0.01 (1)	-0.01 (-1)	0.11
2003	0.02 (4)	0.05 (9)	0.41 (76)		0.06 (10)	0.54 (99)		0.00 (0)	0.00 (1)	0.12
2004	0.05 (2)	0.05 (2)	1.49 (52)	0.40 (14)	0.90 (31)			2.81 (97)	0.08 (3)	0.20
TN										
1999	0.3 (0)	0.3 (0)	18 (28)	31 (47)	16 (24)			66 (100)	-0.04 (0)	2.1
2000	0.4 (5)	0.3 (4)	4 (51)		3 (40)	9 (114)		0 (0)	-1.1 (-14)	1.1
2001	0.4 (1)	0.3 (1)	33 (53)	28 (46)			11 (19)	49 (81)	0.4 (1)	1.5
2002	0.3 (3)	0.3 (3)	6 (52)		5 (42)	11 (96)		0.2 (1)	0.2 (2)	1.7
2003	0.3 (1)	0.3 (2)	8 (44)		10 (53)	19 (100)		0.0 (0)	-0.02 (0)	1.7
2004	0.5 (1)	0.3 (1)	22 (52)		19 (46)	8 (18)		33 (79)	1 (3)	2.8

* End of year minus beginning of year mass of TP in the lake water column.
† Two outlier TP concentrations of >0.5 mg/L (one in 2000 and another in 2004) were set to 0.2 mg/L to better match temporally adjacent measurements.

Table 3.14: Model lake nutrient budget summary for Lower Gar Lake (metric tons, (% of Total Inputs)). (Quantification of Nutrient Inputs into the Iowa Great Lakes, 2005)

West Okoboji Lake 1999 to 2004 Nutrient Budget
The West Okoboji model results indicate that wet and dry deposition together provide about 37 to 77 percent of the annual input of TP while the watershed inputs vary from about 12 to 60 percent of the total for this time. TP input from adjacent East Okoboji varies from zero to just less than 20 percent of the total input. The model indicates that TP flux to the lake sediment varies considerably from about 10 to 200 percent of the total input TP with TP being removed from the lake water column during years when more TP is deposited to the sediment than is input to the lake. Rarely is there any net TP exported from the lake, at least during the relatively dry years. The water column appears to have sufficient storage capacity to store or release as much TP as is input to the lake during the course of a year.

The model indicates that wet and dry deposition together provide about 16 to 60 percent of the annual input of TN. TN input from adjacent East Okoboji varies from zero to 25 percent of the total input. The model indicates that net TN flux to the lake sediment varies considerably from zero to over 400 percent of the total input TN with TN being removed from the lake water column during years when more TN is deposited to the sediment than is input to the lake.

During 1999 and 2002 there was a net TN flux from the lake sediment to the water column that provided about half of the TN input to the lake for each of those years. A net TN export from the lake occurs only during 1999 and this amounts to 10 percent of the TN input. The water column appears to have the capacity to store all of the TN input to the lake during a year, or to release a quantity greater than the annual TN input to the lakebed sediment.

East Okoboji Lake 1999 to 2004 Nutrient Budget
The East Okoboji model results indicate that wet and dry deposition together provide about 19 to 53 percent of the annual input TP while watershed inputs vary from 17 to 71 percent of the total for this time period. TP input from adjacent lakes varies from zero to about 30 percent of the total input. The model indicates that some years show significant TP flux from the water column to the sediment while other years show a net flux of TP from the sediment to the water column, although T flux to the lake sediment is generally substantially greater. Some years show significant net TP export downstream to Upper Gar, while other years show no net output to the lower lakes in the system.

The model results indicate that wet and dry deposition together provide about 9 to 36 percent of the total for this period. TN input from adjacent lakes varies from zero to about 35 percent of the total input. The model indicates that TN flux to the lake sediment varies considerably from zero to over 150 percent of the total input TN while a net TN flux from the sediment to the lake of up to 25 percent occurs in some years. Annual net TN export from East Okoboji to the lower lake system varies from zero to 98 percent of the total TN input.

Lower Gar Lake 1999 to 2004 Nutrient Budget
The Lower Gar model results indicate that wet and dry deposition together provide about 2 to 26 percent of the annual input TP while the watershed inputs vary from 22 to 83 percent of the total for this period. TP input from adjacent Lake Minnewashta varies from zero to 42 percent of the total input. Most years show significant TP flux from the lakebed sediment to the water column. However, in 2001, which was the wettest year during 1999 to 2004, shows a significant net flux of TP from the water column to the sediment. During years when a significant amount of water overtops the spillway, most of the TP input to the lake is exported downstream to Milford Creek.

The Lower Gar results indicate that wet and dry deposition together provide about one to nine percent of the annual TN input while the watershed inputs vary from about 28 to 53 percent of the total input for this time period. TN input from adjacent lakes varies from zero to 47 percent of the total input. The model indicates that TN flux from the lake sediment to the water column varies considerably from zero to over 50 percent of the total input TN. During 2001, the wettest year of the period, shows a significant net flux of TP from the sediment to the water column. Annual net export from Lower Gar to Milford Creek varies from zero to 100 percent of total input.

Nutrient Budget Summary
Lake nutrient budgets indicated that rainfall and dry deposition are major sources of total phosphorous (TP) and total nitrogen (TN) to West Okoboji Lake and East Lake Okoboji Lake, but contribute only a minor amount of the nutrients to Lower Gar Lake. Surface water runoff contributes a substantial proportion of nutrients to all of the lakes, but there is considerable annual variability in contribution from runoff depending on the amount of

precipitation between dry and wet years. Lake to lake flow is a significant factor in the movement of nutrients between lakes, and sediment flux a significant factor in the movement of nutrients within individual lakes, but both demonstrate considerable variability from year to year in the amount and direction of net nutrient flow.

Generally, West Okoboji and East Okoboji sediment appear to be a net TP and TN sink, while Lower Gar sediment appears to be a source of nutrients to the water column; however, these results were based on a dry six-year time period. Sufficient nutrient concentration data to assess the role of sediment as a nutrient source or sink during wetter years is not available from this study.

Potential sources of error for the nutrient budget include:

1) Lake water samples collected only seven times during 2004 between June and September for nutrient analyses are used to characterize the lake nutrient mass and temporal variability in lake mass for the entire year. Lake TP concentration data collected by Bachmann and Jones (1974) indicate that systematic concentration shifts may occur during the course of a year with lower TP concentrations during the spring, and that variation within and between years may be significant. Data collection throughout the year, particularly for late fall, winter, and early spring, is generally lacking in IGL studies available for this work.

2) It is not clear how well equations developed based on flow-weighted TN as a function of percent cropland and TP concentration as a function of discharge coupled with estimated surface runoff from Ocheyedan water yield can be expected to approximate actual nutrient concentration inputs. However, data are insufficient estimate total inputs so some type of approximation is necessary.

3) There is a significant year-to-year variability in the annual nutrient budgets that may not accounted for in this study. This may be especially true for relatively wet years such as the 1992 to 1995 period. The relatively dry years examined in this study may not adequately reflect the nutrient budget for wetter years.

<u>SUMMARY</u>

Based on data collected by Hickock and Associates from 1971-1972, total phosphorous was found to be the critical element in the IGL systems. There was a linear relationship between TP inputs and algal levels, so that a halving of the TP input to a given lake might be expected to reduce the algal population by one-half. There is a lower limit to this relationship for if all inputs were removed; there would still be phosphorous recycled from the sediments.

High amounts of surface runoff correlated to the highest phosphorous concentration in the streams, the greatest input of phosphorous to the lakes, and the highest levels of summer algal blooms in the lakes. The number of animal units in a watershed had a significant correlation with the amount of phosphorous delivered by that watershed, indicating that livestock were a significant source of phosphorous to the IGL in 1971-1972.

The results for nitrate-N concentrations were less clear-cut. There was a significant negative correlation for the percent of watersheds in marshlands and a positive correlation for animal units. However, when the two factors were combined in a multiple regression analysis, no significant correlation was found for animal units. An earlier analysis of 1971 data produced a significant relationship between nitrate-N and percent of watersheds in row crops and a negative relationship with percentage of watersheds in marshland. No significant relationship was found between ammonia-N and any of the watershed land uses.

Data collected by Stenback, Crumpton, and van der Valk from 1999-2004 indicated that while small lake elevation differences produce alternating flow direction between lakes, there is a net long-term flow of water from the upper to lower Iowa Great Lakes, with significant annual variability between wet and dry years. (Quantification of Nutrient Inputs into the Iowa Great Lakes, 2005)

During dry periods, nutrients from the smaller, shallower and more nutrient-rich Lower Gar, Minnewashta, and Upper Gar Lakes may flow up lake into East Okoboji Lake. In addition, during the dry periods East Okoboji Lake may exchange water with West Okoboji Lake. Because East Okoboji has greater TP and TN concentrations, it can be a significant source of nutrients to West Okoboji during periods of up lake water flow.

Rainfall and dry deposition are major sources of TP and TN to West Okoboji Lake and East Lake Okoboji Lake, but contribute only a minor amount of the nutrients to Lower Gar Lake. Surface water runoff contributes a substantial proportion of nutrients to all of the lakes. Lake to lake flow is a significant factor in the movement of nutrients between lakes, and sediment flux a significant factor in the movement of nutrients within individual lakes.

Generally, West Okoboji and East Okoboji sediment appear to be a net TP and TN sink, while Lower Gar sediment appears to be a source of nutrients to the water column; however, these results were based on a dry six-year time period. Sufficient nutrient concentration data to assess the role of sediment as a nutrient source or sink during wetter years is not available from this study.

The CLAMP data collected from 1999 to present indicates that West Okoboji and Big Spirit Lakes are the least productive of the IGL. West Okoboji is in the *mesotrophic* category. Most of the other lakes are in the *eutrophic* category. Little Spirit Lake and Silver Lake have the highest TSI scores, which indicate they are the most productive and are considered *hypereutrophic*.

The data show that nitrate concentrations are highest in the spring and early summer months before declining in the summer. This time coincides with spring applications of fertilizers as well as high amounts of rain.

The data also show that water clarity is greatest in the spring before water temperatures increase and algal populations increase. Secchi depths are generally deepest in June and shallowest in August and September for the lakes. In general, East Okoboji, West Okoboji, Big Spirit, and Lower Gar have small decreasing Secchi depth trends, based on visual assessment, while Secchi depths in Upper Gar and Minnewashta have not changed over time.

The IDNR ambient lake-monitoring program differs from the CLAMP program in that the samples were collected and analyzed by professionals from 2000 to 2007. The ambient monitoring program characterizes current water quality in the monitored lakes and provides an opportunity to track trends in lake water quality. Some of the main factors are summarized below.

Stratification

Data collected through the ambient lake monitoring program indicated that West Okoboji is the only lake in the Iowa Great Lakes that stratifies regularly. The other lakes are too shallow and are susceptible to mixing by the windy conditions in that area of the state. One potential consequence of thermal stratification is anoxia (or low oxygen conditions) in the hypolimnion (the deep cold-water area) due to respiration. Hypolimnetic anoxia can lead to release of phosphorous from the sediment that can lead to algae blooms.

Turbidity

In general, the lakes in the Iowa Great Lakes region have lower turbidities and concentrations of total suspended solids (TSS) than other natural lakes in the state with the exception of Little Spirit, Lower Gar and Upper Gar Lakes.

Higher turbidity increases water temperatures because suspended particles absorb more heat. This, in turn, reduces the concentration of dissolved oxygen (DO) because warm water holds less DO than cold. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of DO. Suspended materials can clog fish gills, reducing resistance to disease in fish, lowering growth rates, and affecting egg and larval development. As the particles settle, they can blanket the stream bottom, especially in slower waters, and smother fish eggs and benthic macro invertebrates. Sources of turbidity include soil erosion, waste discharge, urban runoff, eroding stream banks, large numbers of bottom feeders (such as carp), which stir up bottom sediments, and excessive algal growth.

Total Organic Carbon (TOC)

Little Spirit and Center Lakes have relatively high levels of TOC, above the 75th percentile for all monitored, natural lakes. All other lakes in the Iowa Great Lakes fall below the 25th percentile for all monitored natural lakes.

Total organic carbon (TOC) is the sum of all organic carbon from decaying organic material, bacterial growth, metabolic activities of living organisms, and chemicals. Detergents, pesticides, fertilizers, herbicides, industrial chemicals, and chlorinated organics are synthetic sources of organic carbon. Levels of TOC can be used as a measure of organic contamination.

Conductivity
Center (571 µS/cm) Lake has the highest median specific conductance among the Iowa Great Lakes, which was above the 75th percentile for all monitored, natural lakes. Big Spirit (480 µS/cm) and West Okoboji (466 µS/cm) had the lowest median specific conductance among the Iowa Great Lakes.

Conductivity is useful as a general measure of stream water quality. Significant changes in conductivity can be used as an indicator that a discharge or some other source of pollution has entered a stream. Studies of inland fresh waters indicate that waters supporting good mixed fisheries have a range between 150 and 500 µhos/cm. Conductivity outside this range could indicate that the water is not suitable for certain species of fish or macro invertebrates. Industrial waters can range as high as 10,000 µmhos/cm.

Soluble Reactive Phosphorous (SRP)
Little Spirit (0.09 mg/L) and East Okoboji (0.04 mg/L) have relatively high SRP levels when compared to other monitored, natural lakes in Iowa (greater than the 75th percentile).

Soluble reactive phosphorous is the form of total phosphorous that is available for immediate uptake by algae. In phosphorous-limited situations, this form should be low to undetectable, as is the case in Big Spirit (0.003 mg/L) and West Okoboji (0.003 mg/L). As SRP increases, it implies that phosphorous is either not needed by algae or it is being supplied at a rate that is faster than the rate of biologic uptake. Ideally, soluble reactive phosphorous concentrations should be .01 mg/L or less at spring turnover to prevent summer algae blooms.

Total phosphorous is considered a better indicator of a lake's nutrient status because its levels remain more stable than soluble reactive phosphorous. Total phosphorous includes soluble phosphorous and the phosphorous in plant and animal fragments suspended in lake water.

Total Kjeldahl Nitrogen (TKN)
Little Spirit (2.6 mg/L) and Center (2.0 mg/L) have TKN concentrations above the median for other monitored, natural lakes in Iowa (1.7 mg/L). Little Spirit, Minnewashta, Center, and Lower Gar have the highest median ammonia concentrations, while Big Spirit and West Okoboji have the lowest.

Total Kjeldahl nitrogen is the sum of organic nitrogen and ammonia in water. High concentrations of TKN in a water body are generally from organic pollution, such as sewage or manure discharges. Ammonia is also commonly used as an agricultural fertilizer. Ammonia can be toxic to fish and invertebrate populations when at high levels.

Phytoplankton
Most phytoplankton samples were dominated by cyanobacteria, which often dominate summer plankton in eutrophic lakes. The median phytoplankton wet mass ranged from 9.1 mg/L in West Okoboji to 36.0 mg/L in Upper Gar. All lakes in the Iowa Great Lakes had a lower median concentration than the median for all monitored, natural lakes in Iowa (39.7 mg/L).

Phytoplankton or algae are the photosynthetic organisms that form the base of the food chain in lakes. Phytoplankton wet mass and composition are measured to get a better understanding of the biological dynamics of each lake.

Zooplankton
The median zooplankton wet mass ranged from 94.1 mg/L in West Okoboji to 288.5 mg/L in Lower Gar. Zooplankton is the microscopic and macroscopic animals that float, drift, or swim weakly in the water column. Zooplankton is the primary consumers of algae and many fish rely on them as a food source.

AQUATIC INVASIVE SPECIES

Introducing non-native species into Iowa waters can upset the balance of the ecosystem, hurting the environment. Aquatic Invasive species (AIS), which include plants, animals and other organisms, may dominate aquatic ecosystems where they are introduced because they are freed from natural competitors, predators and diseases.

Presidential Executive Order 13112 of February 3, 1999 - Invasive Species defines an *invasive species* as “an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.” The Executive Summary of the National Invasive Species Management Plan, developed by the federal interagency National Invasive Species Council (NISC) further clarifies and defines an invasive species as “a species that is *non-native to the ecosystem under consideration* and whose introduction causes or is likely to cause economic or environmental harm or harm to human health.”

Congress established the Aquatic Invasive Species (AIS) Task Force with the passage of the Non-indigenous Aquatic Invasive Species Prevention and Control Act in 1990 and reauthorized it with the passage of the National Invasive Species Act in 1996 (Act). The Act charges the AIS Task Force with developing and implementing a program for waters of the United States to prevent introduction and dispersal of aquatic Invasive species; to monitor, control and study such species; and to disseminate related information. Some states, including Iowa, are strengthening their own invasive species laws, regulations, or policies instead of awaiting stronger federal action.

Successful AIS reproduce early, often, in large numbers and in multiple ways, out-competing or consuming native species to the point of extinction. Their ability to grow rapidly, colonize disturbed sites, and tolerate a wide range of environmental conditions can be disastrous for the natural environment, economies, and/or public health.

Once established in a new location, AIS may:

- Negatively impact economies of nearby communities
- Decrease waterfront property values
- Reduce populations of native species
- Reduce fish spawning areas
- Interfere with boating, fishing, swimming and other water recreation
- Clog drinking water plants, power plants, and dams, substantially increasing operating and maintenance costs
- Affect human health
- Be impossible to eradicate

Aquatic Invasive species cost billions of dollars annually in damage and control measures. Zebra mussels alone are estimated to have cost the United States $750 million to $1 billion from 1989 to 2000. Because of the negative impacts to water quality, economies, and public health, both aquatic and terrestrial invasive species have gained new prominence in federal and state policy. There is increased cooperation among environmental nonprofits, government agencies, and trade organizations to halt or slow the spread of invasive species.

The United States has the interagency NISC and a National Invasive Species Management Plan, Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW), and federal AIS Task Force in place to combat invasive species and promote state/interstate invasive species management plans. (USDA, 2007)

IOWA AQUATIC INVASIVE SPECIES PROGRAM

The Iowa Department of Natural Resources Aquatic Invasive Species Program (DNR-AIS) is responsible for monitoring and managing AIS in Iowa. Bighead carp, silver carp, Eurasian watermilfoil, zebra mussels and other nonnative aquatic species threaten Iowa waters.

The Iowa AIS Program aims to:
- Reduce the risk of further introductions of AIS in Iowa
- Limit the spread of established populations of AIS into un-infested waters in Iowa
- Eradicate or minimize the impacts resulting from infestations of AIS in Iowa

(IA DNR, 2005)

In 2005, the Iowa Great Lakes Water Safety Council raised $32,000 to fund three DNR Law Enforcement Bureau Water Patrol Officers. Funding for the positions was donated by the Messengers of Healing Winds, Okoboji Protective Association, Alliant Energy Foundation, East Okoboji Lakes Improvement Corporation, Spirit Lake Protective Association, Conservation Foundation of Dickinson County, Mau Marine, Oak Hill Marina, Bridgewater Boats, and an individual donor. The funding was supplemented by DNR to hire eight additional summer officers. While the officers have the authority to issue citations for violations, the program emphasis is soft enforcement through education and voluntary compliance. The DNR-AIS focuses on raising public awareness to prevent the spread of AIS, monitoring state water bodies for AIS introductions, and control of AIS infestations.

In 2006, the DNR-AIS program targeted twelve high and medium priority boat ramps on the Iowa Great Lakes for inspections and public education because of greater boater activity and/or the greater likelihood boaters could be coming from lakes known to have invasive species. Intervention through early detection and rapid response is a critical strategy for preventing the establishment of new AIS populations. Early detection and rapid response efforts increase the likelihood that invasions will be addressed successfully while populations are still localized and population levels are not beyond that, which can be contained and eradicated.

High Priority Boat Ramps	Medium Priority Boat Ramps
Emerson Bay	Mini Waukon
Highway 9 Bridge	Lazy Lagoon
Hattie Elston	Hinshaw Bridge - Upper Gar
Marble Beach	Dam Road
Templar Harbor	East Okoboji Beach
Isthmus-Ainsworth Beach	Arnolds Park City Park

Table 4.1: Boat Ramps in the IGL area.

In addition to the boat ramps listed above, there are eighteen smaller, less well known Dickinson County lakes and sloughs with boat ramps, including Christopherson, Diamond, Grovers, Hottes, Jemmerson, Lilly, Little Spirit, Marble, Prairie, Spring Run, Sunken, and Yeager.

Because of the critical need for early detection, the DNR-AIS and its local partners have identified the need for increased measures to prevent the spread of AIS in Iowa.

A successful AIS program must include:

- A comprehensive public outreach effort-including but not limited to, facilitated public meetings, distribution of fact sheets, public service announcements, newspaper advertisements, rest area displays, traveler information systems, and gas pump toppers
- Active local partnerships to assist with developing watershed AIS management plans
- Permanent DNR-AIS program staff to conduct public education and volunteer programs
- Seasonal officers to conduct watercraft inspections and on-site public education
- Support for research that identifies pathways to limit the spread of AIS and identifies new AIS control methods
- Education of recreational users (boaters and anglers)

(IA DNR, 2005)

What the public can do

Some things the public can do to reduce the chance of spreading AIS in the Iowa Great Lakes and they include:

- Personal watercraft users should avoid running the engine through aquatic plants. When they are finished riding, they should run the engine for 5-10 seconds on the trailer to blow out excess water and vegetation from the internal drive, then turn off the engine.

- Sailors should remove aquatic plants and animals from the hull, centerboard or bilge board wells, rudderpost area and trailer.

- Boaters should inspect their boats after taking them out of the lake and remove any vegetation caught on the trailer or anything attached to the boat. Drain all water from the boat. In addition, boaters should rinse the boat and trailer with a high-pressure washer or hot tap water above 104 degrees before the boat is used somewhere else, or allow the boat to dry for up to five days.

- Anglers should throw away unwanted bait by putting it in the trash, rather than throwing it into the water.

- Waterfowl hunters should remove all plant and animal material and mud from their boats, motors, trailers, waders or hip boots, decoy lines and anchors, and cut cattails or other plants above the waterline when they are used for camouflage or blinds.

Photo 4.1: Shows the recent AIS signs posted at all lakes. **Photo 4.2:** Shows a boater conducting a proper inspection of the boat and trailer. This should be done before and after pulling it out of the water. Photos Courtesy of Iowa DNR.

Important Fish AIS in Iowa

Bighead and Silver Carp (Hypophthalmichthys nobilis, Hypophthalmichthys molitrix)

Photo 4.3: Bighead Carp. Photo courtesy of David Riecks.

- Native to central and southern China (bighead) and eastern Asia (silver)
- Introduced in 1970s by fish farmers
- Bighead have spread to at least 23 states; silver has spread to 16
- Both species found in the Mississippi and Missouri Rivers bordering Iowa
- Bighead carp also in the Des Moines, Iowa, Chariton, Cedar, Platte, Nodaway, Nishnabotna, and Big Sioux Rivers and smaller tributaries
- Silver carp also in the Des Moines and Chariton Rivers

Identification

- Deep, laterally-compressed body
- Large mouth without teeth
- Tiny scales
- Eyes far forward and project downward

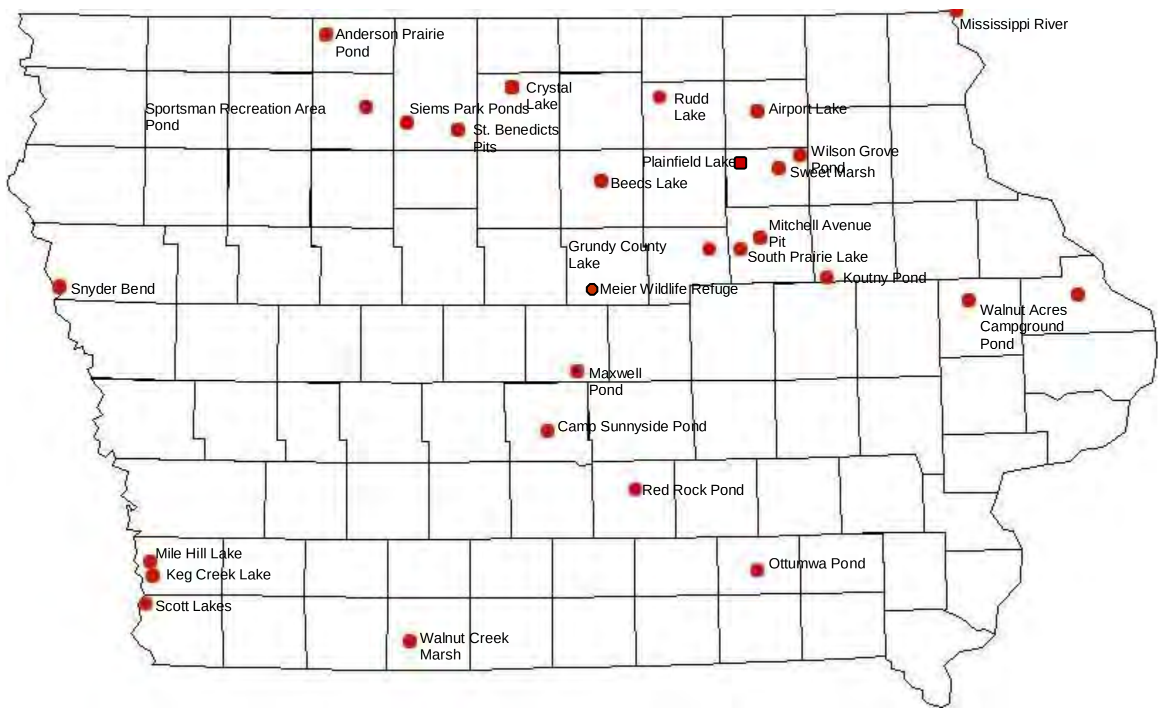
Impacts

- Compete with native filter-feeders (paddlefish, buffalo, mussels, larval fish)
- Disrupt commercial fishing
- Leap out of water when boats approach

Other Fish AIS:
Black Carp
White Perch
Round Goby
Rudd
Ruffe

Important Plant AIS in Iowa
Eurasian Watermilfoil
It can form thick underwater stands of tangled stems and vast mats of vegetation at the water's surface. In shallow areas, the plant can interfere with water recreation such as boating, fishing, and swimming. The plant's floating canopy can also crowd out important native water plants.

Eurasian Watermilfoil Infestations in Iowa through 2007



Map 4.1: Eurasian Watermilfoil Infestations in Iowa through 2007. Map and locations of Eurasian Watermilfoil provided by Kim Bogenshutz with the Iowa DNR, 2007.

Eurasian watermilfoil (Myriophyllum spicatum)

Photo 4.4: Eurasian Watermilfoil. Photo courtesy of Minnesota DNR.

- Native to Europe and Asia
- Introduced into North America in the 1940s
- Invaded at least 45 states and three Canadian provinces

Identification

- 12-21 pairs of leaflets
    - Appearance - leaves collapse against stem when removed from water

Photo 4.5: Eurasian Watermilfoil. Photo courtesy of Iowa DNR.

- Branches profusely at water surface forming dense mats

Impacts

- Displaces native aquatic vegetation
- Forms dense surface mats which restrict boating, water-skiing, fishing, and other aquatic recreation
- Lowers value of lake front property
- Reproduces primarily by vegetative propagation and spreads from lake to lake by watercraft and/or trailers

Purple Loosestrife (Lythrum salicaria)

Photo 4.6: Purple Loosestrife much as it would appear in the IGL.
Photo courtesy of the Iowa DNR.

- Native to Europe and Asia
- Established along the east coast of the U.S. by 1800s
- Currently found in almost all states and all Canadian provinces

Identification
- Plant height 2-7 feet
- Linear leaves with smooth edges, usually opposite
- Long spikes of purple or magenta flowers with 5-6 petals
- Flowers in July and August

Impacts
- Dense stands displace native vegetation and wildlife
- Clogs drainage ditches
- Single plants produce up to two million seeds each year; roots and underground shoots also produce new plants
- Tolerant of a wide variety of growing conditions

Brittle Naiad (Najas minor)

Photo 4.7: Brittle Naiad. Photo courtesy of North Carolina State University.

- Native to Europe
- Introduced into North America in the 1930s
- Invaded at least 24 states in the eastern and southern United States
- First identified in Iowa in 2003

Identification
- Stems - up to four feet long, highly branched, crowded terminal nodes
- Leaves - opposite, about one inch long, prominent marginal teeth, often re-curved

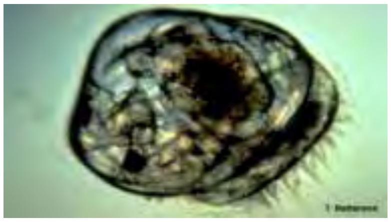
Impacts
- Displaces native aquatic vegetation
- Forms dense mats which restrict boating, water-skiing, fishing, and other aquatic recreation
- Reproduces by fragmentation and seeds
- Plant is very brittle, breaks apart, and spreads from lake to lake by watercraft and water movement

A key factor in the plant's success is its ability to reproduce through stem fragmentation and underground runners. A single segment of stem and leaves can take root and form a new colony. Fragments clinging to boats and trailers can spread the plant from lake to lake. The mechanical clearing of weed beds for beaches, docks, and landings creates thousands of new stem fragments that can drift with the wind and current. Removing native vegetation creates perfect habitat for invading Eurasian watermilfoil.

For example, water hyacinth is commonly used in aquatic gardens, but populations that have escaped to natural areas have completely covered lakes and rivers, devastating the water bodies and the life they support.

Other Plant AIS:
Curly-leaf Pondweed
Flowering Rush
Salt Cedar

Important Invertebrate AIS in Iowa
Zebra Mussel (Dreissena polymorpha)



Photos 4.8, 4.9, 4.10: Zebra Mussels at various stages of development.

- First found in Iowa in 1992 in the Mississippi River
- In one year, spread throughout the entire Mississippi River along Iowa
- Veligers (Juvenile Zebra Mussels) collected in 2003 from Missouri River in South Dakota
- Discovered in Clear Lake in 2005
- Discovered in Lake Delhi in 2006

Identification
- Yellow and/or brown D-shaped shells up to two inches long with alternating light and dark bands
- Usually grow in clusters containing numerous individuals
- Only freshwater mollusks that attaches to solid objects

Biology
- Sexually mature within one year
- Each female may produce up to one million eggs each year
- Veligers are free swimming and move with the currents
- Veligers fall out of the water column after 2-4 weeks

Impacts
- Clog pipes
- Hamper boating
- Clog beaches
- Kill native mussels, plants, crayfish
- Compete with small fish and native mussels for food

A series of aquatic invaders in the Iowa Great Lakes, including the rusty crayfish, silver carp and zebra mussel, could introduce new parasites and diseases causing catastrophic declines in populations of native species.

Other Invertebrate AIS:
Quagga Mussel
Rusty Crayfish
Fishhook Waterflea

New Zealand Mudsnail
Spiny Water Flea

Photo 4.11: Adult Zebra Mussel.

Zebra mussels can spread rapidly in the United States because they have no natural enemies here. Clear Lake – less than 100 miles from the Iowa Great Lakes - provides a textbook example of the threat. In 2005, two adult zebra mussels were found. Two years later there is a wide spread outbreak of zebra mussels in Clear Lake.

When docks and hoists were removed from Clear Lake in the fall of 2007, the exponential increase of zebra mussels became readily apparent.

Photo 4.12: Zebra Mussels on boat hoist.

The boat hoist at left shows what was found in the fall of 2007 as docks and hoists were removed from the lake. In comparison, only 2005 two adult Zebra Mussels were found in Clear Lake in 2005. In 2006, juvenile Zebra Mussels were found in the same area of Clear Lake.

Photo 4.13: Plate sampler at Clear Lake.

To monitor the mussels, the DNR set out five plate samplers around Clear Lake and checked them monthly during summer 2007. All of the plate samplers had zebra mussels. The plate at left had the most, with more than 500 zebra mussels on it in July.

The Zebra Mussels in Clear Lake probably arrived on or in a boat that had picked up the mussels in an infested water body. Young Zebra Mussels are microscopic and can be unintentionally transported on boats or trailers.

Our environment, particularly our public lands and waters, is facing many different, complex threats like expanding pollution impacts, invasive species, urban sprawl and the consequences feeding off of our culture‘s insatiable demand for petroleum-based products (ethanol). All of these issues threaten our natural resources; however, when they are combined with greater demands on our public resources and a scarcity of public funding to support traditional resource management, the sustainability of our natural resource base is being questioned by taxpayers who wonder why tax dollars are going towards acquisition of public land. (Starinchak, 2006)

Affected Areas

- Eurasian watermilfoil and curly-leafed pondweed can be found around Iowa. Although they most likely cannot be eradicated completely, natural resources officials have had areas around boat docks, beaches and fishing jetties treated for the weeds to keep the areas clear.

  Zebra mussels, which have inundated the Mississippi and Missouri rivers, have now been found in Clear Lake and Lake Delhi.

  Big-head carp have reached the Red Rock Dam on the Des Moines River. They also can be found in the Chariton, Cedar, Platte, Nodaway, Nishnabotna, Mississippi, Missouri and Big Sioux Rivers and smaller tributaries. In 2007, Iowa fisheries biologists found a fish kill in a wetland area off the Missouri River, called Louisville Bend. The 40-acre area had an estimated 6,000-8,000 dead fish, of which 50 to 60 percent were bighead, grass, and silver carp.

How to Battle Invasive Species

Iowa Department of Natural Resources officials are asking people who recreate in Iowa waters, as well as in other states, to take precautions to help prevent the spread of invasive species like big-head carp, silver carp, Eurasian watermilfoil, curly-leafed pondweed and zebra mussels.

To decrease the chances of spreading some of these invasive species:

- Remove any visible plants, fish, animals or mud from boat, trailer, and other equipment

- Drain water from all equipment- motor, live well, bilge, transom well

- Clean and dry anything that is exposed to water - equipment, boots, clothing, and pets.

- Before transporting to another water body, rinse boat and equipment with water 104 degrees or hotter, spray boat and trailer with high-pressure water at a car wash, or dry boat and equipment for at least five days

- Never release fish, animals or plants into a water body unless they came from that water body

- Empty unwanted bait in trash

- Learn to identify aquatic invasive species and report any suspected infestations to the nearest DNR fisheries station

- People who shore and fly-fish should remove aquatic plants, animals and mud from waders and hip boots and drain water from bait containers.

2008 Volunteer AIS Inspection Program - Iowa Great Lakes
There are 12 major boat ramps in Dickinson County plus another 18 minor boat ramps. The DNR summer Water Patrol Officers are visiting several of the major boat ramps each summer day to educate boaters about the threat of Aquatic Invasive Species and how the boater can avoid transporting AIS into the Iowa Great Lakes.

The 2008 AIS volunteer program is being developed by the DNR and the Iowa Great Lakes Water Safety Council to supplement the WPO effort. The Okoboji Protective Association, East Okoboji Lakes Improvement Corporation, Spirit Lake Protection Association, and other lake protective organizations will provide boat ramp volunteers on their lakes to educate boaters about the threat of AIS and how AIS can be controlled from gaining a foothold on the Iowa Great Lakes.

SUMMARY
Aquatic Invasive species greatly affect the balance of the ecosystem. These AIS choke native species so that they cannot thrive in their natural environment. More times than not, people are at fault for unknowingly transporting these species. Understanding what we can do to keep our ecosystem clean will ensure that the same outdoor activities can be experienced for generations to come.

CYANOBACTERIA

Cyanobacteria, sometimes called blue-green algae, are organisms that naturally occur in fresh, brackish, and marine water. Cyanobacteria have many characteristics of bacteria, but they also contain chlorophyll and can photosynthesize like algae and plants. Cyanobacteria often have a blue-green color, which is why they are also called blue-green algae. Cyanobacteria come in many sizes and shapes including microscopic single cells as well as filaments and colonies that are easily visible to the naked eye.

Photo 5.1: Cyanobacteria can be large enough to be seen with the naked eye. Photo courtesy of J. Graham, U.S. Geological Survey.

Cyanobacteria occur naturally in most lakes, but under the right conditions, cyanobacteria may grow excessively causing massive accumulations (called blooms) of the algae. Many different factors may lead to cyanobacteria blooms including excessive nutrients, low light levels, elevated temperatures, and low water levels. Cyanobacteria blooms are unsightly and caused low dissolved oxygen levels and reduced water quality. In addition, cyanobacteria have the potential to produce toxins (called cyanotoxins), that are potent enough to poison aquatic and terrestrial organisms, including animals and humans. Alteration, degradation, and eutrophication of aquatic ecosystems have lead to an increasing occurrence of cyanobacteria blooms worldwide. Blooms have occurred everywhere from Brazil to China, Australia to the United States. During 2006, Cyanobacteria made the news in at least twenty-one states seven of those in the Midwest including Minnesota, Wisconsin, Illinois, Iowa, Missouri, Kansas, and Nebraska. Even more startling is the statistic that at least 33 States have anecdotal reports of human or animal poisonings associated with cyanotoxins.

Photos 5.2 & 5.3: Cyanobacteria blooms in East Okoboji during June 2000 (top) and Upper Gar during August 2006 (bottom).
Photos courtesy of Jennifer Graham, U.S. Geological Survey.

There are many different ways that the algae can be transferred between ecosystems including flow from one lake to the next or from one reservoir to the next, transport of live cells or spores by animals, and people, and transport of spores by wind. There are several factors complicating our understanding of how and how often cyanobacteria are transferred among water bodies including: cyanobacteria spores may be dormant in lake sediments for many years or the cyanobacteria may typically be present in the water column at levels that are too low to detect until conditions become ideal for cyanobacteria growth. Transfer probably is not as much of concern in the Iowa Great Lakes. Water quality is greater concerns as from what biologists can see most of the lakes have the same cyanobacteria species present, although the dominant species may vary from lake to lake.

ADDITIONAL RESEARCH COMPLETED ON CYANOBACTERIA

The United States Geological Survey (USGS) has been involved with further research on cyanobacteria. The USGS Kansas Water Science Center has established an Algal Toxin Team and some of their research have included sampling the Iowa Great Lakes during bloom events. (Graham, 2005)

Research Needs

- Consistent sampling protocols. Collection technique and sample location(s) when collecting samples for cyanotoxin analysis are important and should be as consistent as possible to enable readings that are more accurate.
- Robust and quantitative analytical methods. Analytical methods for a variety of cyanotoxins will depend on the capabilities of the USGS and other laboratories.
- Regional distribution and occurrence of cyanotoxins
- Long term studies to identify the key environmental factors leading to toxic cyanobacteria blooms.
- for early detection should include continuous real-time water-quality monitors
- models

Problems

During the last ten years, only about 10% of row crops within the Iowa Great Lakes area watershed were converted to Conservation Reserve Program (CRP) acres. The area continues to urbanize with construction of summer homes and condominiums and the associated recreational and service facilities, such as golf courses, strip malls, and restaurants. These changes may cause increased runoff and nutrient loading to the Iowa Great Lakes, as well as other ecosystem disturbances, conditions that favor the growth of cyanobacteria.

Concerns

There are four main concerns with cyanobacteria:

1. Cyanobacteria may potentially produce taste-and-odor compounds and toxins that are poisonous to both aquatic and terrestrial organisms.
2. Cyanobacteria blooms may form in warm, slow-moving waters that are rich in nutrients such as fertilizer runoff or septic tank overflows.
3. Cyanobacteria blooms in the Iowa Great Lakes may occur at any time, but most often occur in late summer or early fall.
4. Unsightly, potentially toxic, cyanobacteria blooms may lead to a loss of recreational revenue. In addition, treating drinking water supplies with taste-and-odor problems associated with cyanobacteria are costly.

Solutions

A long-range strategic plan developed by the Dickinson Clean Water Alliance has identified four main watershed goals for the Great Lakes area:

1. Native biological diversity is respected and encouraged
2. Infiltration practices are promoted throughout the watershed
3. Impaired waters are protected and improved

4. High quality waters are maintained and improved

These goals will assist in the reduction of the number of occurrences of cyanobacteria blooms. They can be achieved by protecting and improving water quality, which could reduce sediment and nutrient loads, which may decrease the low light/high nutrient conditions favored by the cyanobacteria; and native diversity of aquatic plants may discourage the growth of cyanobacteria.

How to protect yourself, family, and pets from exposure to cyanobacteria toxins:

- Do not swim, water ski, or boat in areas where the water is discolored or where you see foam, scum, or mats of algae on the water.
- If you do swim in water that might have a cyanobacteria bloom, rinse off with fresh water as soon as possible.
- Do not let pets or livestock swim in or drink from areas where the water is discolored or where you see foam, scum, or mats of algae on the water.
- If pets (especially dogs) swim in scummy water, rinse them off immediately—do not let them lick the algae (and toxins) off their fur.
- Do not irrigate lawns or golf courses with pond water that looks scummy or smells bad.
- Report any "musty" smell or taste in your drinking water to your local water utility.
- Respect any water-body closures announced by local public health authorities.

SOURCE WATER PROTECTION

The following paragraphs present an overview of source water resources in Dickinson County and the Iowa Great Lakes Source Water Action Team (SWAT) Source Water Protection Plan. For a complete review, see the *Management Plan for Water Quality - Iowa Great Lakes*, February 1974, and *Iowa Great Lakes Source Water Action Team (SWAT) Source Water Protection Plan*, August 2006.

The Iowa Great Lakes Source Water Action Team (SWAT) have determined that instead of finding alternate water sources after traditional sources of water have been contaminated, source water protection planning allows communities to plan in advance to protect their vital resource and avoid the high costs of developing new water sources. Representatives from the municipal water systems in Dickinson County and interested educators, environmentalists, and other citizens have worked together through the SWAT to create their community-based plan.

SOURCE WATER RESOURCES

Iowa Great Lakes' Source Water Facts

The IGL are the resource or the source of the water, which provides the local communities their drinking water. Below is a matrix, which explains the amount of water that is used throughout the community and the capacity of the Public Water Supplies as of May 2006:

	Milford	**Wahpeton**	**Central**	**Spirit Lake**
Gallons of water produced each year	173 million	44 to 46 million	215 million	308 million
Households served	1,293	514	0 served directly	2,750
People served	2,474 (census), Additional summer Does not include consecutive system population	572 (census) Summer estimate 2,000	2,000 (permanent population served by Arnolds Park & Okoboji), Additional summer	4,250 (permanent), additional population served in the summer
Design capacity of intake	1.44 Million Gallons per Day	864,000 Gallons per Day	2.4 MGD	3.3 MGD
Design capacity of treatment plant	1.2 MGD	432,000 GPD	2.4 MGD	1.5 MGD
Maximum pumping capacity of intake (gpm)	1,300 gallons per minute	300 gpm	1,600 gpm	2,500 gpm

Maximum pumping capacity of treatment plant	1.8 MGD	300 gpm	1,600 gpm	1,100 gpm
Raw water temperature	3.2 to 25 C	4 to 25 C	2.0 to 25 C	34 to 80 F
Raw water pH	8.3 to 8.6	8.0 to 8.5	8.2 to 8.7	7.05 to 8.65
Finished water turbidity	0.03 to 0.05 NTU	0.030 to 0.261 NTU	0.050 to 0.150 NTU	0.03 to 0.20 NTU
Finished water fluoride	0.9 to 1.2 mg/L	0.040 mg/L	0.90 to 1.2 mg/L	0.86 to 1.17 mg/L
Finished water chlorine	0.6 to 1.7 mg/L free chlorine	0.80 to 1.20 mg/L free chlorine	0.80 to 2.00 mg/L free chlorine	0.78 to 3.70 mg/L free chlorine
Finished water hardness	230 mg/L as $CaCO_3$	235 mg/L as $CaCO_3$ (14 grains)	13 grains	120 to 190 mg/L

Table 6.1: The amount of water that is used throughout the community and the capacity of the Public Water Supplies as of May 2006.

Central water sells water to Iowa Lakes Regional Water. Milford Municipal Utilities sells water to Wahpeton, West Okoboji, Iowa Lakes Regional Water and North Shore (a portion of Osceola Rural Water‘s system on the north end of West Okoboji.
The municipal water utilities serve water to these entities with the understanding that the water pumped and treated from one of the Iowa Great Lakes Water Utilities must remain within the watershed of the Iowa Great Lakes.

Background
The 1996 Amendments to the Safe Drinking Water Act required that the primary agency in charge of enforcing the Clean Water Act, the Iowa Department of Natural Resources, conduct a source water assessment on every public water supply. In September 1998, the IGL that feed source water to the Public Water Supplies of Milford, Wahpeton, Central Water System, and Spirit Lake was assessed. The assessment report delineated the Source Water Protection Area and inventoried potential point sources of contamination to the IGL watershed and the water systems that use it for their drinking water.

The Source Water Assessment was completed in 1999. In 2002, the Region 7 USEPA invited its four-state region (IA, KS, MO, and NE) to self -nominate potential communities that had completed their Source Water Assessments to participate in a pilot project. The pilot project was to be used to help communities move from assessment to a community-supported plan to protect their source water. Once completed, these communities will become a mentor community to help other communities learn about community-created Source Water Planning.

The IGL community was selected, and a partnership was created between USEPA and the Public Water Supply of Milford. The local environmental cooperative, the Clean

Water Alliance, was engaged to help organize the effort through its membership. A public meeting was held where over 70 citizens attended. However, a year into the effort the Clean Water Alliance removed itself as the lead organization.

In the summer of 2003, the Public water suppliers, Milford, Wahpeton, Spirit Lake and Central Water, and the USEPA continued the work on plan development. In September 2004, the public water supply directors recruited twelve local citizens with a diverse background to serve on the SWAT and help with the effort. Seven resource agencies also participated.

THE IOWA GREAT LAKES SWAT SOURCE WATER PROTECTION PLAN
In September 2003, SWAT was created with the assistance of the USEPA. Local Public Water Supply directors' recruited local citizens throughout the watershed to begin efforts to create an achievable, affordable, and locally created Source Water Action Plan**.**

Mission Statement
To create and implement a Source Water Action Plan that will preserve, protect and sustain the drinking water of the Iowa Great Lakes and its surrounding communities.

Guiding Principals
The Source Water Action Team created its Source Water Action Plan around these eight concepts.

1) Educate consumers and users about the source of their drinking water, methods available to protect the source water, and the benefits of protecting the source water

2) Promote the benefits of Source Water Protection through community planning and implementation

3) Evaluate and address current conservation practices in the watershed with the rural landowners and operators

4) Evaluate and address best management practices in the urban watershed with specific focus on storm water run-off;

5) Coordinate with the various IGL stakeholders who are working to protect water quality

6) Plan and collaborate responses to hazardous events at critical sites threatening source water

7) Develop local leadership to+ help continue and improve source water protection through an ongoing liaison with the SWAT

8) Implement the IGL Source Water Protection plan through community action.

PRIORITY SOURCE WATER PROTECTION PROJECTS

The SWAT discussed a variety of ways in which the community could take action to protect their lakes. The detailed plan gives much more insight into the various action items that could be implemented and completed as part of the Source Water Protection Plan. The following priority action projects have been highlighted by SWAT as the most important. They were identified and prioritized by the SWAT as additional measures that would enhance the above-mentioned eight Source Water Protection concepts:

1st Priority: Transportation of Hazardous Materials-Emergency Planning - work with all of the communities/local partners to create one plan that will focus on how the community will address hazardous materials accidents, spills, and contamination to the lakes.

2nd Priority: Identify and prioritize storm sewers, tiles, urban/rural drainage systems, etc. through a color-coded stenciling project. Implement the stenciling project to educate all community members about what areas feed directly into the lakes and use this map of the drainage system for future planning efforts.

3rd Priority: Septic Tanks Inventory identifies and addresses a prioritized list of the malfunctioning and failing septic systems throughout the watershed.

Education

One of the main goals the SWAT highlighted as an important action is to educate the public at-large. The SWAT would like to educate everyone in the lakes area, residents and tourists alike, that the lakes are not only used for recreational purposes, but also for our drinking water. Many people do not understand this. The SWAT has brainstormed many activities that will be beneficial to educating the community. Below is a list of ideas that is prioritized in order of importance.

1st priority: Deliver student education regarding Source Water Protection (i.e. our lake = our drinking water) and encourage particular behaviors to promote its protection.

2nd priority: Create and deliver a set of ―Top Ten" Best Practices for homeowners, businesses, children, and tourists to understand how they can better protect the Iowa Great Lakes.

Additional ideas are listed below that were created by the SWAT for consideration in the education piece of the Source Water Protection Plan:

1) The SWAT recommends that the community start a youth education program. Student education would target kids of all ages K-12 and those that support them. The county naturalist is already working with children. The SWAT wants to take this idea one-step further and include parents, staff, and administration. These efforts could be linked with school testing, school projects, science fairs, social and environmental events, informational handouts and curriculum.

2) The public would also have to be educated. The SWAT had several suggestions on how this would best be accomplished. The focus would be through educational campaigns. The following are their suggestions:

- Don't top off when you fill up your gas tank!" This campaign would educate drivers of cars and boaters who fill up their tanks when they are on or near the lake.
- SWAT would also like to do education campaigns on the idea that many people in the area (citizens and visitors) do not understand that the lakes are our source for drinking water (Our Drinking Water = Our Lakes). The group thought of making up bumper stickers, hotel room reminders, and restaurant and drinking establishment reminders to use for this campaign.
- Another campaign would define for the community what storm water run-off is and what effects it has on the lakes.

3) A campaign could be created to educate parties regarding what the best practices are for lawn maintenance. For homeowners and businesses lists could be created, (e.g. the top 10 list of what to do to protect the lakes) and distributed, so that the community and its visitors know what the acceptable practices are and are encouraged to practice these important behaviors.

4) A specific campaign would be created to educate the hundreds of thousands of recreation and outdoors people and visitors to the lakes. They include boaters, fishers and swimmers, Winter Games participants and shoppers. Everything these visitors do can directly influence the lakes, thus affecting our drinking water. The intent is to educate at local celebrations (Winter Games, 4th of July, church events, church camps, Boy Scout events, etc.). The lakes have many people around during many of the holidays. It would be a good time to capture these audiences. The 4th of July and Winter Games were the two holidays that were prioritized to reach the most people.

5) Focus on working with our local farming and agricultural community. They are perhaps the most knowledgeable about the land, including animal management, use of chemicals and fertilizers and crop management. The team wanted to make sure that they too know the best practices available to keep the lakes protected.

6) Create a Lake History that could be used throughout the community. This could be as simple as creating pamphlets or brochures that businesses, organizations and residents could use during key events to inform their memberships about the Lakes History, its value, and the best management practices to preserve and protect the lake for the future. Education is vitally important in protecting our lakes and our drinking water.

Four drinking water intakes supply the water needs for the residents and industries for the Iowa Great Lakes. Two of these intakes have a high potential for hazardous waste spills (See Map 6.1). These intakes are located along two of the major highways that go through the lakes area. They are U. S. Highway 71, which has a traffic count of 14,000 vehicles per day, and State Highway 86 which has a count of over 5,300 vehicles per day.

Many of these vehicles are trucks and semi tractor-trailers that haul various types of commodities. An accident and resulting spill could be disastrous to the water supply of the Iowa Great Lakes.

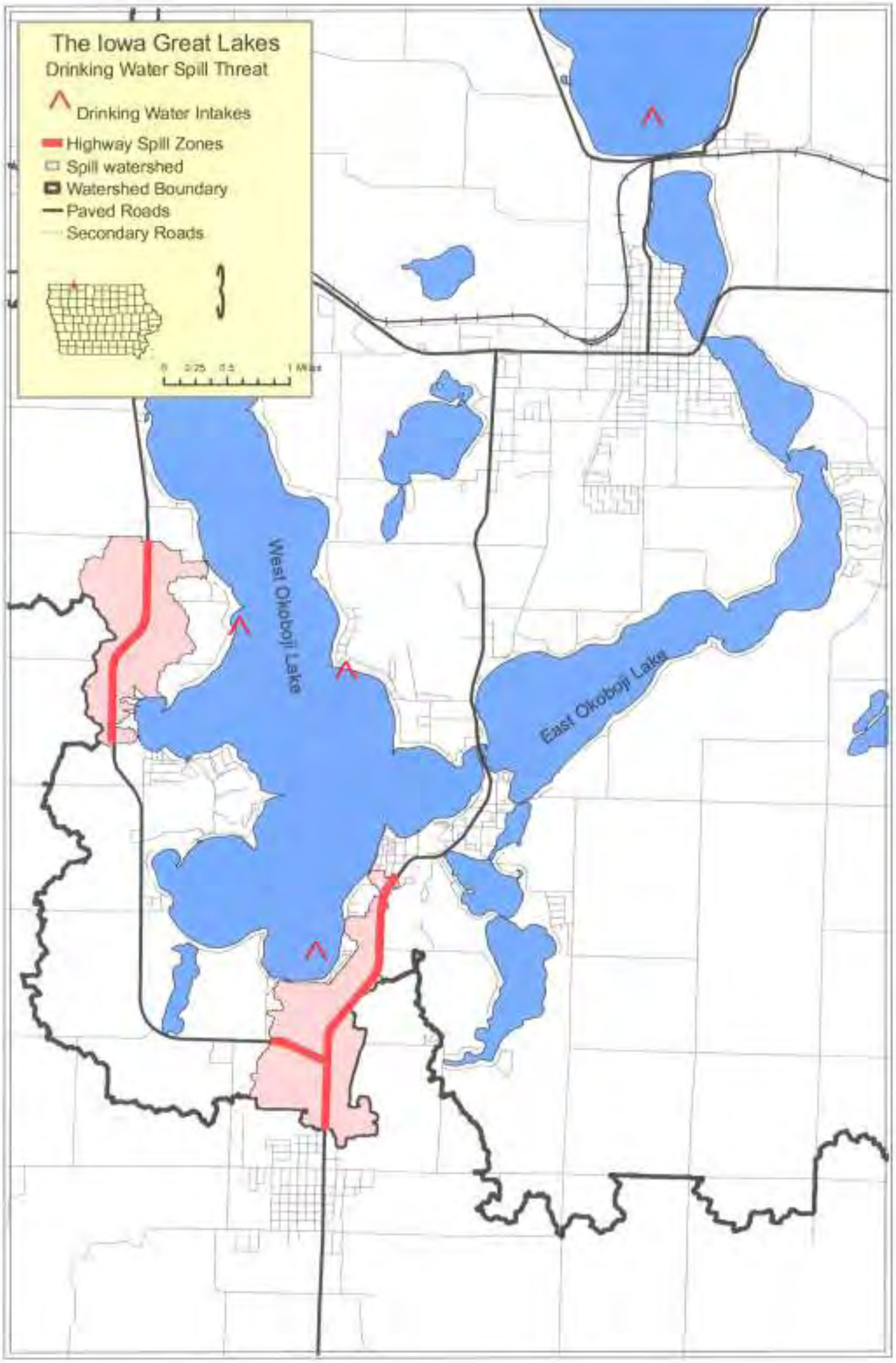
Now, in the event of an accidental hazardous materials spill, action will be taken by the fire department of that jurisdiction. However, in all cases outside help will be needed if a major hazardous materials spill occurs. The fire department personnel, who respond to a spill accident, would most likely not be able to identify the hazardous materials. It may not be immediately possible to identify the hazardous or toxic chemicals involved in the spill, which is the first thing that needs to be done to make an initial assessment as to the severity or magnitude of the spill.

The main problem with this type of response is that the volunteer fire department personnel have very little hazardous spill training. Once they decide that a hazardous spill has occurred they would need to contact the HazMat team, which is located in Sioux City, 110 miles away. It would take two hours to get to the scene and by that time, the hazardous material could be in the drinking water system.

There are several alternatives available to avoid the chance of a spill and how to respond to a hazardous spill threat:

1 Develop a truck route around the lakes. This would eliminate most of the potential for spills.
2 Establish a trained volunteer HazMat team in the immediate area.
3 Equip the volunteers with the necessary vehicles with the proper equipment to identify and treat the spill.

It is imperative that the water utilities be notified immediately in case of a spill. Presently communications between the volunteer fire departments and the municipal water utilities is non-existent. There are established communications between the sheriff's office and the fire departments. Additionally, the area fire departments should begin training on hazardous materials and established an on-call group to respond to these hazardous threats. It would be prudent for the Iowa Great Lakes Communities to establish a hazardous materials task force to ensure that all threats are avoided. Finally, in the event that a spill would occur it should be the responsibility of this task force to have a response plan in place.



Map 6.1: IGL Drinking Water Spill Threat

Critical Behaviors Identified
During one of the SWAT meetings, members analyzed potentially critical behaviors practiced within the community and why these behaviors are detrimental to the health of the lakes. These critical behaviors identified below, along with why they are important, are the basis of many of the projects the SWAT wants to implement for better protection of the lakes.

The critical behaviors that were identified and should be practiced in the Iowa Great Lakes include:

- Topping off gas takes at the tank
- Non-pervious surface drainage planning using Low Impact Development
- Implementation of a regional drinking water plan between immediate responders and drinking water operators
- An education plan that will teach visitors as well as residents the value of our lake water – our drinking water
- Lawn fertilizer and pesticide standards and practices should be adjusted to reduce chemicals reaching the lake
- Develop an education program for agricultural lands
- Proper disposal of household hazardous materials
- Promote the use of low carbon footprint boats
- Apply speed restrictions to boats to prevent the stirring of bottom sediments in the water column
- Inform citizens to contact water operators as soon as a hazardous spill, lift station failure, or any other action that would affect the drinking water occurs.

Communication
The SWAT was able to present some ideas of how to communicate their message to the public and those ideas are identified below in the communication plan matrix.

Citizens will understand what their lawn chemical assessment is before adding more fertilizers/pesticides	After being trained, lawn applicators will assess the lawns prior to the delivery of any additional lawn care chemicals. Lawn care providers/customers will know soil assessment before any additional fertilizer/pesticide is applied. Applicators are trained and certified to assess the lawns.	We will work with lawn care companies, local state and federal agency experts and citizens
Educate public about non-point source pollution-with our goal for everyone to know our	Educate city residents, farmers, and rural citizens.	Work together with SWCD, NRCS, IDNR, Farmers, urban

drinking water sources and what their individual impact is.	Method: develop drainage maps and engage citizens in a stenciling/color-coding of the access points to the lakes.	and rural landowners, drainage districts, and the SWAT

Table 6.2: Community SWAT Analysis

A Priority List of Critical Sites throughout the IGL
Because of the surface and subsurface flow of water in the IGL watershed, any potentially large or hazardous spill could affect one or all four of the water supply utilities' intakes and municipalities. The SWAT identified critical sites and areas that would pose the greatest risk to the community and the Public Water Supply areas that provide the communities their water. Below is the list and why the SWAT believed them to be vulnerable, and the ways to address these vulnerabilities.

- Highway bridges and major traffic areas – vulnerable to spills
- The four water intakes in the Iowa Great Lakes – immediate intake to the water supply
- Upstream watershed areas – the upstream watershed areas come downstream
- Agricultural lands – has the greatest percentage of the watershed and a lot of activity
- Drainage tiles – take surface water and drain directly to the lake or major water body
- Urban run-off – some of the most disturbing activity and with storm sewers there is direct access to a water body
- U.S. Highway 71 near Oak Hill Marina – poor planning has caused flooding of the street
- Old and non-functional septic tanks – cause pollution
- Malfunctioning lift stations – direct access to the lake
- Center Lake – drains directly to West Okoboji Lake

Hazardous Waste Contamination Prevention Measures
The first priority action item that the SWAT identified is to create one inclusive watershed-wide emergency management plan that will address various threats to the IGL (e.g. hazardous waste spills, potential terrorists attacks, back-up plans.)

Funding Plans and Opportunities
The SWAT also identified the need for funding to implement many of the actions highlighted in the plan. The following are ideas that would help sustain the intended efforts of the SWAT and its Source Water Protection implementation efforts:

Iowa Great Lake's Research, Science and Cutting-edge Technology Projects - Past, Present, & Planned
There is a rich history of water quality activities in the IGL. Data and research goes back to the early 1900's by some of Iowa's most well known scientist such as Dr. Thomas McBride, Dr. Lewis Pammel, and Dr. Bohumil Shimek. Through the foresight of these early scientists, the Iowa Lakeside Laboratory was formed and is now an Iowa Regents-

sponsored field data station. Since the 1900's, the Lab has collected water quality data and data related to the watershed that surrounds these lakes.

Much of the work started in the past is being continued to this date and has been shared by the Iowa Department of Natural Resources with the SWAT during education presentations at their monthly meetings. Many of the ideas that the SWAT has recommended in this plan, have a link to the current work that is being completed by local, state, and Federal agencies. The following is a narrative of the scientific work that is ongoing:

The county and many of the municipalities in Dickinson County are in the process of re-writing long-range watershed and land use plans.

This information will help county and municipal governments rewrite ordinances that will help create acceptable land use practices for at-risk areas. Assessments have been completed on the IGL for the protection of water quality. A few of the recent assessments are:

- In 1974, *"Water Quality in the Iowa Great Lakes a report of the Iowa Great Lakes Water Quality Control Plan" was published and was written* by Roger Bachman and John Jones. This assessment found that a series of eutrophication had taken place over the last 100 years. Bachman and Jones found that the accelerated eutrophic state of the lakes was due to tillage within the watershed, treated and untreated sewage piped to the lakes, drainage of wetlands and more.

- Also in 1974, Hickok and Associates wrote the *"Management Plan for Water Quality, Iowa Great Lakes."* This plan found that untreated sewage around Big Spirit and East Okoboji Lakes was having negative impacts on water quality. This report also found that the animal feeding operations within the watershed were also having an impact on water quality.

The IGL water quality is still considered some of the best in the state of Iowa, as stated by water quality studies completed by Iowa State University and the Iowa Department of Natural Resources. These reports can be found through the Iowa Lakes Survey available at:
http://limnology.eeob.iastate.edu/lakereport/chemical_report.aspx

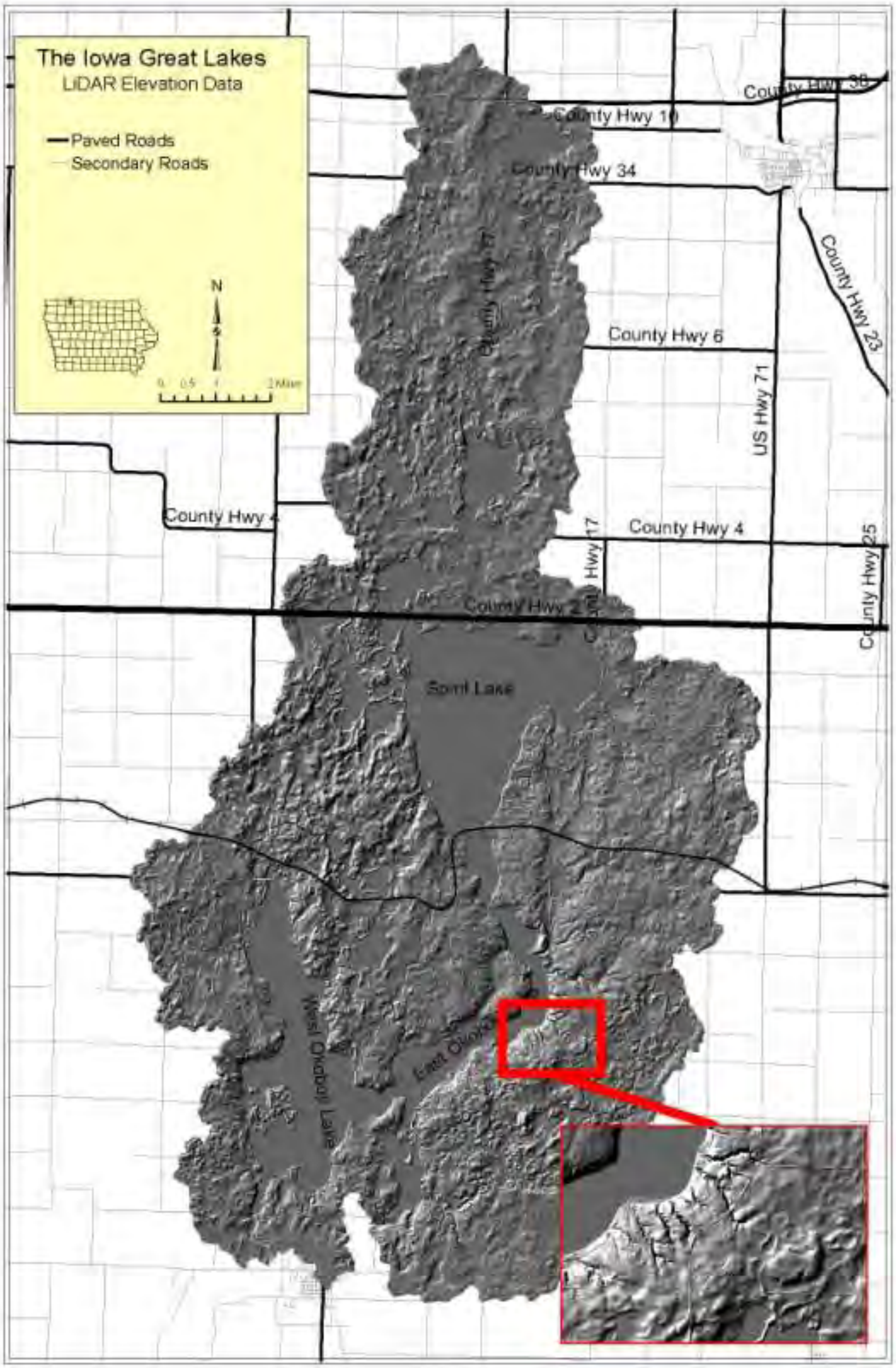
- Over 90+ years of research has been collected at Iowa Lakeside Laboratory and has covered all aspects of water quality. The following categories of work detail the research completed: Diatoms, Aquatic Macrophytes, Fish, Thermocline, Mollusks, Amphibians, Core Sampling, Prairie, Wetlands, Nutrient, and Turtles Algae, and Turtles. All of this work is documented at Iowa Lakeside Laboratory and much of the work has been published in the Iowa Academy of Science journals. Research continues at Iowa Lakeside Laboratory with an on-going water-monitoring program and new graduate students coming to the facility every year.

Much of the work mentioned above has been funded, in part, by the community, and has strengthened partnerships among local, state, and federal agencies.

AGRICULTURAL LAND

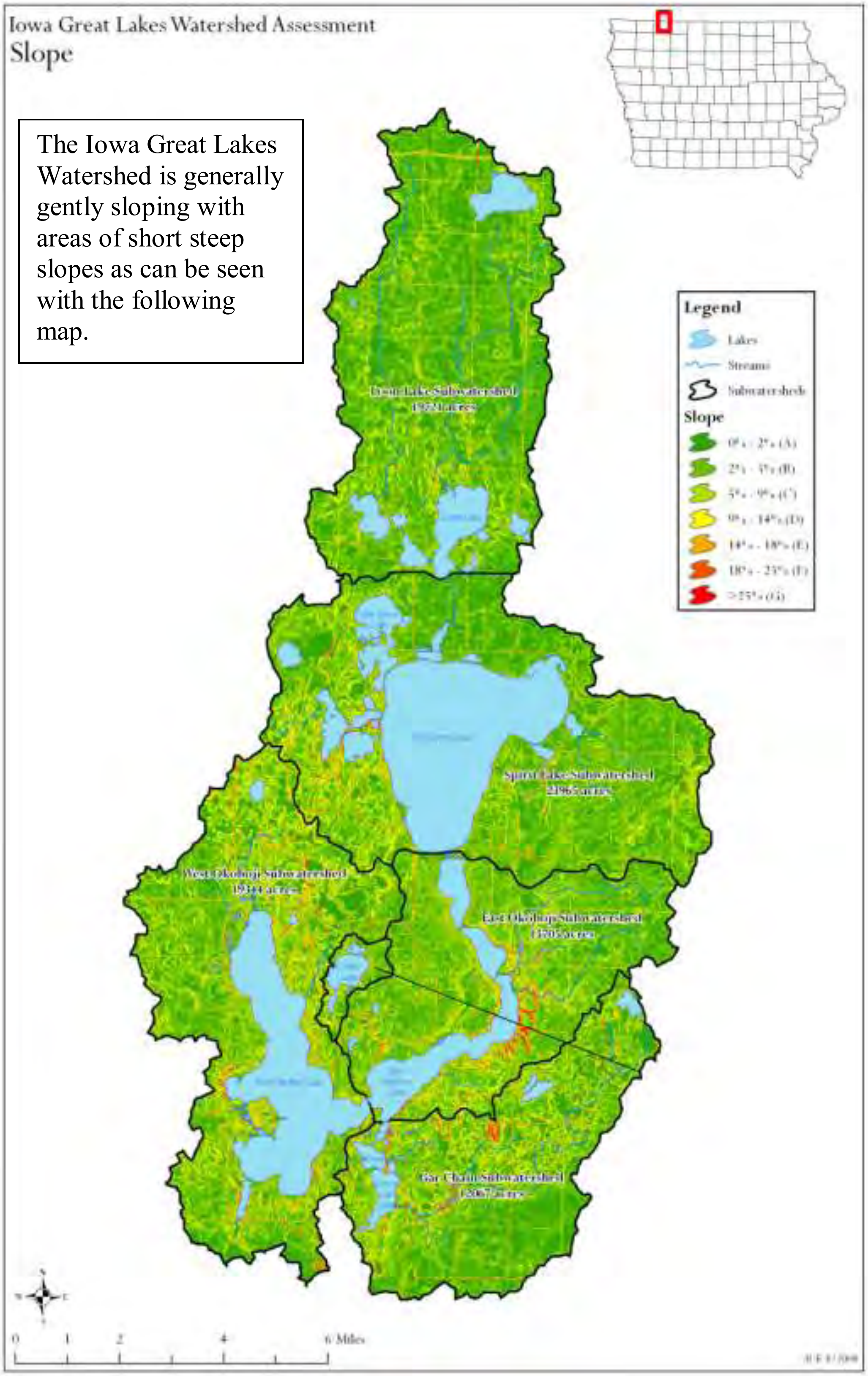
AGRICULTURAL OVERVIEW

Throughout this assessment, many maps and graphics will be used to reinforce and support the data given. These maps were created using LiDAR (Light Detection and Ranging) data and GIS. The quality of this data is unmatched for this type of work and the Iowa Great Lakes watershed will prove to benefit from this work. The detail of GIS interfaced with LiDAR data is shown in the following map.

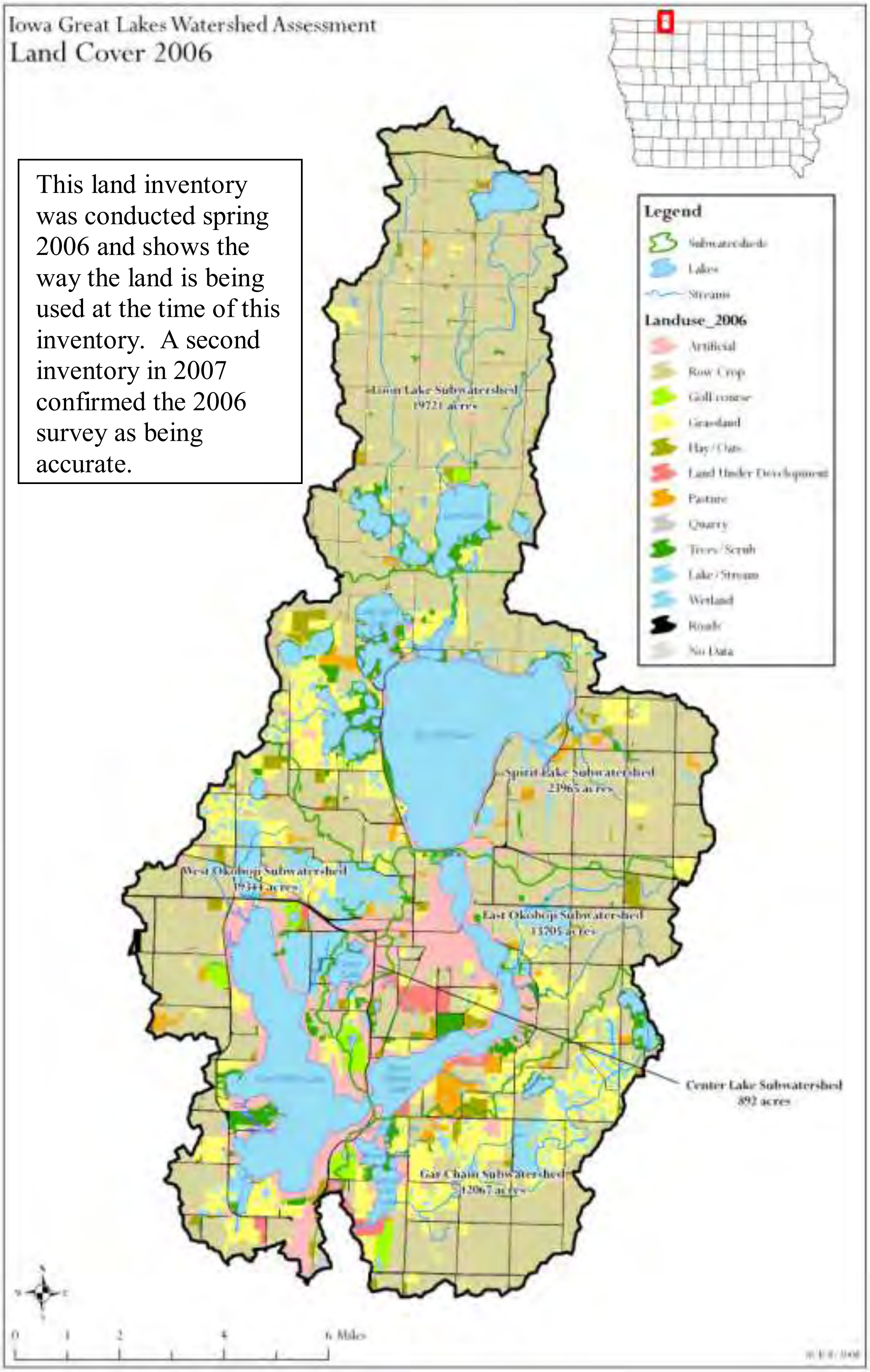


Map 7.1: IGL LiDAR Elevation Data. Courtesy of Iowa DNR.

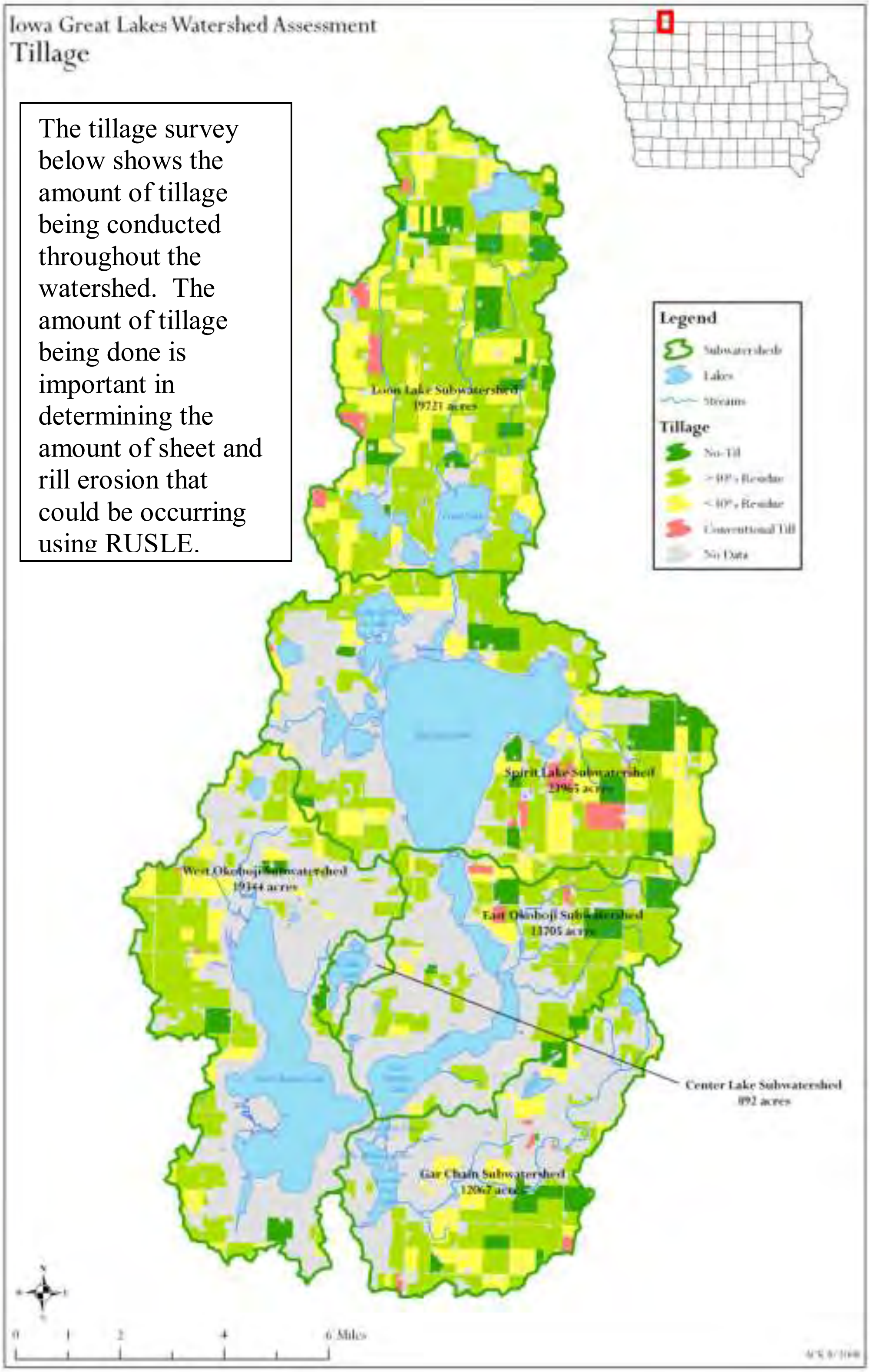
Dickinson County and the Iowa Great Lakes is host to one of the state‘s unique environments. Agriculture is one of the primary economic engines in the county. The Iowa Great Lakes watershed is in the prairie pothole region of Iowa and Minnesota. The Clarion-Nicollet, Nicollet-Clarion, and Canisteo-Nicollet-Okoboji associations comprise approximately 80% of the soil types in the watershed. These soils are level to strongly sloping, somewhat poorly drained to very poorly drained. These soils are loamy and silty soils formed in the glacial till uplands. The low impounded areas are commonly referred to as potholes. These potholes require drainage before they can be productive for row crops. Most of these soils have been drained and are in intensive row crops. The primary crops are corn and soybeans. This crop rotation of corn and soybeans is a standard in Iowa and has been shown to be profitable to the landowner/operator.



Map 7.2: Watershed Assessment, Land Slope. Courtesy of Iowa DNR



Map 7.3: Land Use Inventory. Courtesy of Iowa DNR.



Map 7.4: Map above shows tillage on agricultural lands. The tillage and land use were used to calculate below soil loss and sedimentation rates. Courtesy of Iowa DNR.

There are approximately 44,328 acres of cropland in the watershed. There are a limited number of small feedlots and pastures in the Iowa Great Lakes watershed. There are over 1 million chickens located, on several farms, within 40 miles of the Iowa Great Lakes watershed and the manure from these farms, and others, is being brought into the watershed and applied, in some instances on frozen ground. Application of chicken manure has been observed in 2005, 2006, and 2007 on frozen ground within the watershed and has been applied one time within 300 feet of the Wahpeton municipal water intake. A loophole in the State of Iowa Manure Management Plan allows animal waste to be sold to elevators where it becomes fertilizer and then sold back to farmers or custom applicators that are not then regulated in how they apply the manure. The incorporation of any manure that is applied in the watershed should be of utmost importance.

As in the rest of the state, the number of farms in the watershed continues to decline at a steady pace. Farming operations continue to grow larger which in turn lead to intense row crop production. The Natural Resources Conservation Service (NRCS) and the Dickinson and Jackson, MN Soil and Water Conservation Districts have done a great amount of planning and applying conservation practices and land retirement programs in the watershed. Farm programs such as Conservation Reserve Program (CRP), Environment Quality Incentive Program (EQIP), Wetlands Reserve Program (WRP) and several state and local cost share programs have been very popular with landowners to assist them in controlling soil erosion. The farmers in the Iowa Great Lakes watershed have accepted conservation tillage and to a limited extent, no-till. These farmers tend to move away from these practices, when conditions do not seem to favor a dry year. Dickinson County is fortunate to have some of the most nutrient rich black topsoil in the state, therefore keeping land values higher than statewide averages.

Most farmers use some type of conservation tillage system in their crop rotation. The majority of the watershed is not highly erodible which allows farmers to use as much tillage as they deem suitable. Unfortunately, with the high commodity and land prices, land retirement programs are becoming less popular to landowners in the watershed. There is approximately 5% of the watershed enrolled in the CRP Program. The contracts are due to retire and it is doubtful that many of these acres will be reenrolled in CRP if the trends in high commodity and land prices continue.

Confinement and Feedlots

There are currently nine animal feeding operations and one confined feeding operation located within the watershed or near the boundary of the watershed. These operations contain mostly cattle but also contain hogs. There are approximately 500-animal units in the watershed in these ten operations. Of these ten operations, three are located in Minnesota where the animal feedlot industry is regulated a bit more stringently than it is in Iowa.

In the summer of 2008, an agreement was announced between pork producers in the area to create an "eco-tourism" buffer zone around the Iowa Great Lakes where no new hog facilities will be built within a 4-mile area around the Iowa Great Lakes. The agreement is between national pork producer organizations and does not have any legal backing. It is a simply a voluntary agreement between hog producers and is not binding.

It seems a larger threat to the water quality of the Iowa Great Lakes than resident animal feeding operations is the amount of chicken manure brought into the watershed from outside the watershed. Several large animal-feeding operations located outside the watershed transport manure long distances to custom farmers and to farmers who pay someone to bring the manure into the watershed to use as fertilizer. As sometimes happens this manure has been left on the surface of frozen ground and not incorporated until the spring thaw.

Ethanol

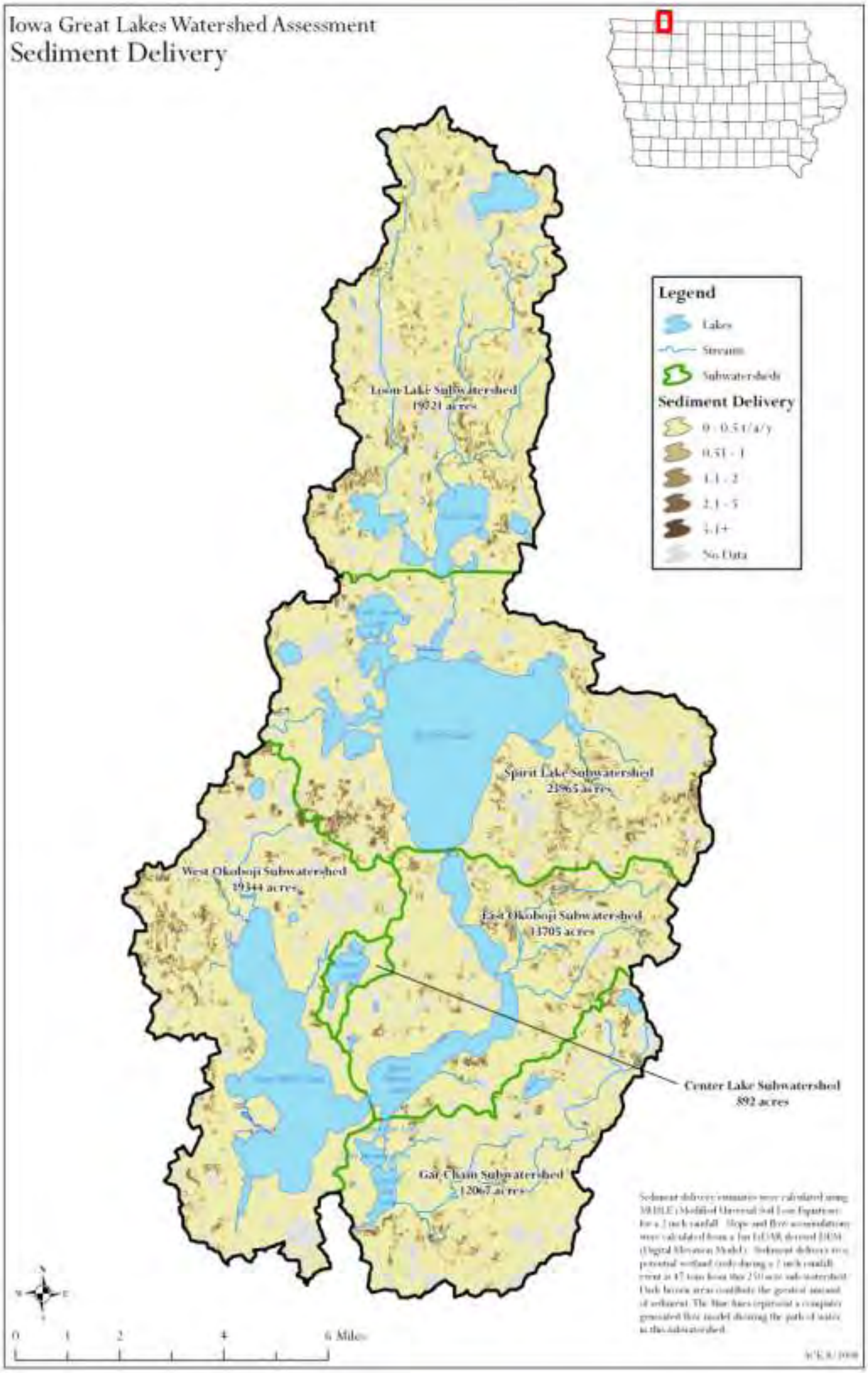
According to iowacorn.org, there are fifteen (15) dry corn ethanol-milling plants in production within the State of Iowa. Eight (8) more ethanol plants are either under construction or in planning phases. One of these ethanol plants was built and is currently in production on the east side of Dickinson County near Superior, Iowa. The closest ethanol plants currently in production are Otter Creek Ethanol plant in Ashton (Osceola Co.) and Voyager Ethanol plant in Emmetsburg (Palo Alto Co.). The Voyager Ethanol Plant is currently gearing up to begin using cellulose fiber in its ethanol production.

The impact on agricultural production in the Iowa Great Lakes because of these two plants is an increase in corn production, in some cases, corn on corn. The ethanol plants tend to pay a premium for corn and therefore making it a more attractive crop for farmers who typically farmed a corn and soybean rotation. The impact of a corn on corn crop rotation is the increased use of fertilizers and insect pesticides.

Sediment Delivery/Erosion
It has been estimated that an average of 0.91 tons sheet and rill erosion per acre per year of soil occurs in the Iowa Great Lakes watershed using the Revised Universal Soil Loss Equation (RUSLE). Using this model the Iowa Great Lakes Watershed realizes a total average erosion rate of 65,302 tons of sediment per year on the 71,761 land area acres within the watershed of sheet and rill erosion.

Map 7.5: Sheet and Rill Erosion. Courtesy of Iowa DNR.

In the map below sediment delivery estimates were calculated using MUSLE (Modified Universal Soil Loss Equation) for a 2-inch rainfall. Slope and flow accumulations were calculated from a 1-meter LiDAR derived DEM (Digital Elevation Model). Sediment delivery to a wetland basin or a lake can be derived using this model. Using an example sub-watershed within the Iowa Great Lakes Watershed the total sediment delivered to a basin or the lake can be determined.

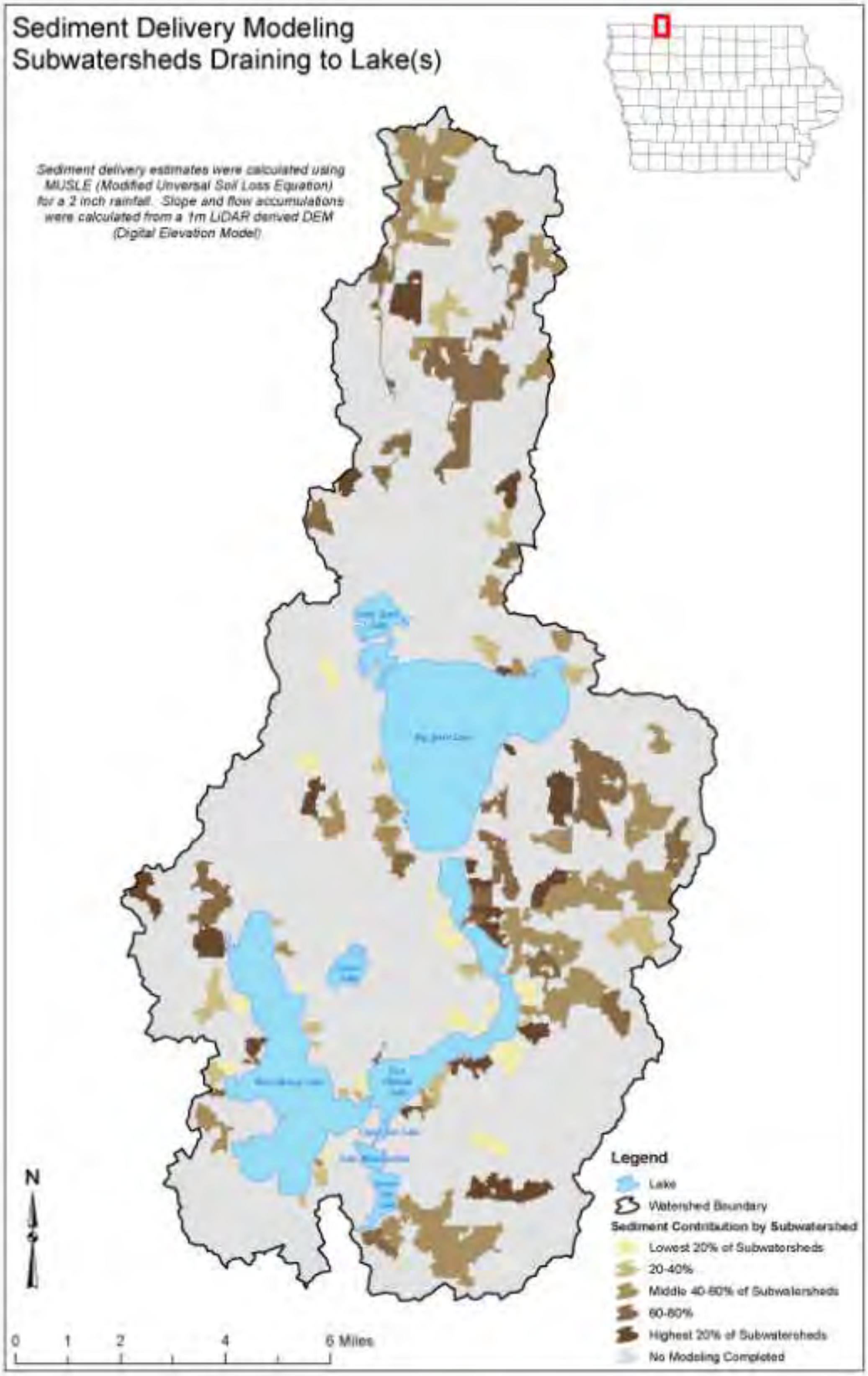


Map 7.6: Sediment Delivery. Courtesy of Iowa DNR.

In the example below a 250 acre sub-watershed is pulled from the Iowa Great Lakes Watershed and shows the amount of sediment that would be assumed to reach the basin after a 2-inch rainfall event. The darker areas contribute the greatest amount of sediment to the basin. In this 250-acre sub-watershed 47 tons of sediment is delivered to the basin after a 2-inch rainfall event. The significance of this modeling shows the sediment delivery is difficult to predict. The average sediment rate for the Iowa Great Lakes is 65,302 and yet the sediment deliver in this 250 acres sub-watershed is 47 tons for a 2-inch rainfall.

Map 7.7: Sediment Delivery – in detail. Courtesy of Iowa DNR.

Looking at the following map one can identify the areas of agricultural land that have the potentially highest impact on the Iowa Great Lakes by contributing the most sediment to the Lakes. Using this map, we can identify areas that need immediate attention and are of a higher priority than others are. The areas that will require the full attention of conservation organizations should be those in the highest 20% of sediment delivery. As can be seen those sites are located in the highest concentration on the East side of East Okoboji Lake, on the West side of West Okoboji Lake and in the Gar chain of lakes sub-watershed.



Map 7.8: Sediment Delivery. Courtesy of Iowa DNR.

As little as 15 parts per billion of total phosphorous can encourage excessive production of algae. Undesirable aquatic plant growth results from additions of phosphorous to the water. The net result of this eutrophic condition and excess plant growth in water is the depletion of oxygen in the water due to the heavy oxygen demand by microorganisms as they decompose the organic material. It severely influences the lakes natural ability to support aquatic life. (Algae Management, 2007) Further it is significant to note that “one pound of phosphorous can grow up to 1000 pounds of algae and concentrations as low a 0.03 parts per million of total phosphorous will support an algae bloom”. (Carlson, 2008) When looking at an additional 378,751 pounds of phosphorous each year into the lake we can assume, using accepted multipliers, that an additional 379 million pounds of algae could be produced in Iowa Great Lakes each year due to the influx of additional phosphorous. This growth of algae does not include the phosphorous that is already in the Iowa Great Lakes but is rather the “newly added” phosphorous.

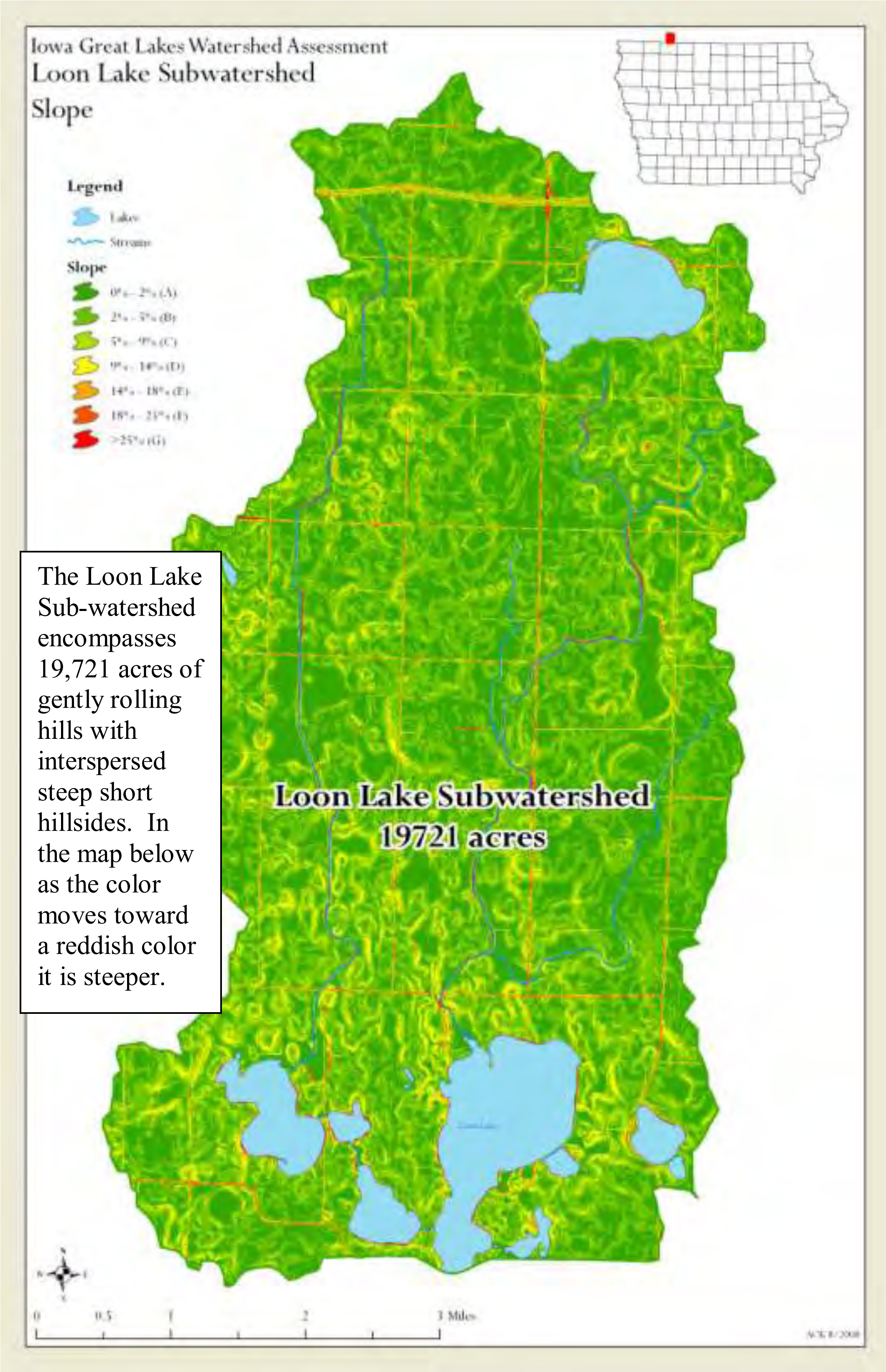
“Shannon and Brezonik (1972a, 1972b) have found a relationship between lake trophic state and nitrogen and phosphorous loading rates, indicating that lake trophic state is largely dependent upon the gross supply of nitrogen and phosphorous to the lake, mainly phosphorous”. (Bachman, 1974)

Using the RUSLE, we are able to see a part of the sediment delivery problem but not a complete picture. When considering sediment and erosion one must account for gully erosion as well. In some instances, a gully can produce more tons of erosion per acre than an entire field. Grassed waterways have been used with great success in the past to prevent sediment delivery and gully formation to water bodies.

Phosphorous has been found to be the key factor in production of algae in all of the Iowa Great Lakes. According to Bachman, “Improvements in algal problems can be expected if the present level of phosphorous inputs can be reduced”. (Bachman, 1974) Because agricultural use inherently causes sedimentation to occur, processes need to be put in place to reduce sedimentation.

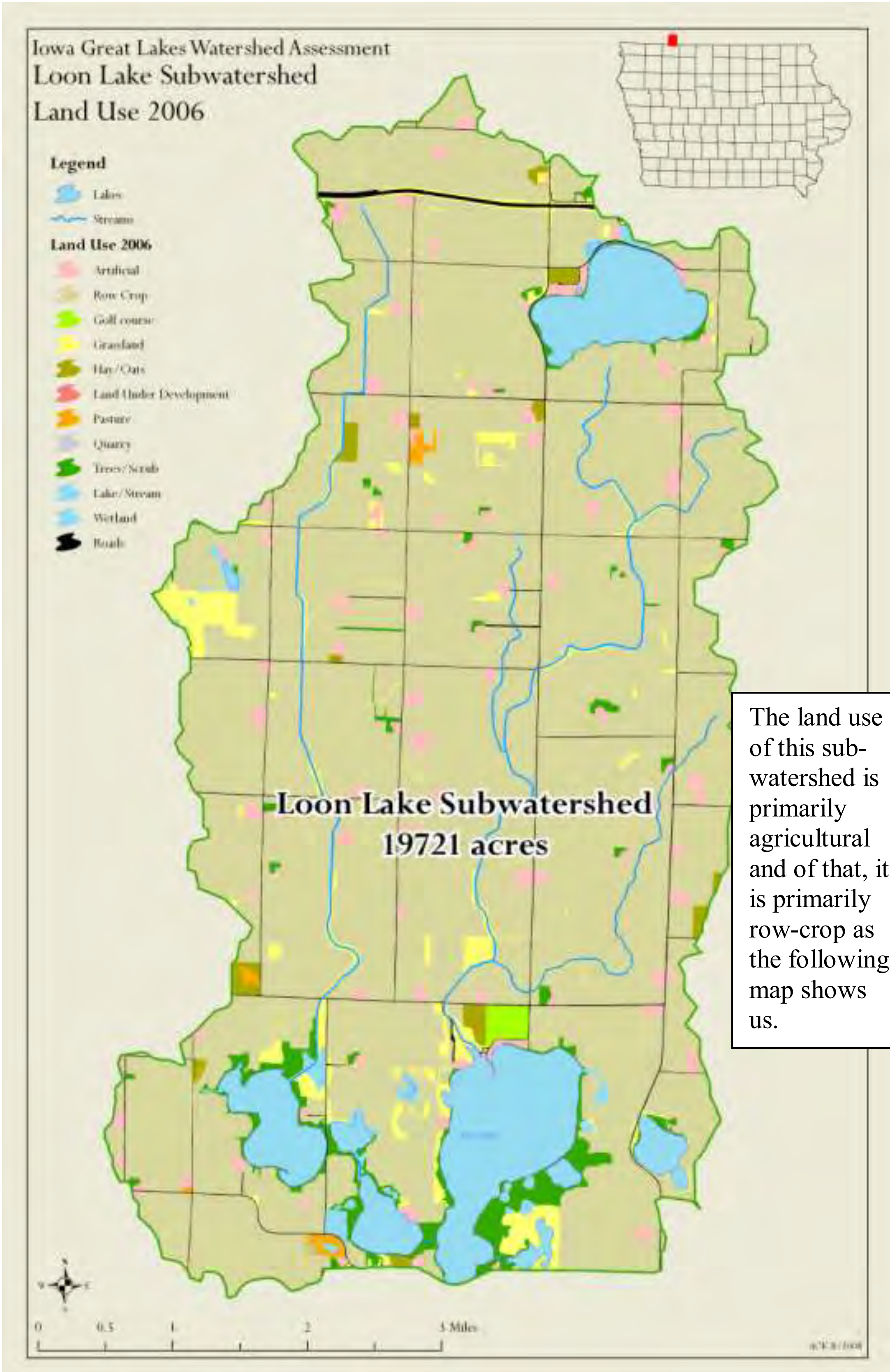
In the following sections, the watershed will be broken into smaller sub-watersheds based on the actual flow of the water to each of the main lakes, with the exception of the Minnesota portion of the watershed. That portion will be broken down in an easy to identify “sub-watershed” so as to give a general idea of what is occurring in the Minnesota side of the watershed.

Loon Lake Sub-Watershed



The Loon Lake Sub-watershed encompasses 19,721 acres of gently rolling hills with interspersed steep short hillsides. In the map below as the color moves toward a reddish color it is steeper.

Map 7.9: Loon Lake Slope. Courtesy of Iowa DNR.

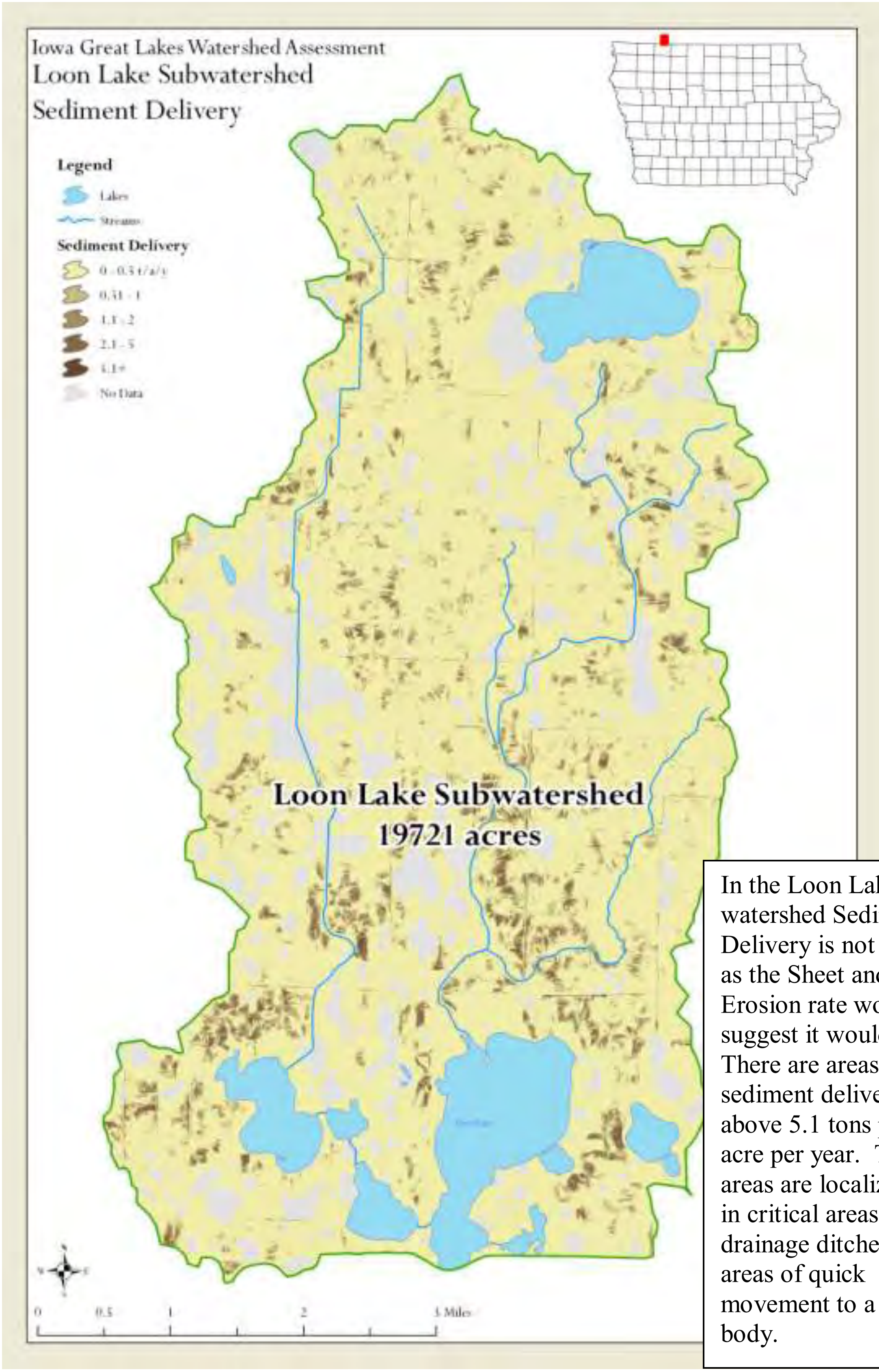


The land use of this sub-watershed is primarily agricultural and of that, it is primarily row-crop as the following map shows us.

Map 7.10: Loon Lake Land use. Courtesy of Iowa DNR.

Using the land use and the slope of this sub-watershed, we are able to determine the sheet and rill erosion using RUSLE. As can be seen in the following map, sheet and rill erosion in this sub-watershed tends to be more toward the higher end of the spectrum when considering slope and tillage of the row-crop.

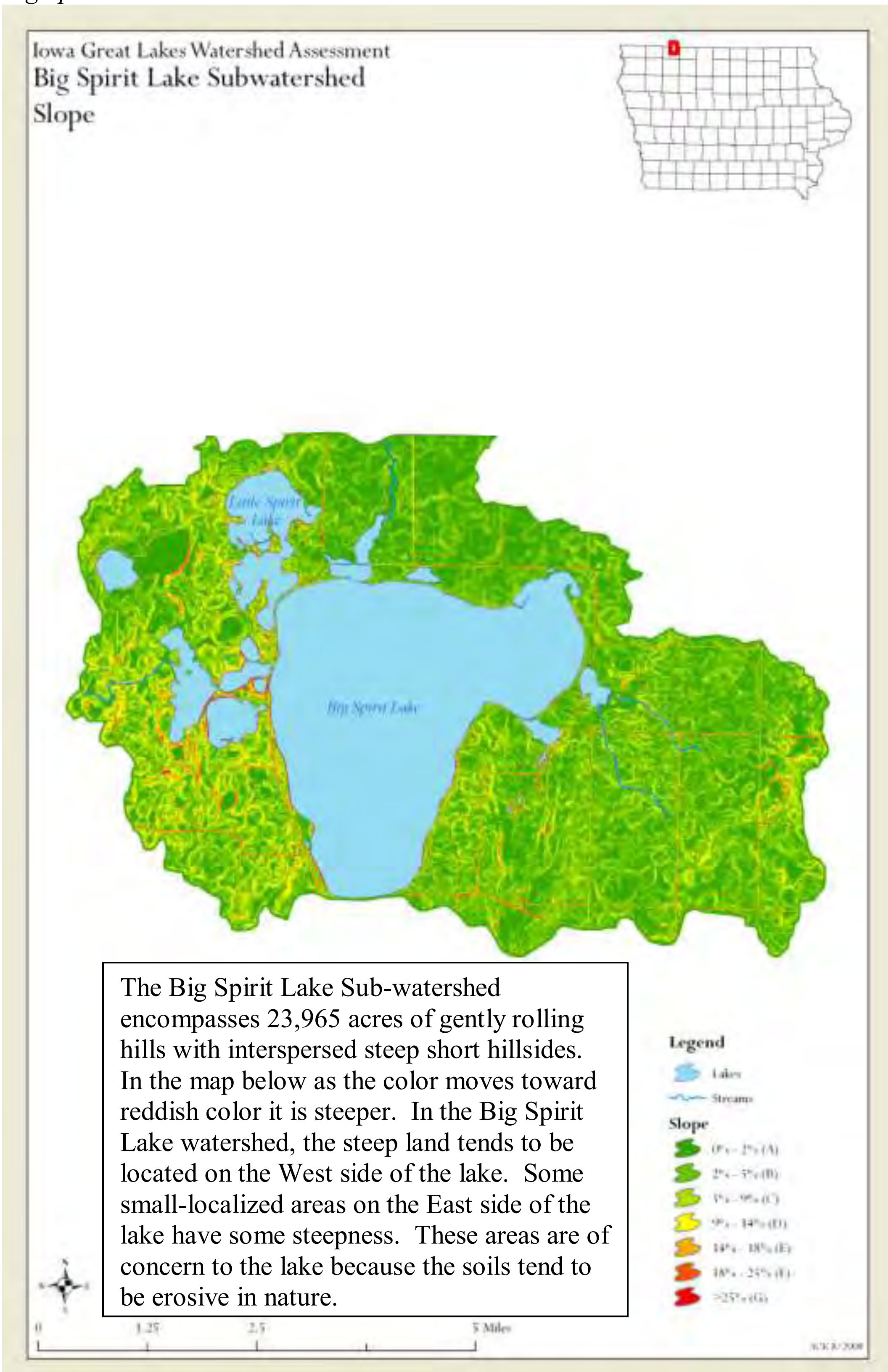
Map 7.11: Loon Lake Sheet and Rill Erosion. Courtesy of Iowa DNR.



In the Loon Lake Sub-watershed Sediment Delivery is not as high as the Sheet and Rill Erosion rate would suggest it would be. There are areas where sediment delivery is above 5.1 tons per acre per year. These areas are localized but in critical areas near drainage ditches or areas of quick movement to a water body.

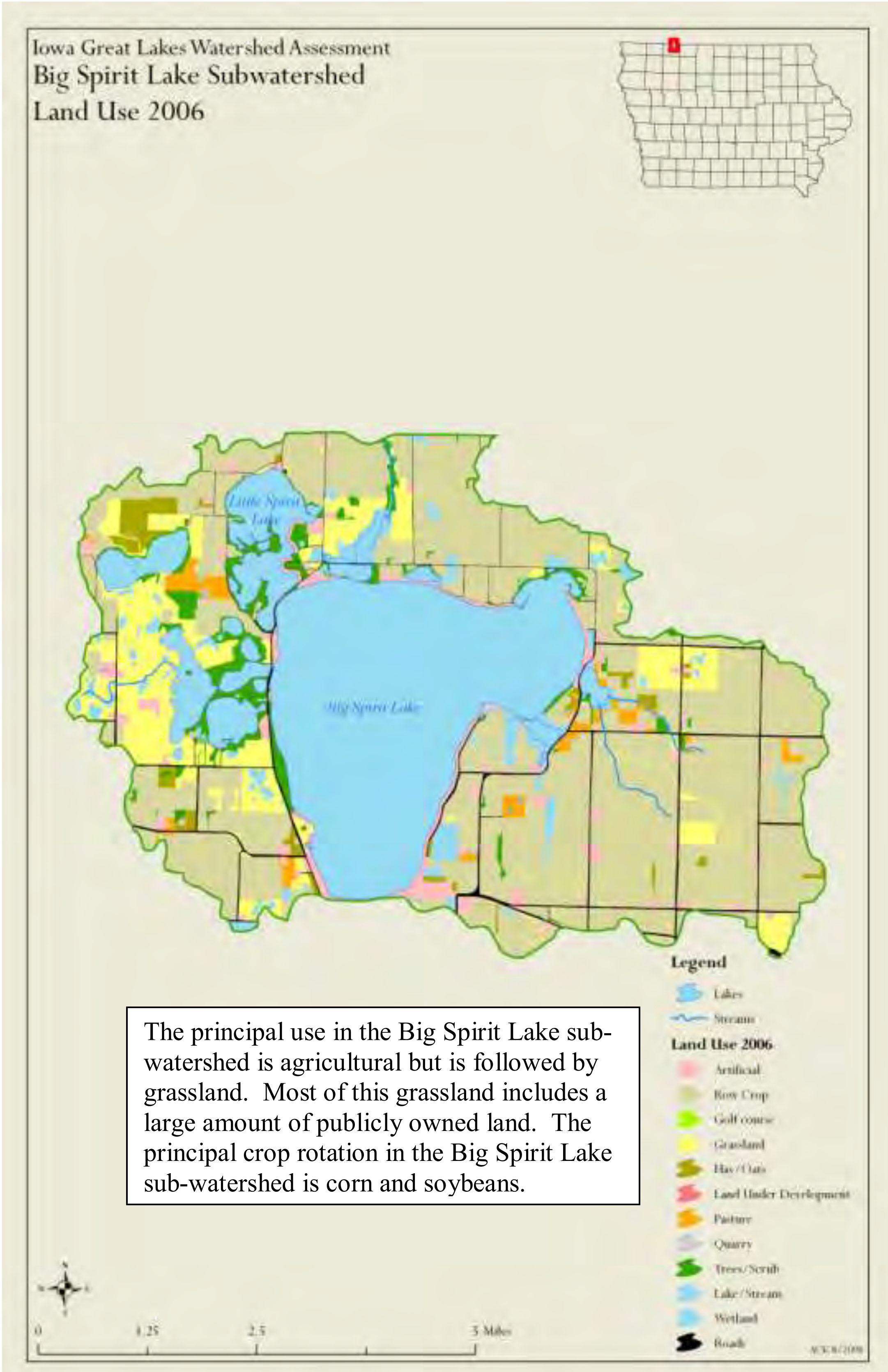
Map 7.12: Loon Lake Sediment Delivery. Courtesy of Iowa DNR.

Big Spirit Lake Sub-Watershed

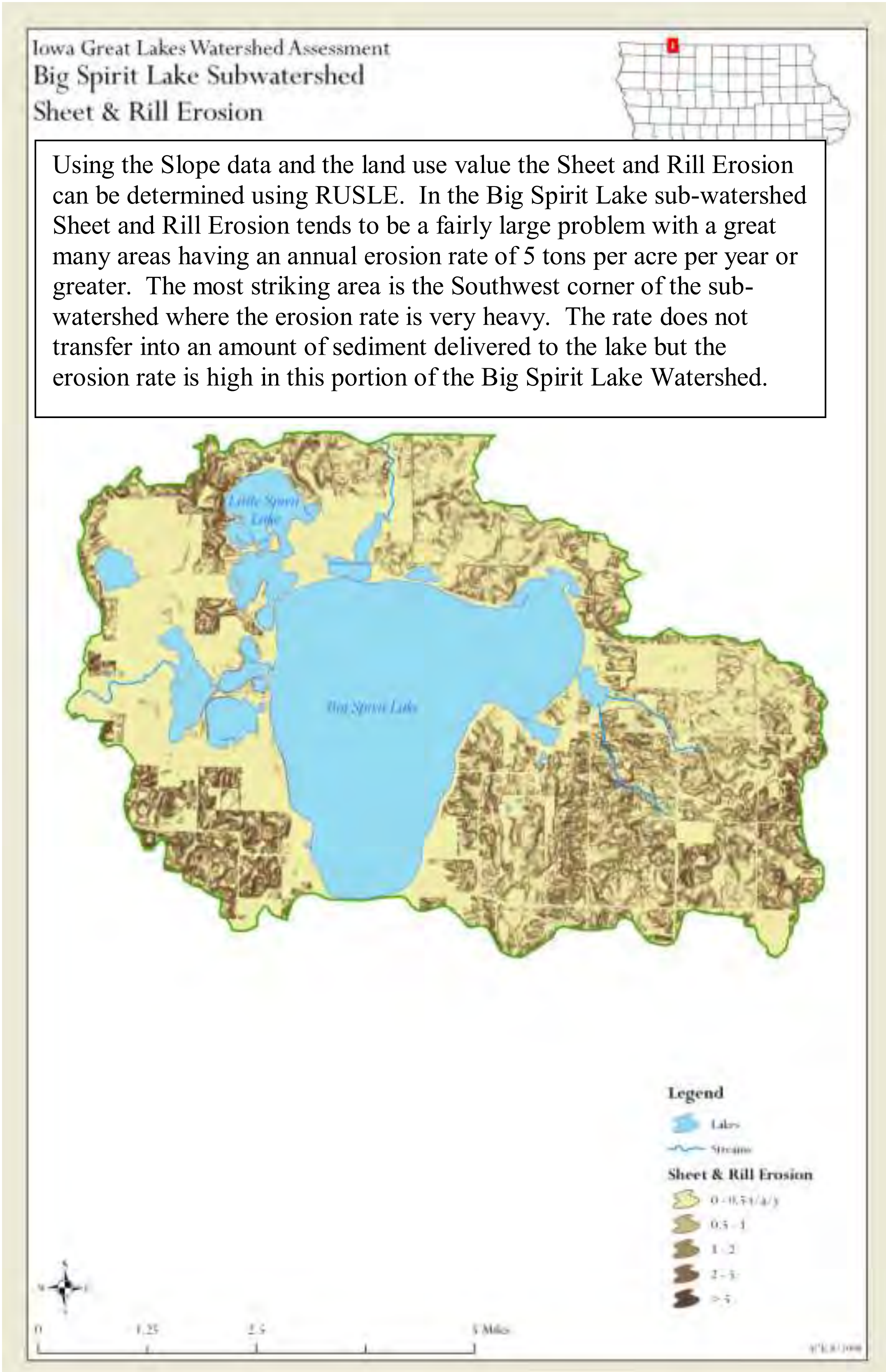


The Big Spirit Lake Sub-watershed encompasses 23,965 acres of gently rolling hills with interspersed steep short hillsides. In the map below as the color moves toward reddish color it is steeper. In the Big Spirit Lake watershed, the steep land tends to be located on the West side of the lake. Some small-localized areas on the East side of the lake have some steepness. These areas are of concern to the lake because the soils tend to be erosive in nature.

Map 7.13: Big Spirit Lake Slope. Courtesy of Iowa DNR.

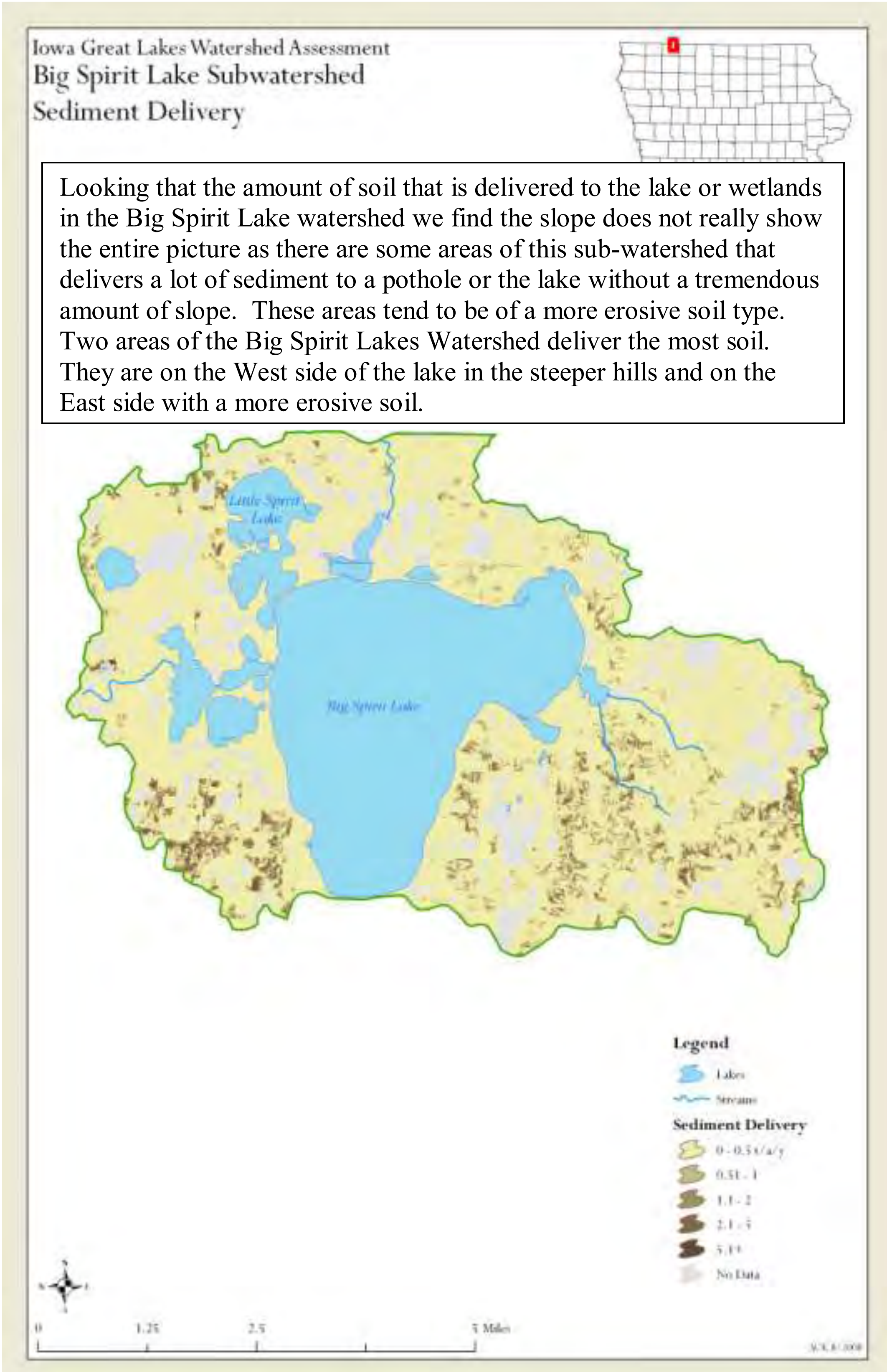


Map 7.14: Big Spirit Lake Land Use Survey 2006. Courtesy of Iowa DNR.



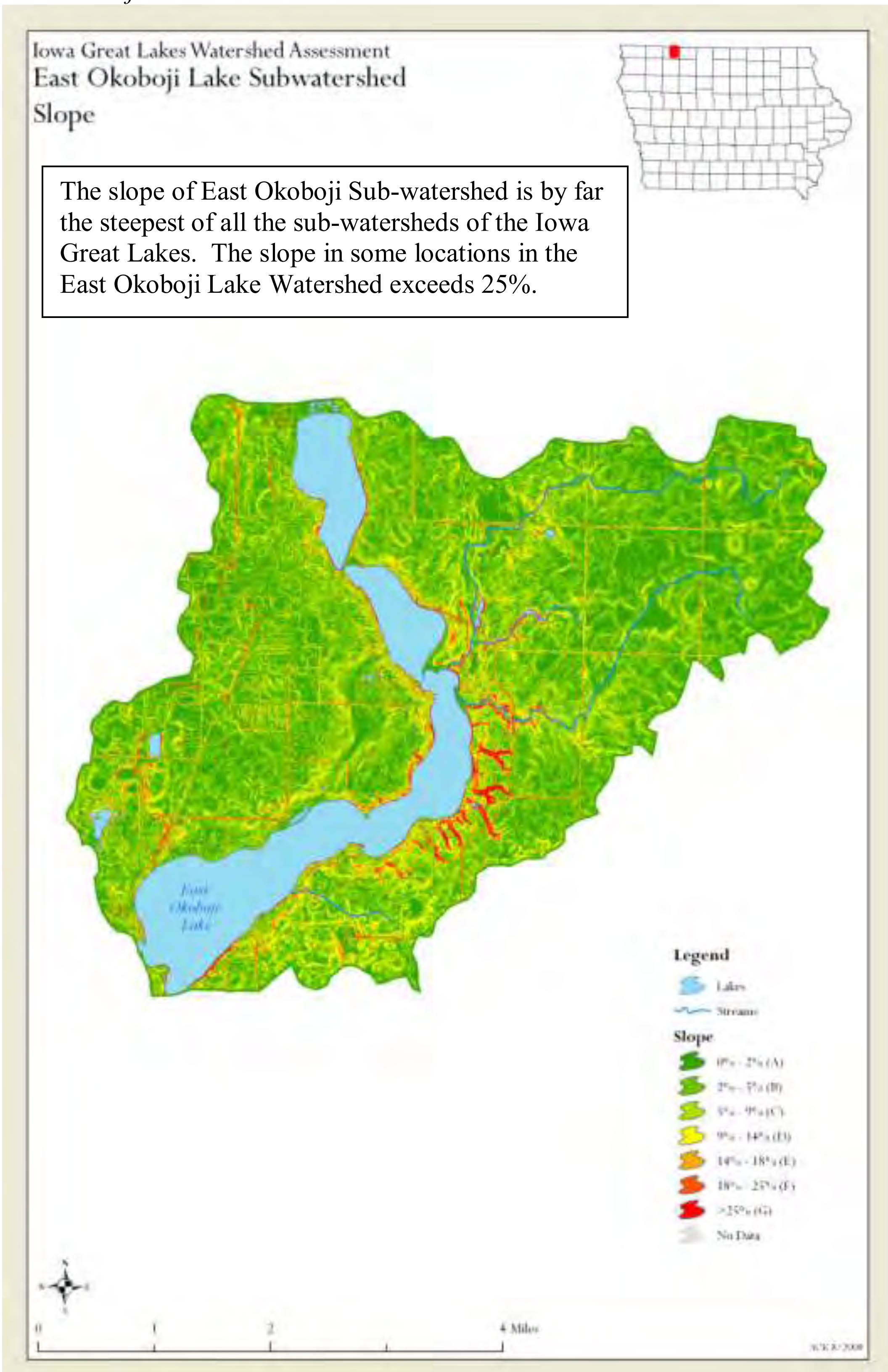
Map 7.15: Big Spirit Lake Sheet and Rill Erosion. Courtesy of Iowa DNR.

Looking that the amount of soil that is delivered to the lake or wetlands in the Big Spirit Lake watershed we find the slope does not really show the entire picture as there are some areas of this sub-watershed that delivers a lot of sediment to a pothole or the lake without a tremendous amount of slope. These areas tend to be of a more erosive soil type. Two areas of the Big Spirit Lakes Watershed deliver the most soil. They are on the West side of the lake in the steeper hills and on the East side with a more erosive soil.

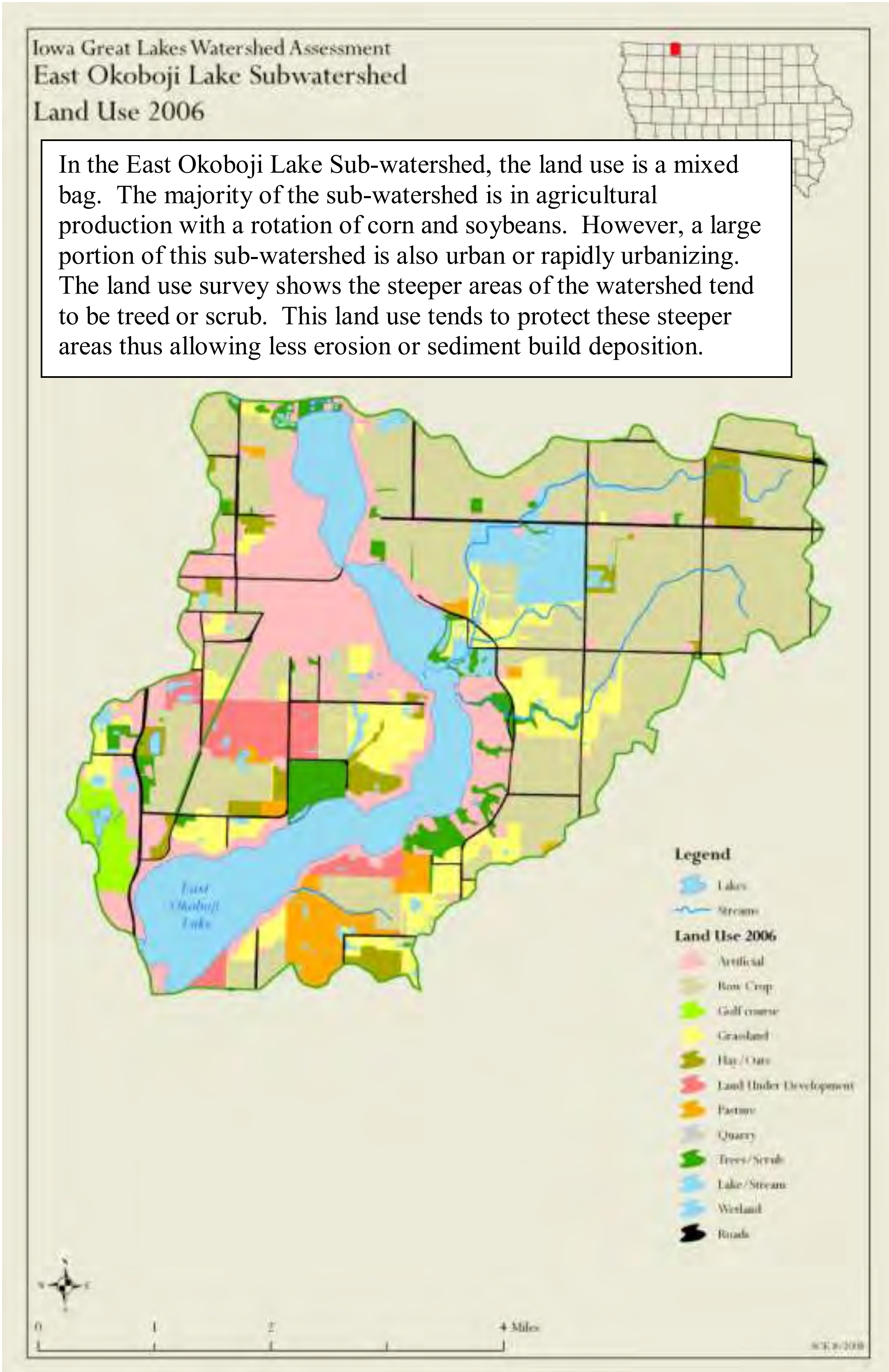


Map 7.16: Big Spirit Lake Sediment Delivery. Courtesy of Iowa DNR.

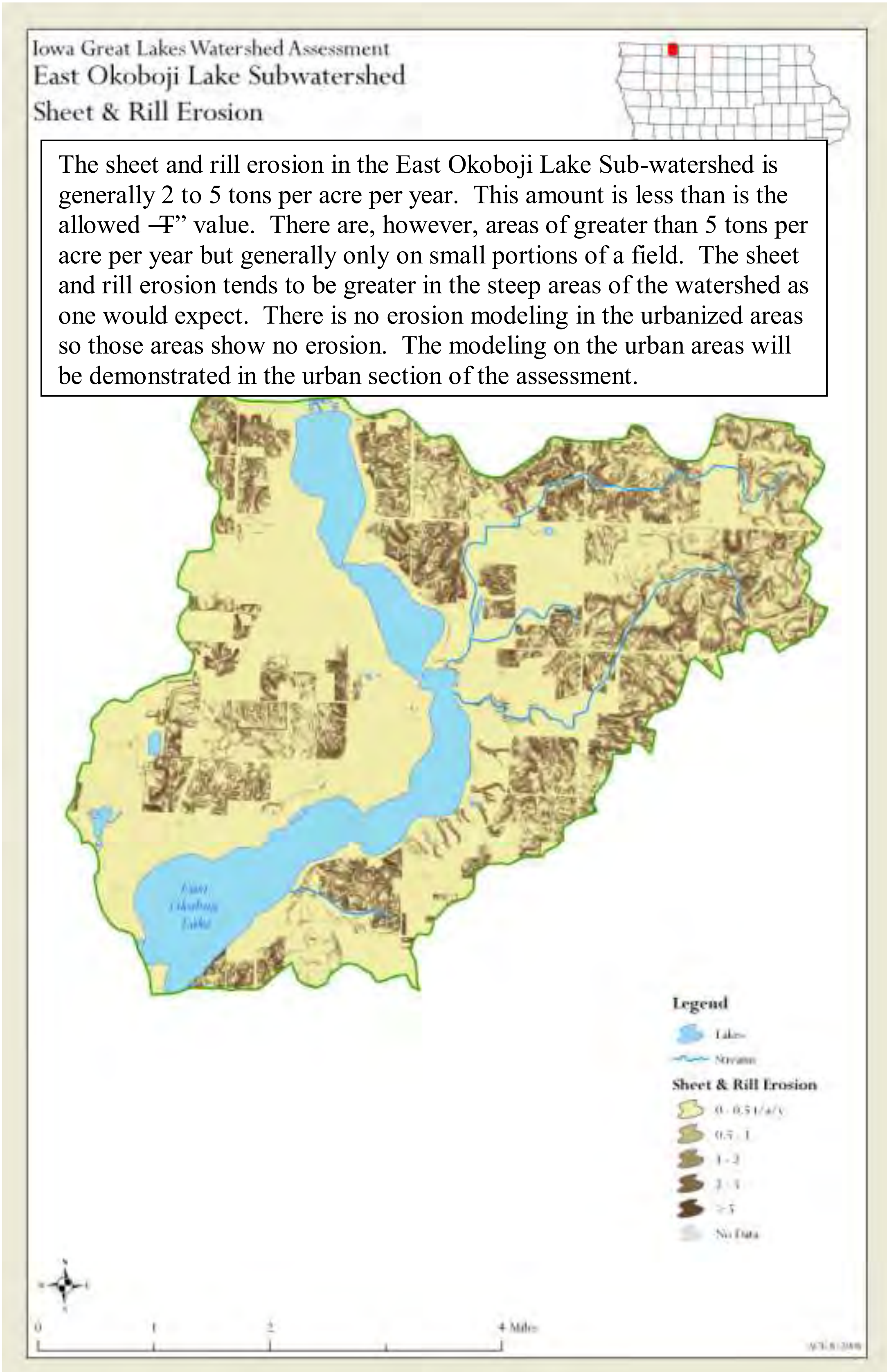
East Okoboji Lake Sub-Watershed



Map 7.17: East Okoboji Lake Slope. Courtesy of Iowa DNR.

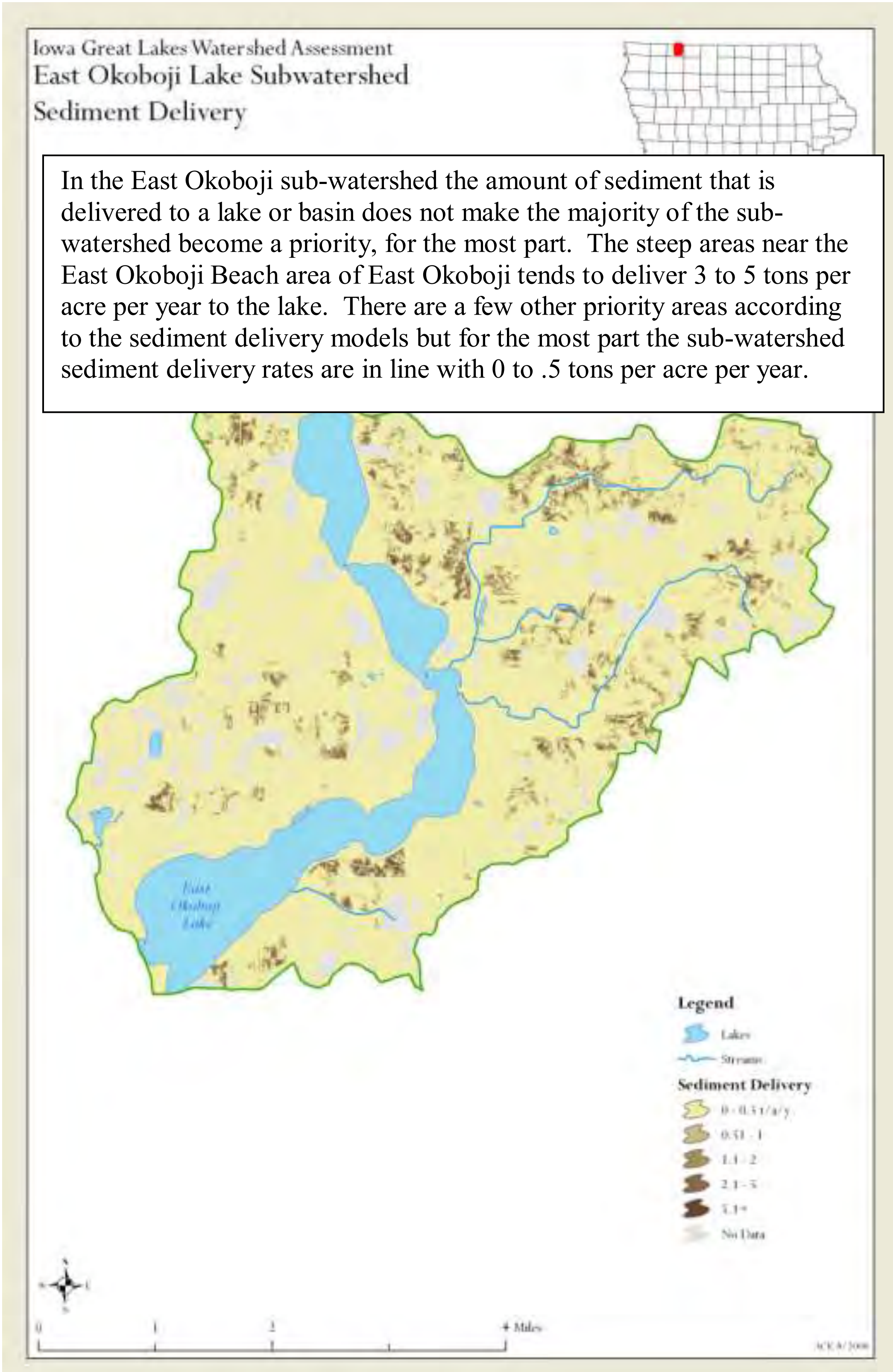


Map 7.18: East Okoboji Lake Land Use 2006. Courtesy of Iowa DNR.



The sheet and rill erosion in the East Okoboji Lake Sub-watershed is generally 2 to 5 tons per acre per year. This amount is less than is the allowed “T” value. There are, however, areas of greater than 5 tons per acre per year but generally only on small portions of a field. The sheet and rill erosion tends to be greater in the steep areas of the watershed as one would expect. There is no erosion modeling in the urbanized areas so those areas show no erosion. The modeling on the urban areas will be demonstrated in the urban section of the assessment.

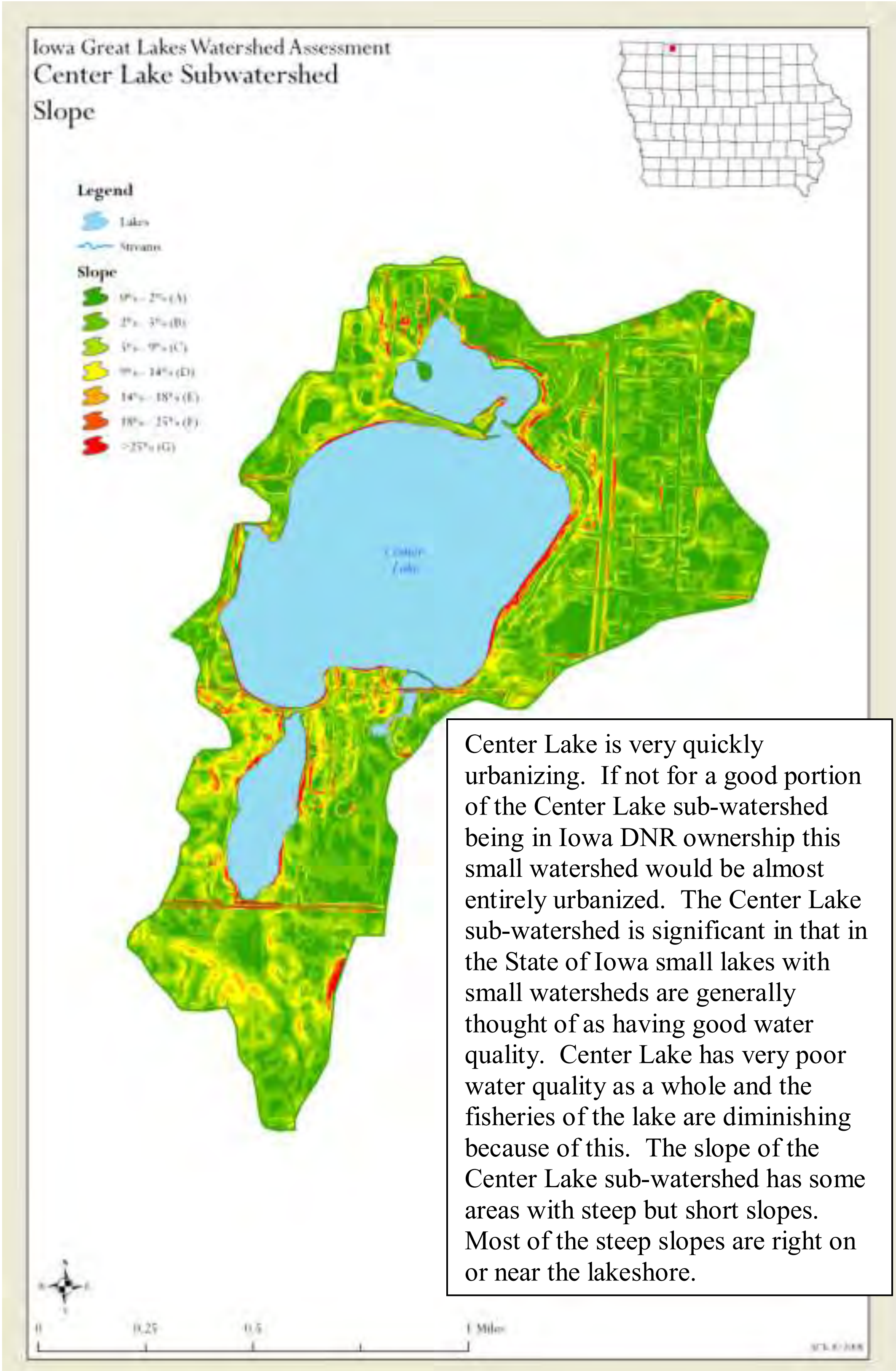
Map 7.19: East Okoboji Sheet and Rill Erosion**.** Courtesy of Iowa DNR.



In the East Okoboji sub-watershed the amount of sediment that is delivered to a lake or basin does not make the majority of the sub-watershed become a priority, for the most part. The steep areas near the East Okoboji Beach area of East Okoboji tends to deliver 3 to 5 tons per acre per year to the lake. There are a few other priority areas according to the sediment delivery models but for the most part the sub-watershed sediment delivery rates are in line with 0 to .5 tons per acre per year.

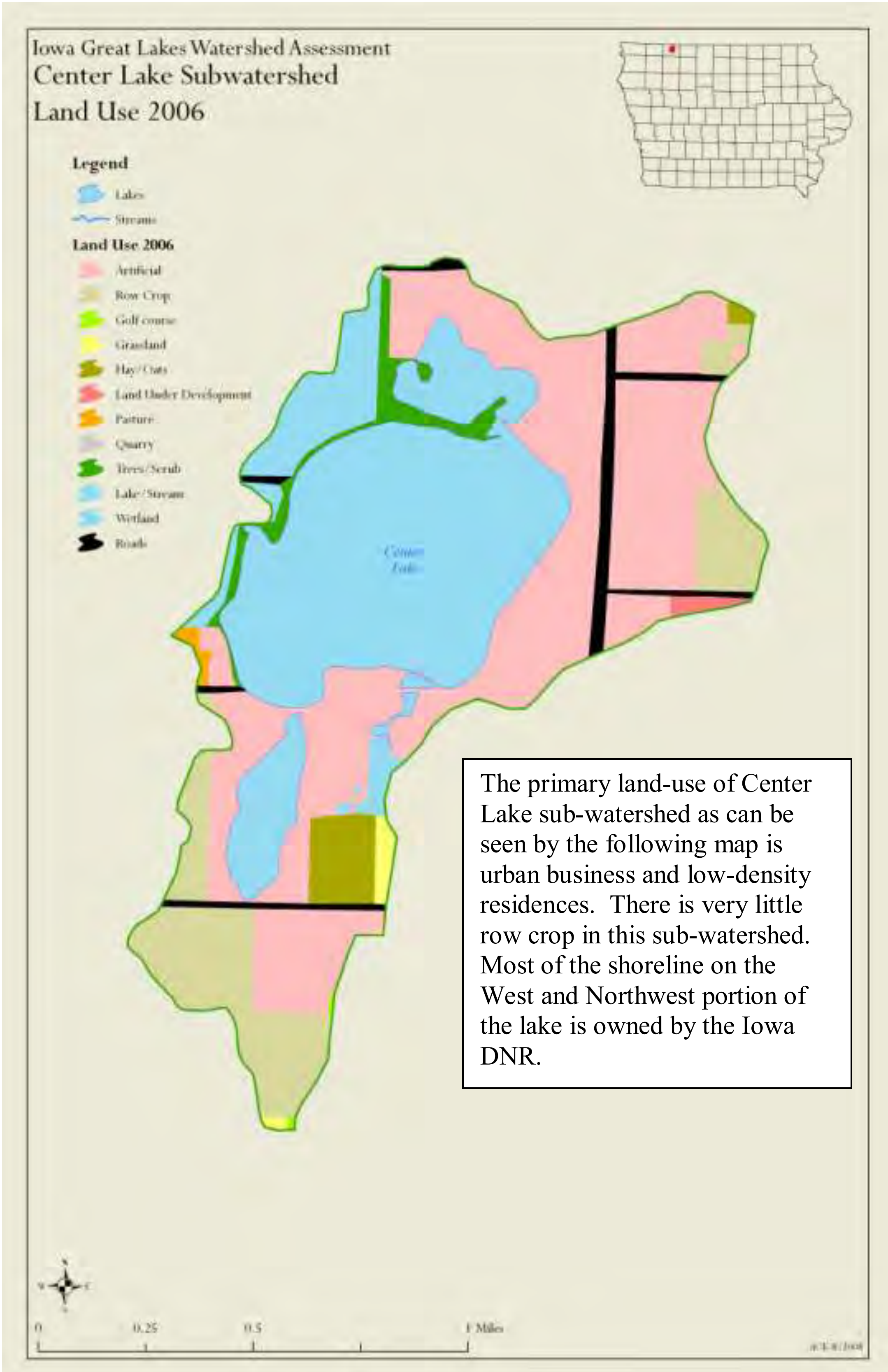
Map 7.20: East Okoboji Lake Sediment Delivery. Courtesy of Iowa DNR.

Center Lake Sub-Watershed



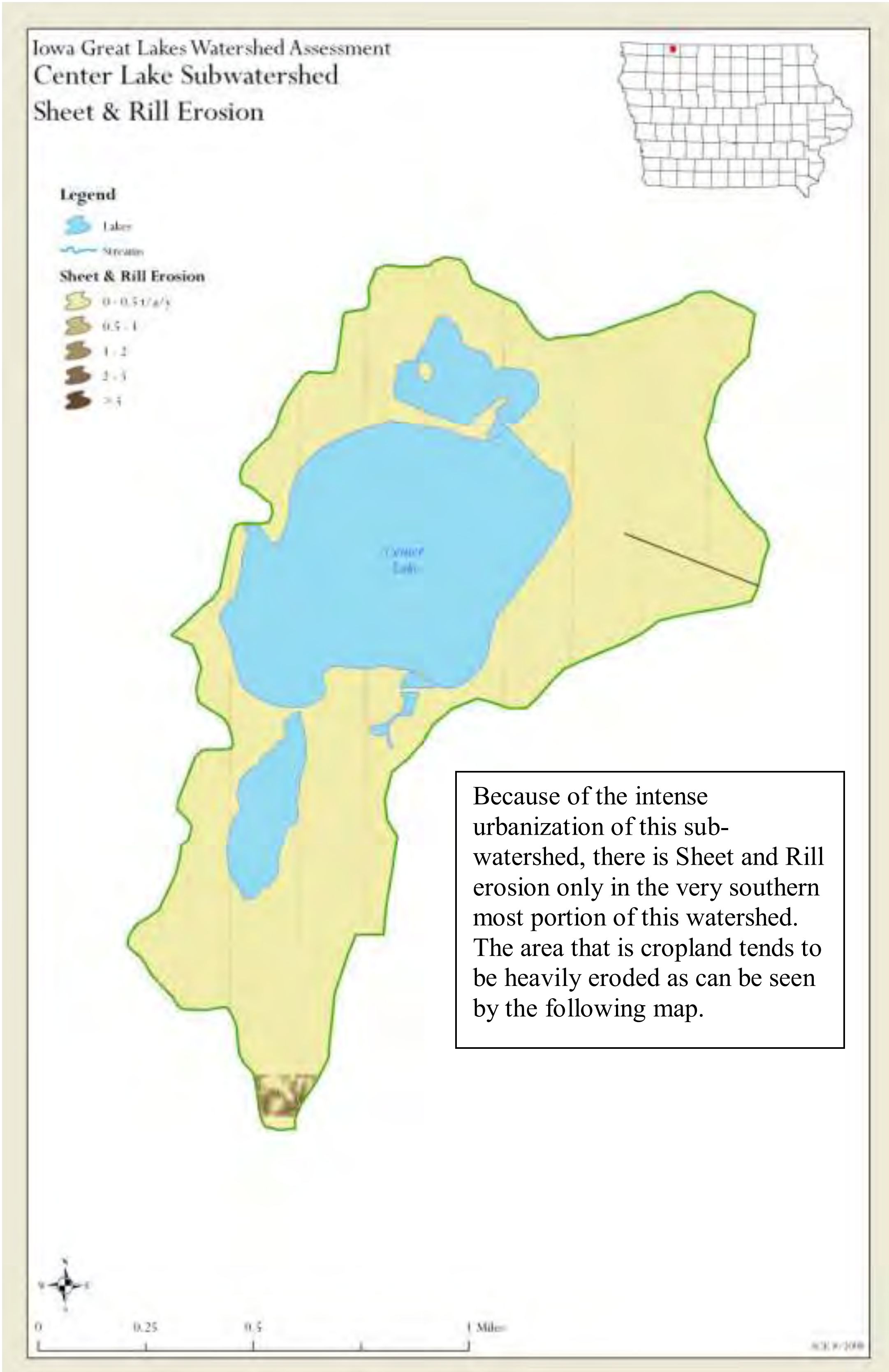
Center Lake is very quickly urbanizing. If not for a good portion of the Center Lake sub-watershed being in Iowa DNR ownership this small watershed would be almost entirely urbanized. The Center Lake sub-watershed is significant in that in the State of Iowa small lakes with small watersheds are generally thought of as having good water quality. Center Lake has very poor water quality as a whole and the fisheries of the lake are diminishing because of this. The slope of the Center Lake sub-watershed has some areas with steep but short slopes. Most of the steep slopes are right on or near the lakeshore.

Map 7.21: Center Lake Slope. Courtesy of Iowa DNR.



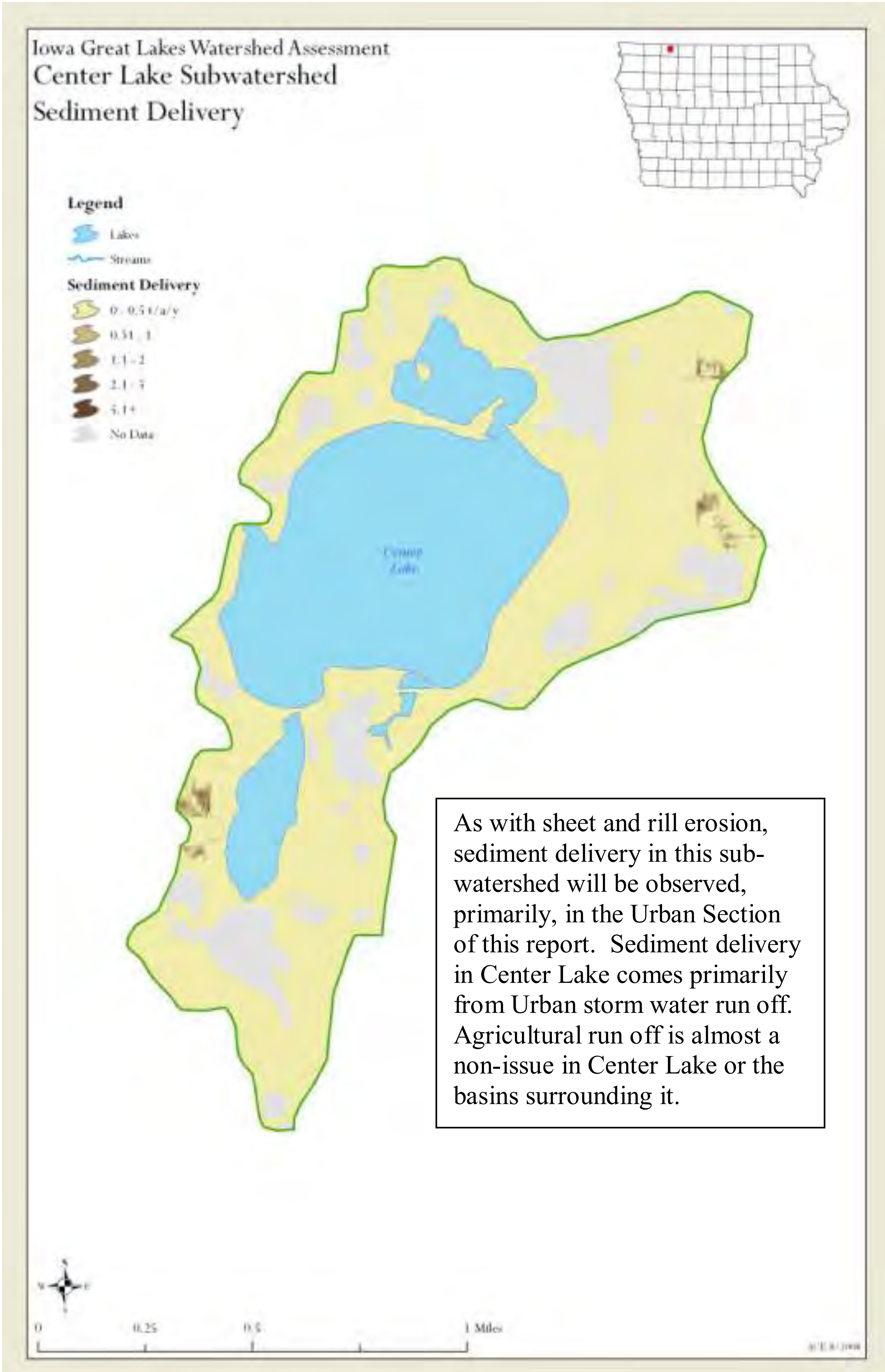
The primary land-use of Center Lake sub-watershed as can be seen by the following map is urban business and low-density residences. There is very little row crop in this sub-watershed. Most of the shoreline on the West and Northwest portion of the lake is owned by the Iowa DNR.

Map 7.22: Center Lake Land Use 2006. Courtesy of Iowa DNR.



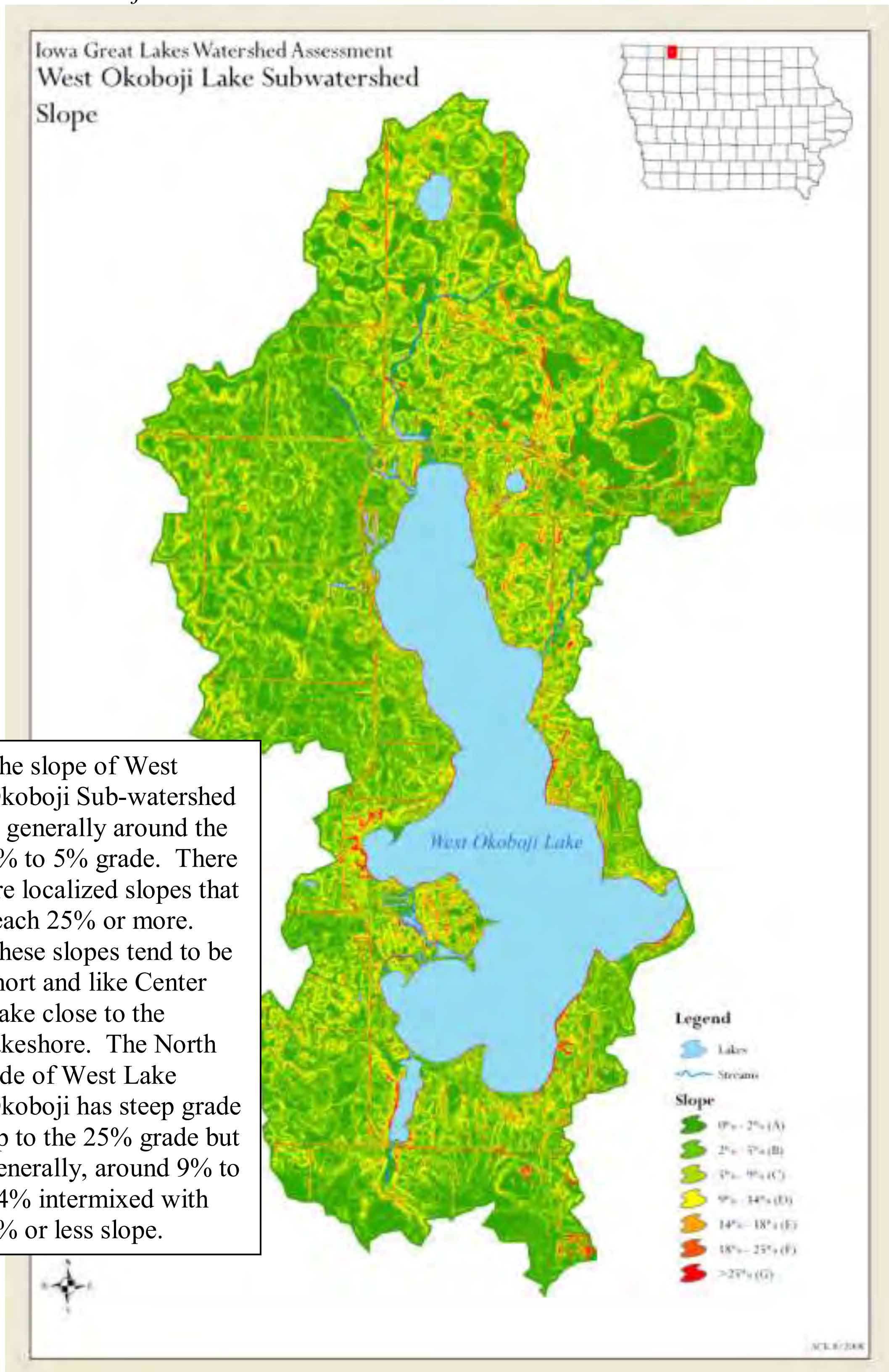
Because of the intense urbanization of this sub-watershed, there is Sheet and Rill erosion only in the very southern most portion of this watershed. The area that is cropland tends to be heavily eroded as can be seen by the following map.

Map 7.23: Center Lake Sheet and Rill Erosion. Courtesy of Iowa DNR.



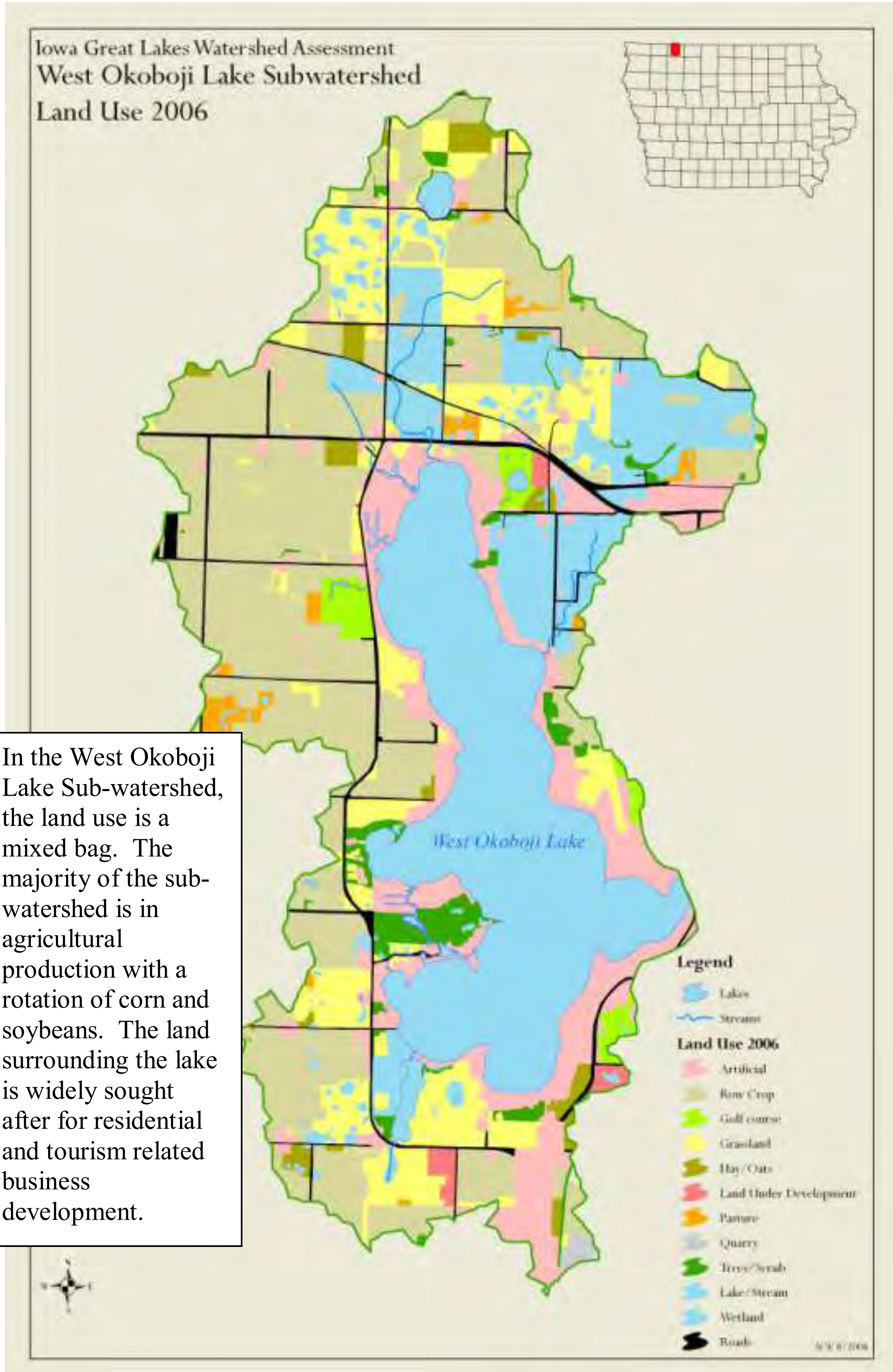
Map 7.24: Center Lake Sediment Delivery. Courtesy of Iowa DNR.

West Okoboji Lake Sub-watershed



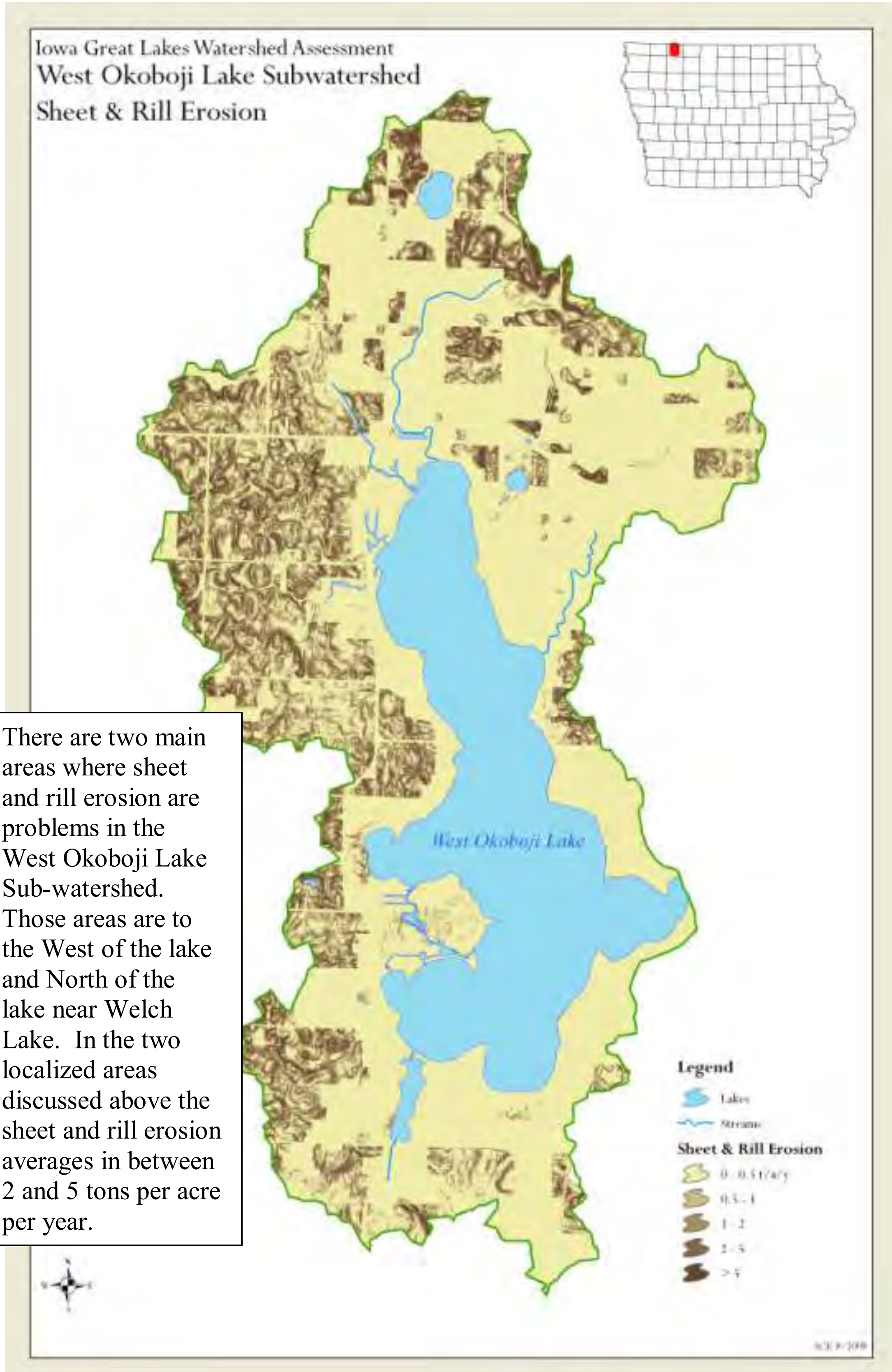
The slope of West Okoboji Sub-watershed is generally around the 0% to 5% grade. There are localized slopes that reach 25% or more. These slopes tend to be short and like Center Lake close to the lakeshore. The North side of West Lake Okoboji has steep grade up to the 25% grade but generally, around 9% to 14% intermixed with 5% or less slope.

Map 7.25: West Okoboji Lake Slope. Courtesy of Iowa DNR.



In the West Okoboji Lake Sub-watershed, the land use is a mixed bag. The majority of the sub-watershed is in agricultural production with a rotation of corn and soybeans. The land surrounding the lake is widely sought after for residential and tourism related business development.

Map 7.26: West Okoboji Lake Land Use 2006. Courtesy of Iowa DNR.



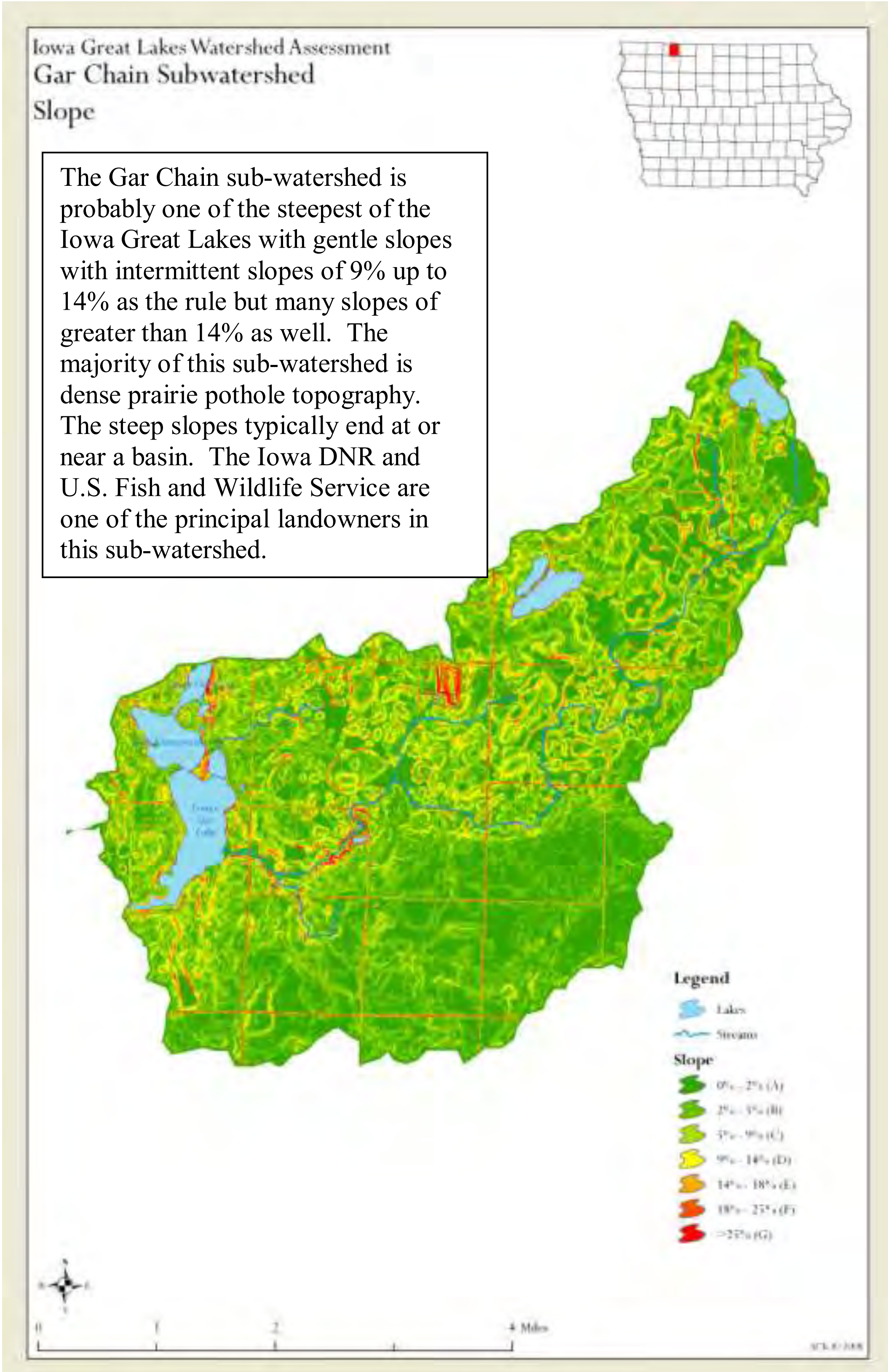
There are two main areas where sheet and rill erosion are problems in the West Okoboji Lake Sub-watershed. Those areas are to the West of the lake and North of the lake near Welch Lake. In the two localized areas discussed above the sheet and rill erosion averages in between 2 and 5 tons per acre per year.

Map 7.27: West Okoboji Sheet and Rill Erosion. Courtesy of Iowa DNR.

The majority of the West Okoboji Lake sub-watershed does not have any problem with sediment delivery to a basin or to the lake. The two main areas where a sheet and rill erosion (the West side and to the North) seem to have the greatest amount of delivery. West Okoboji's main problems stem from these two areas according to the models although a great deal of information will be available in the Urban Section that will detail any problems that may occur near the lake itself.

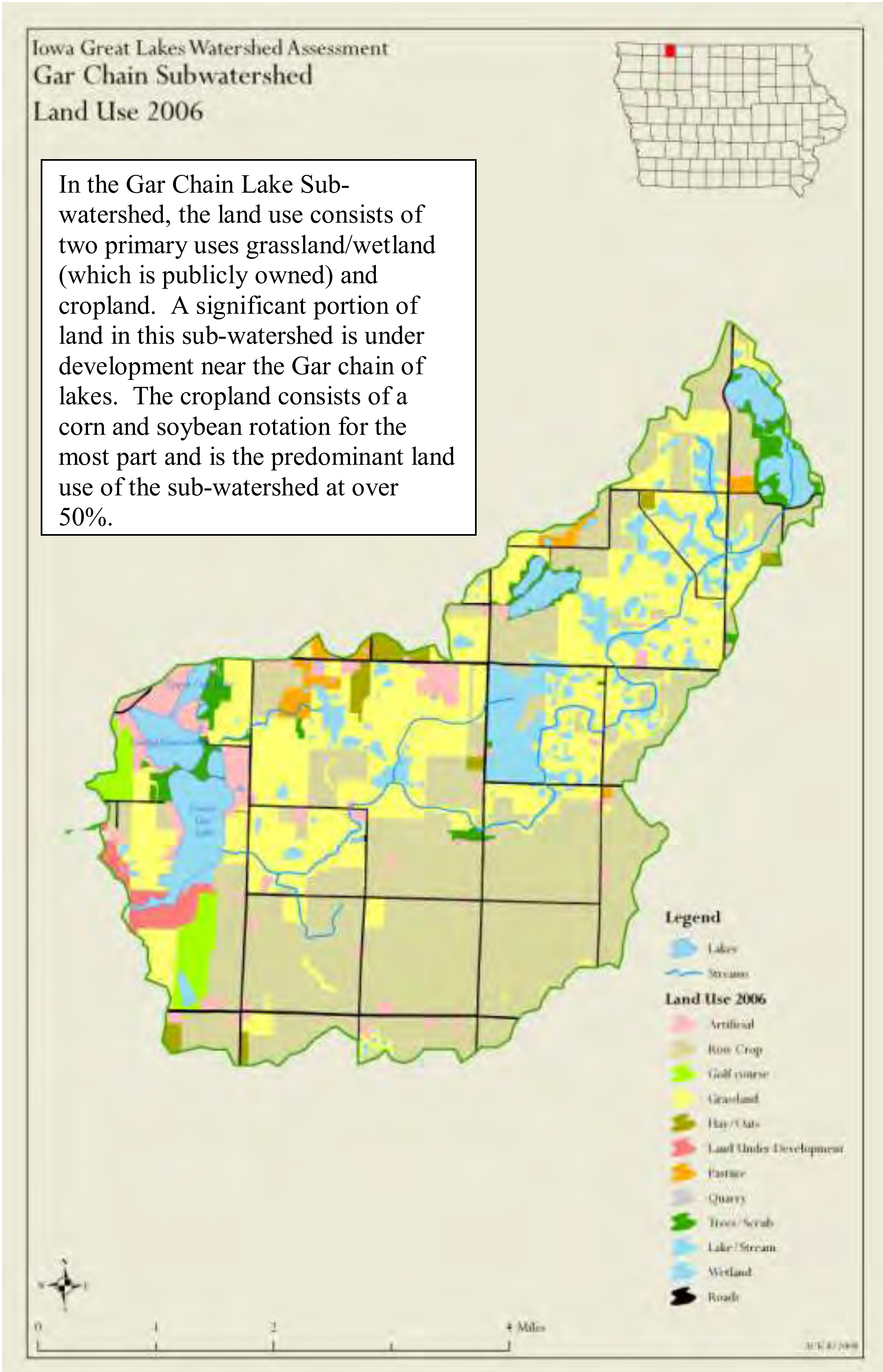
Map 7.28: West Okoboji Lake Sediment Delivery. Courtesy of Iowa DNR.

Gar Chain Sub-watershed

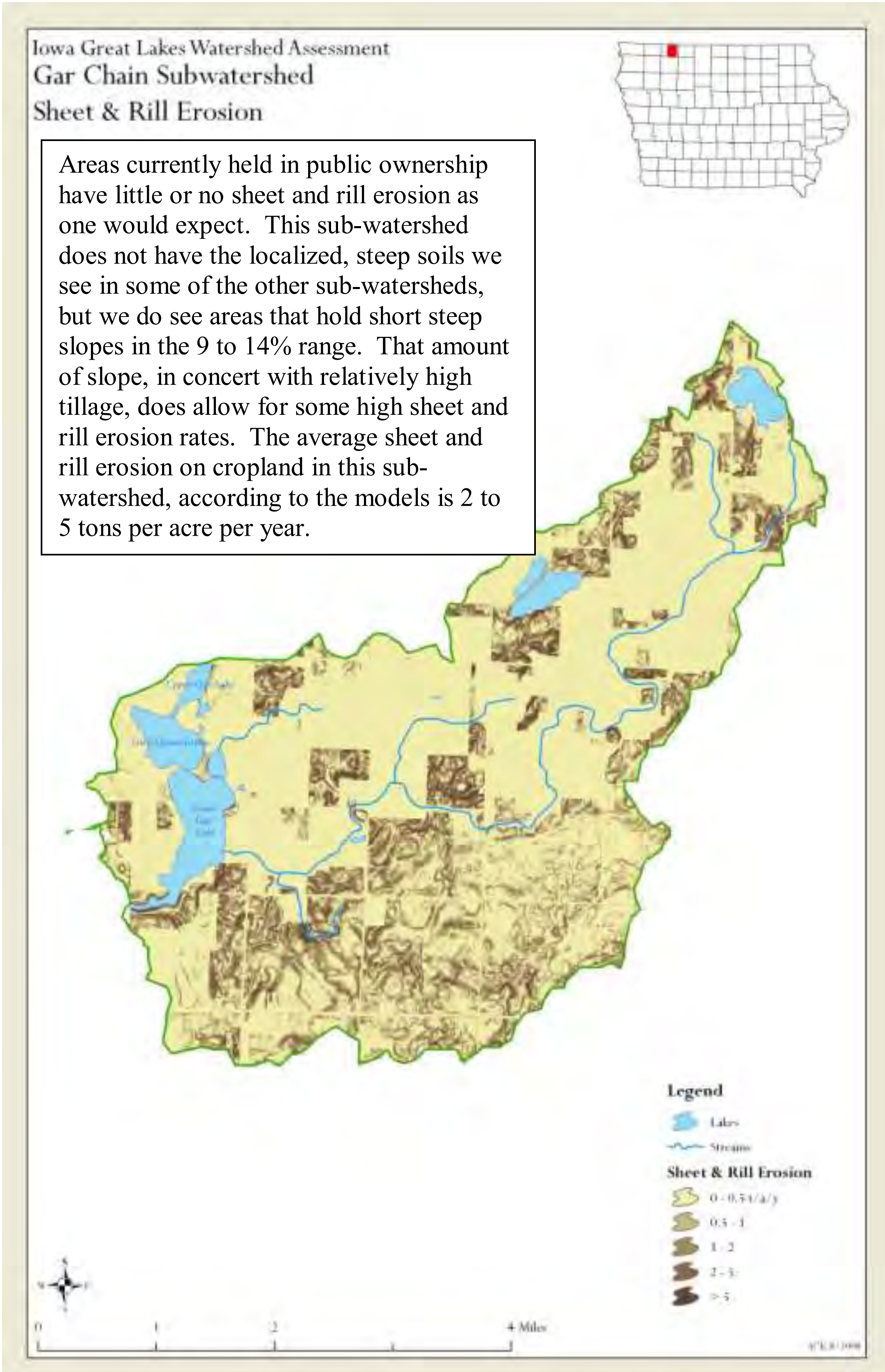


The Gar Chain sub-watershed is probably one of the steepest of the Iowa Great Lakes with gentle slopes with intermittent slopes of 9% up to 14% as the rule but many slopes of greater than 14% as well. The majority of this sub-watershed is dense prairie pothole topography. The steep slopes typically end at or near a basin. The Iowa DNR and U.S. Fish and Wildlife Service are one of the principal landowners in this sub-watershed.

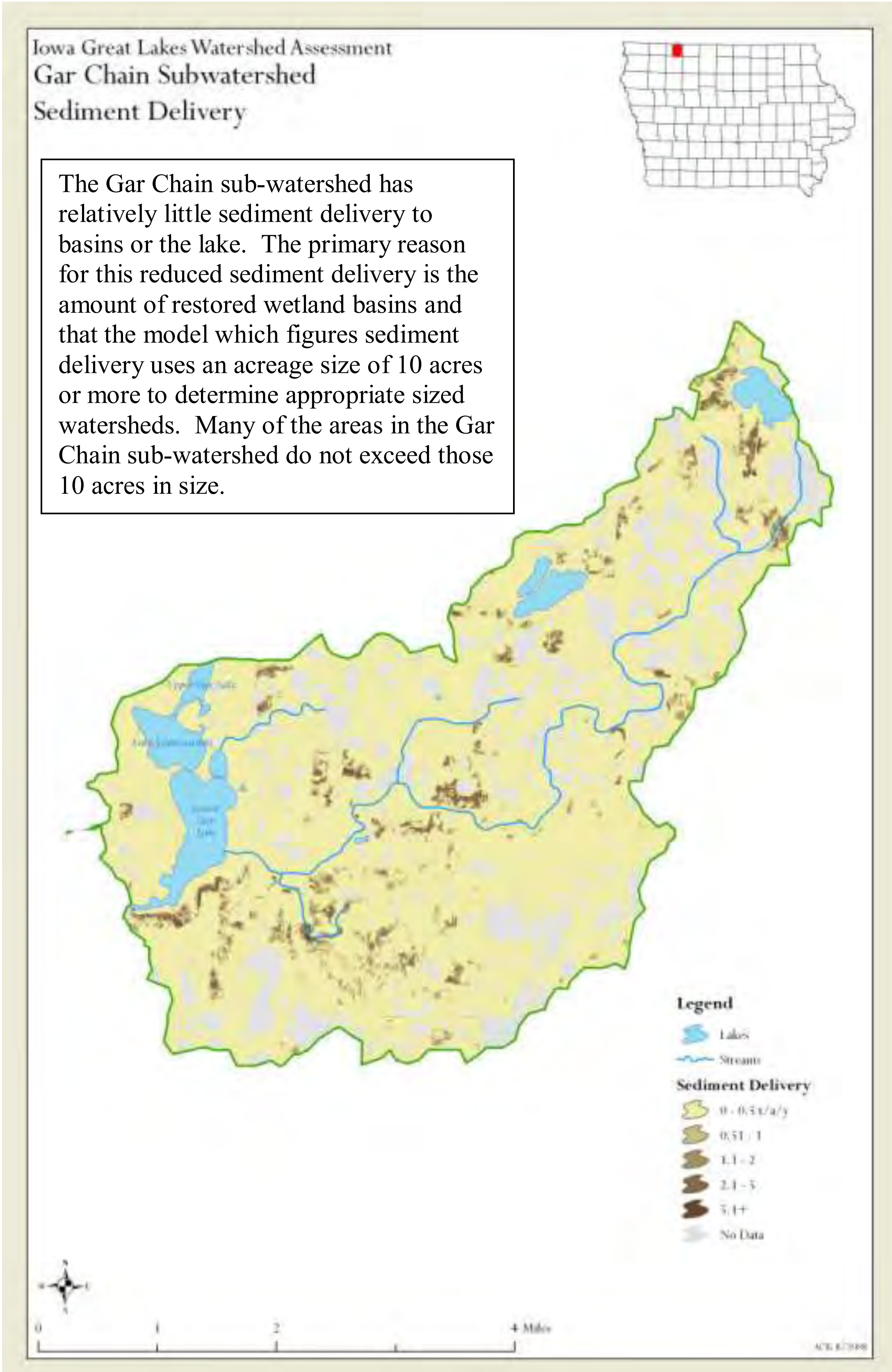
Map 7.29: Gar Chain Slope. Courtesy of Iowa DNR.



Map 7.30: Gar Chain Land Use 2006. Courtesy of Iowa DNR.



Map 7.31: Gar Chain Sheet and Rill Erosion. Courtesy of Iowa DNR.



Map 7.32: Gar Chain Sediment Delivery. Courtesy of Iowa DNR.

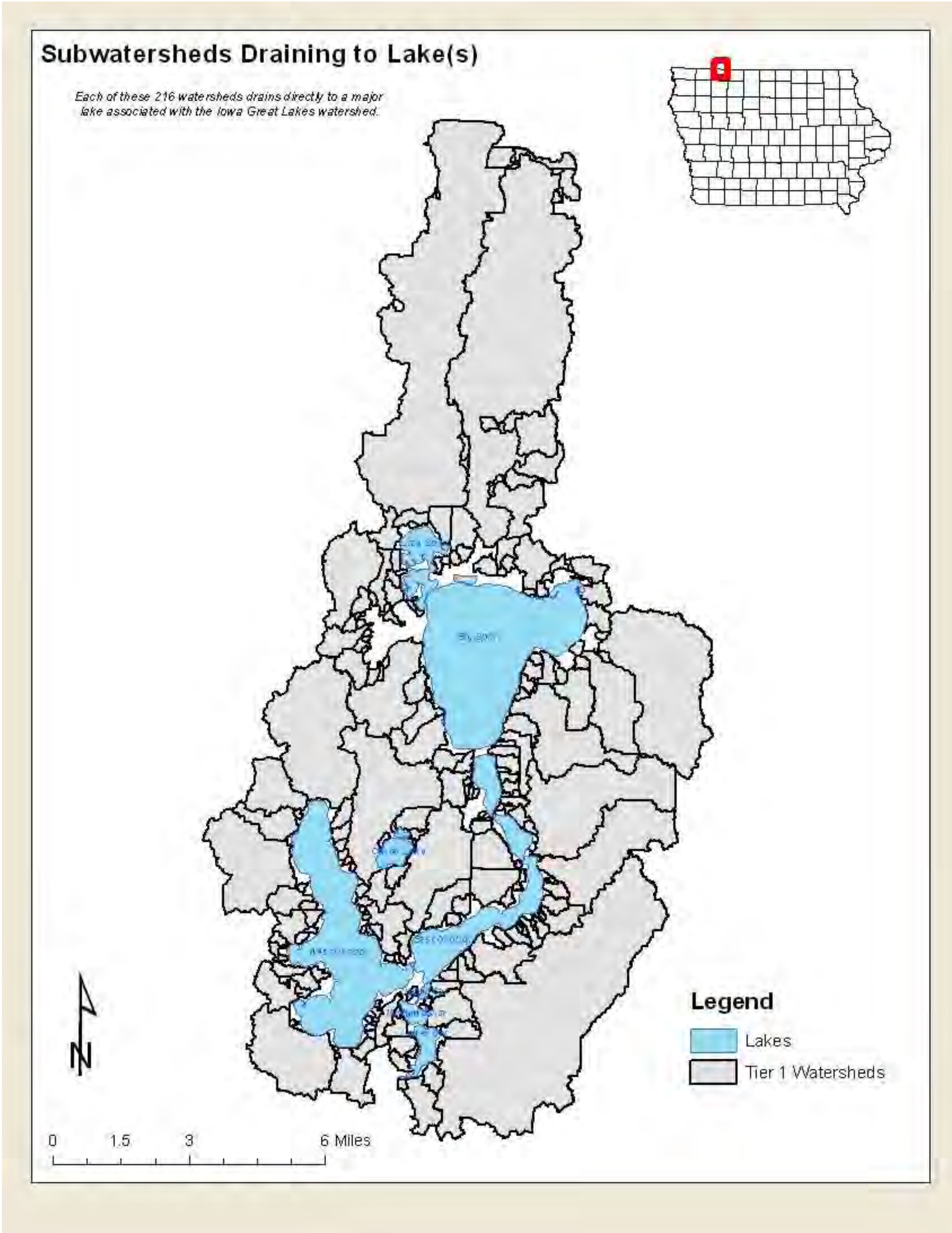
Priority Areas:
In completing modeling of the Iowa Great Lakes Watershed, several forms of modeling have been attempted. “The Iowa Great Lakes topography is not suited to traditional modeling methodology and several considerations were made to allow for accurate prioritization of key sub-watersheds” (Michael Hawkins, IA DNR) of the Iowa Great Lakes. In attempting to model the Iowa Great Lakes, an attempt was made to develop a linear relationship between annual soil loss estimates and sediment delivery. Since sediment loss has been calculated for the entire IGL Watershed, the relationship was used to predict sediment delivery in portions of the catchments of depressed areas not included in the original analysis.

Typically, to prioritize a watershed for wetland restoration and agricultural BMPs the goal would be accomplished through a combination of sediment and nutrient delivery monitoring and modeling. In the case of the Iowa Great Lakes Watershed, water quality monitoring is part of a long-term plan, but not included in this assessment. Because of the complexity of the hydrological landscape of the IGL Watershed modeling performed in this assessment was needed to focus future monitoring efforts.

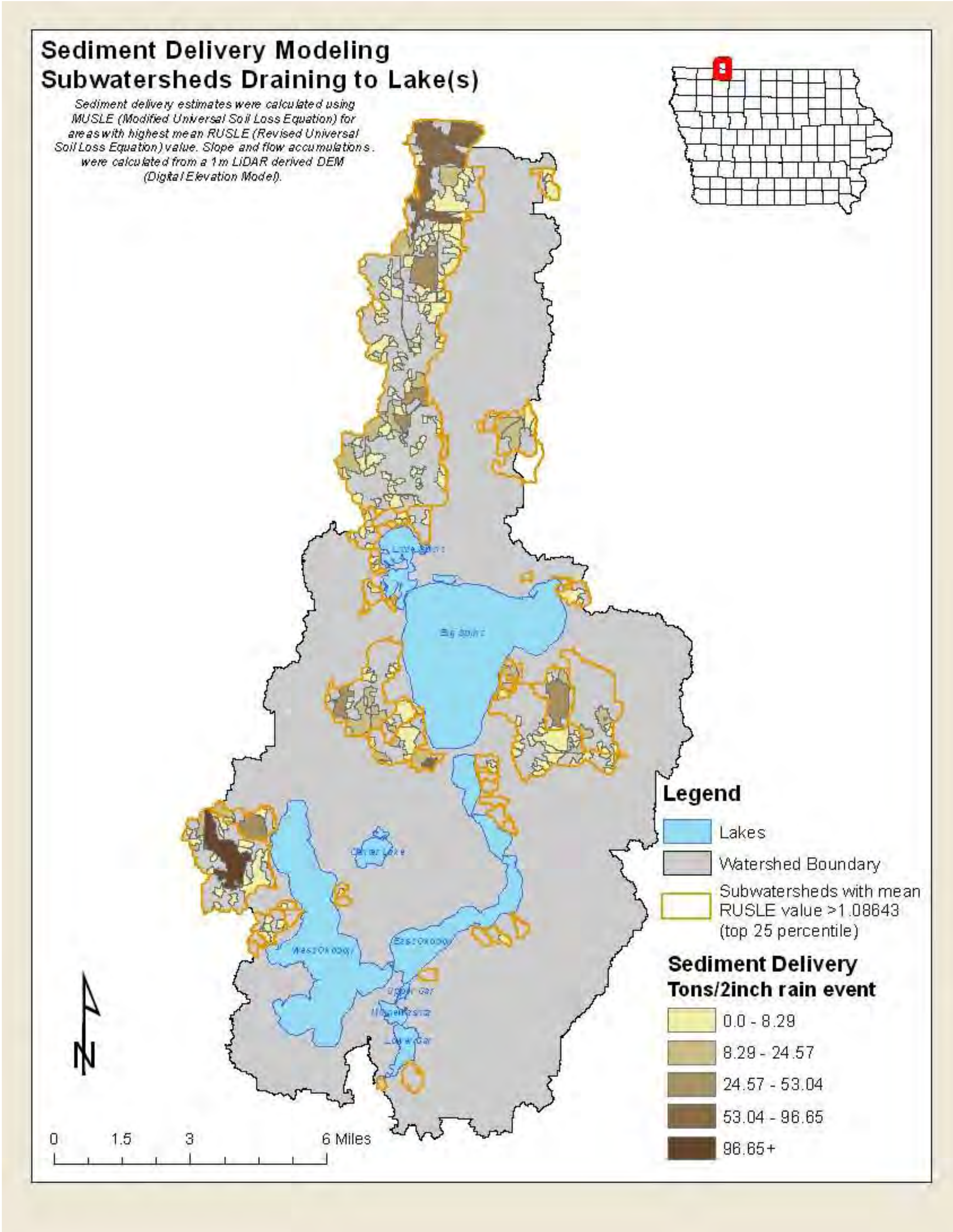
Priority areas identified in this plan have been developed from using a process through discussions with project partners and should guide watershed protection and enhancement efforts. The prioritization of the Iowa Great Lakes follows three steps:

1. Identification of priority Tier 1 watersheds based on high average sheet and rill erosion values.
2. Targeting of wetland restoration and agricultural BMP‘s within priority Tier 1 sub-watersheds using sediment delivery modeling.
3. Identification of high delivery and sediment loss areas within direct contribution zones.

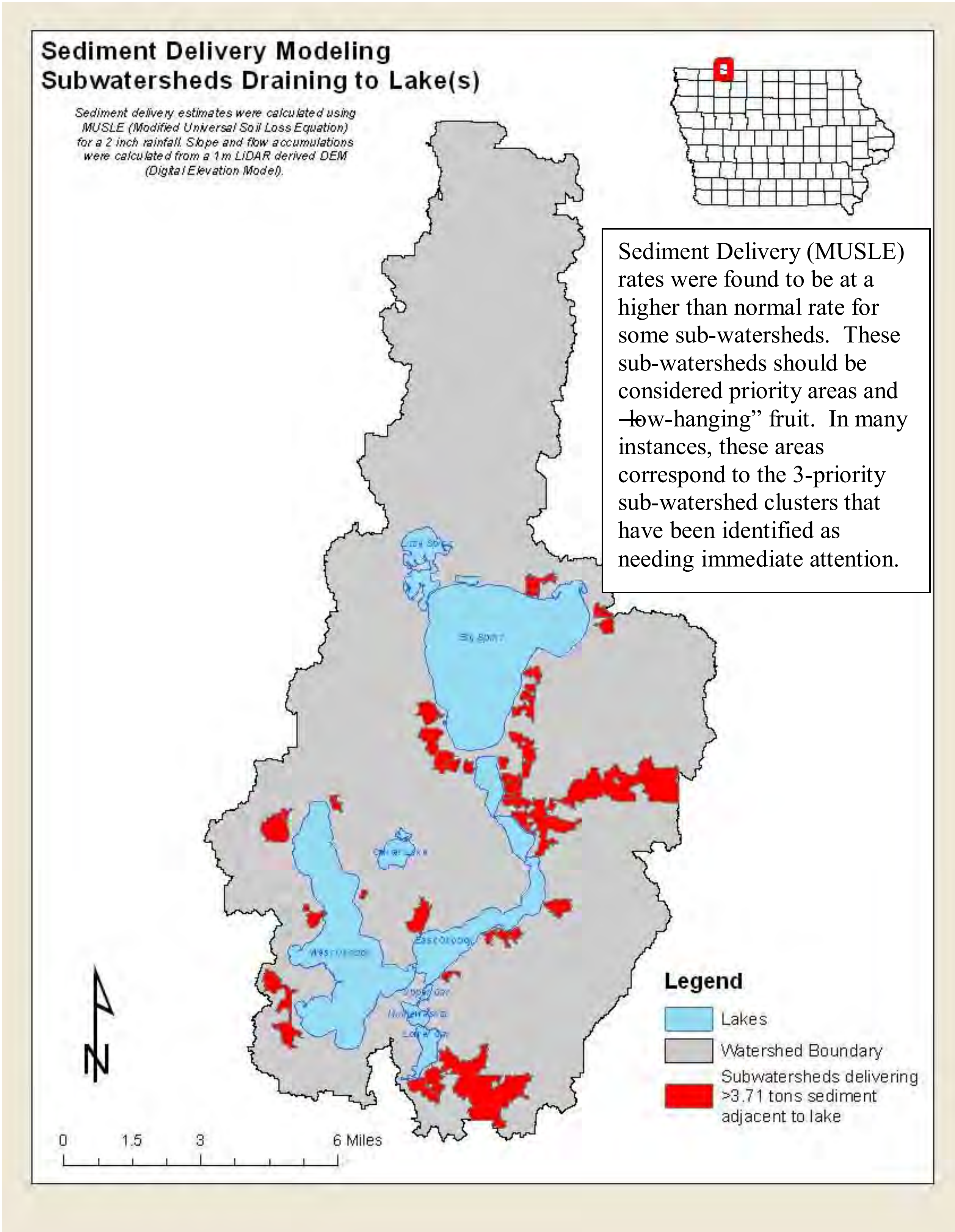
Tier 1 Sub-watersheds
Several Tier 1 watersheds have been identified as having high average soil loss estimates (Map 7.33). These priority Tier 1 sub-watersheds correspond well with known problem areas in the watershed. Sediment delivery (MUSLE) modeling and RUSLE completed within these priority sub-watersheds to determine the top 25 percentile of sub-watersheds with a high than normal MUSLE sediment delivery as well as a higher than normal RUSLE soil erosion rate (Map 7.34). The two models, it was found, do correlate very well and from there areas could be prioritized using this correlation.



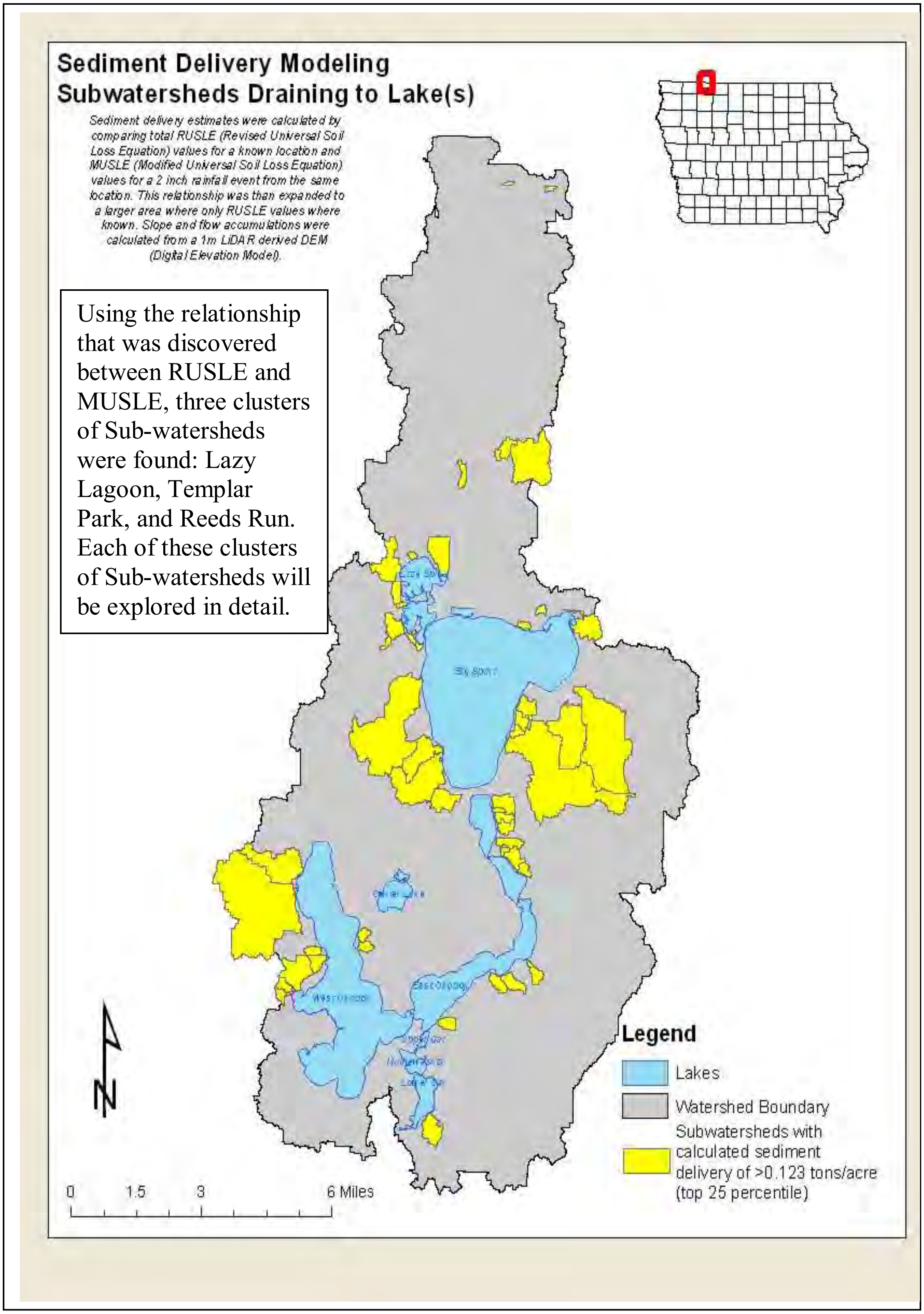
Map 7.33: Tier 1 Sub-watersheds, Courtesy of IA DNR.



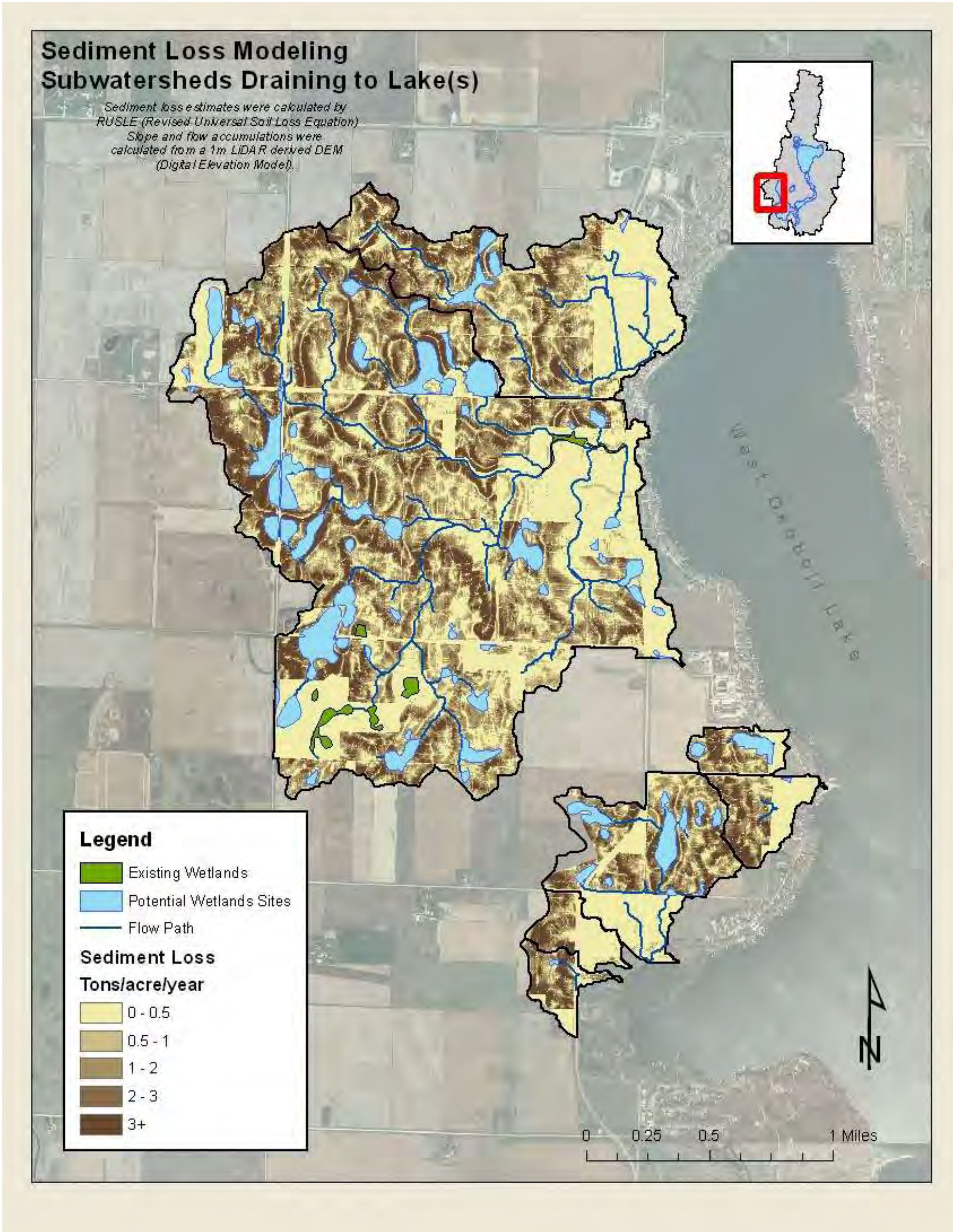
Map 7.34: Top 25%, MUSLE within RUSLE, Courtesy IA DNR.



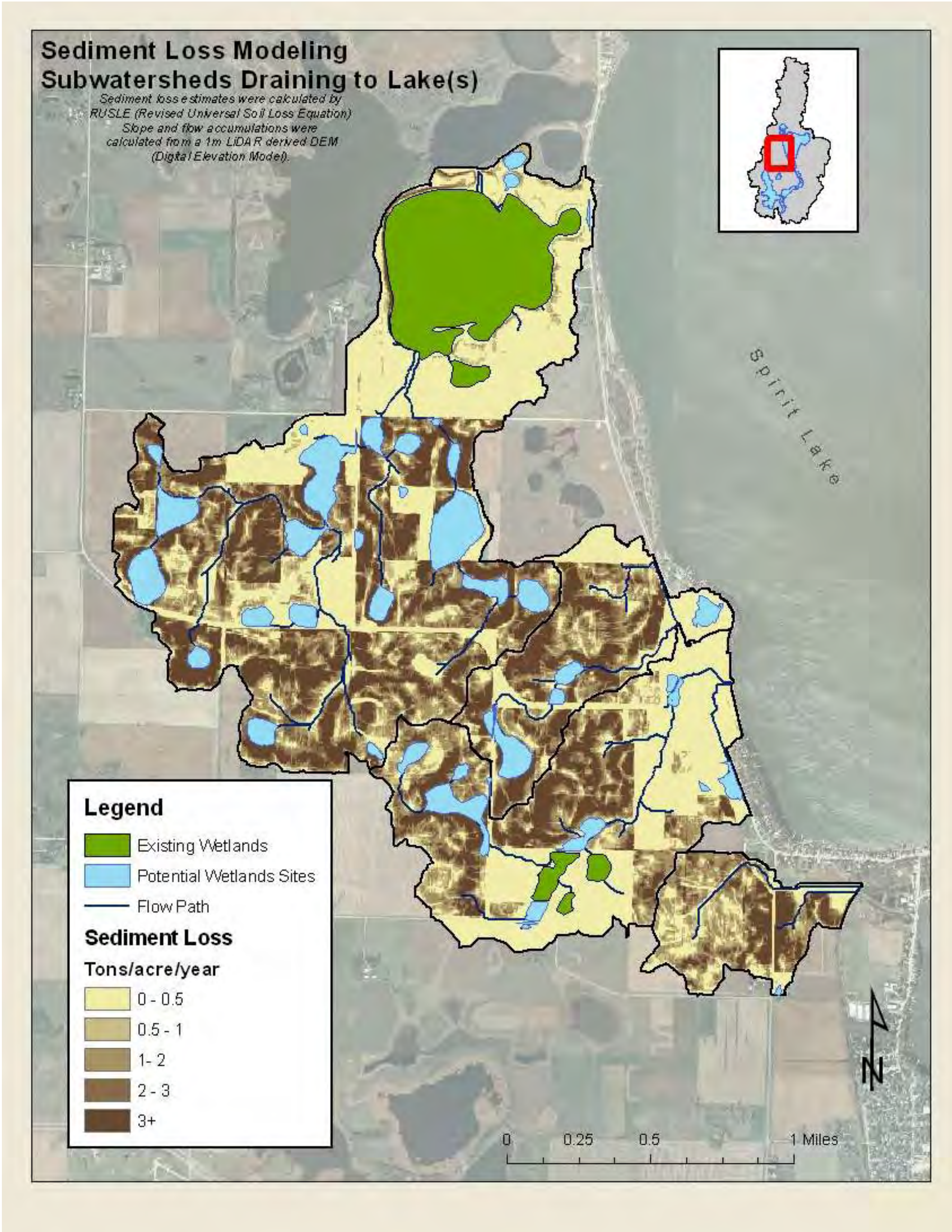
Map 7.35: Highest Sediment Delivery Rates adjacent to lake, Courtesy IA DNR.



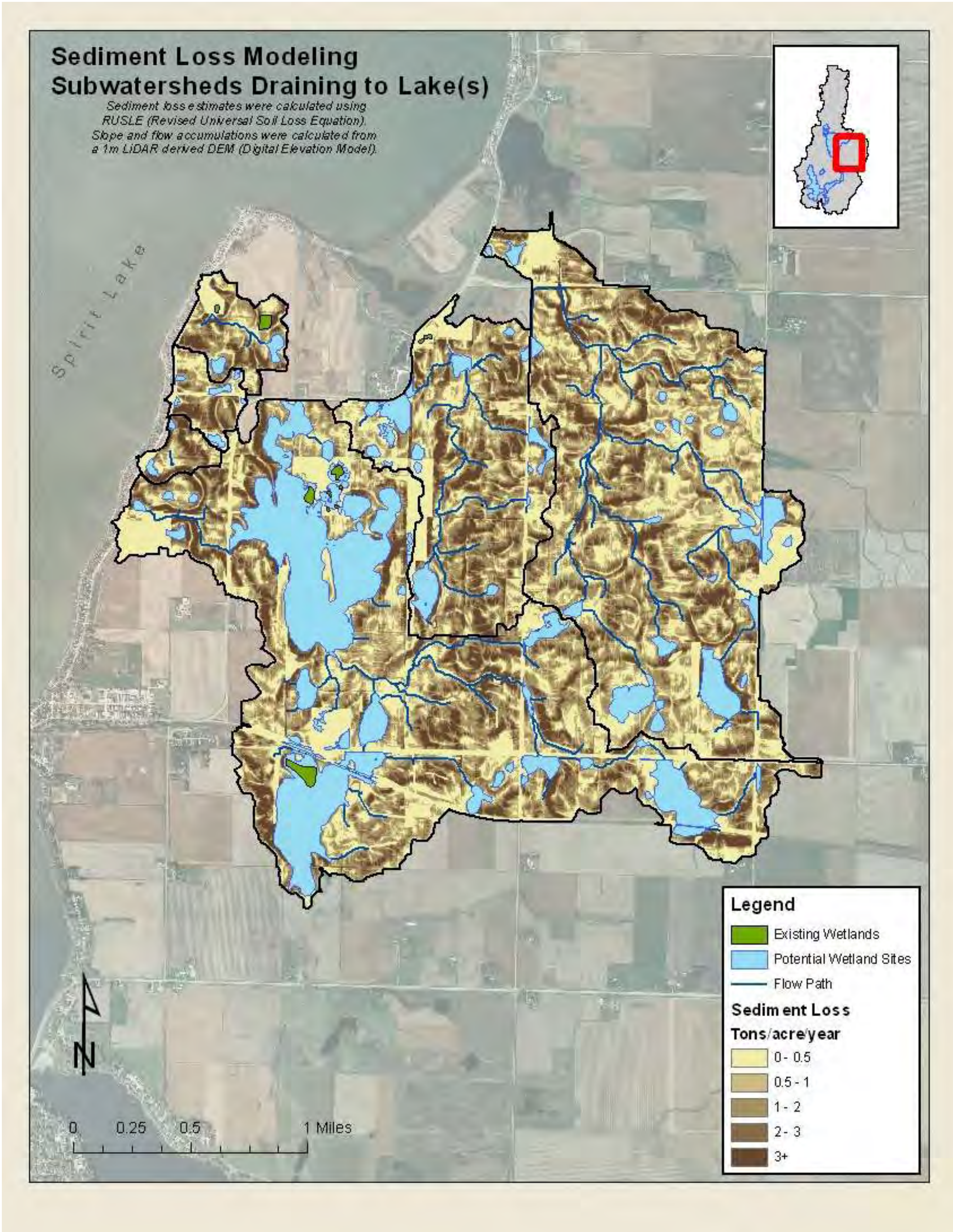
Map 7.36: Three priority cluster, sub-watershed areas using the relationship between RUSLE and MUSLE, Courtesy IA DNR.



Map 7.37: Lazy Lagoon Priority Sub-watershed Cluster, Courtesy IA DNR.



Map 7.38: Templar Park Priority Sub-watershed Cluster, Courtesy IA DNR.



Map 7.39: Reeds Run Priority Sub-watershed Cluster, Courtesy IA DNR.

In addition to the 3-priority sub-watershed clusters that have been identified as producing the greatest amount of sediment, based on the modeling, there are some individual sub-watersheds that are worthy of making a priority because of their location. These sub-watersheds, for the most part are located on a lake or water body, which allows any sediment delivery to be nearly a direct delivery to that water body. One of these sub-watersheds, on Lower Gar Lake, should have special attention paid to it as it produces a large amount of sediment and Lower Gar is an impaired water body because of sediment and nutrient input.

Cultural Resources

There are Cultural Resources found in the watershed especially in the areas adjacent to the lakes within the Iowa Great Lakes watershed. The map below shows the sections in which cultural resources have been discovered in the past. These sections would receive special consideration when conservation planning and construction of conservation practices are going to be conducted.

Map 7.40: Cultural Resources. Courtesy of USDA NRCS.

URBAN LAND

INTRODUCTION

Urban conservation is a new concept to most communities across Iowa but it is a critical part of the state's environmental protection if we are serious about water quality improvement and protection. As areas become urbanized the urbanized areas hydrology changes due to filling of wetlands, compacting of soils, and the creation of impervious surfaces that create high runoff rates.

The Iowa Great Lakes pre-historic hydrology was such that up to 50% of the annual precipitation would have infiltrated and 40% evaporating and used by plants and 10% running off into water bodies. Typically, the 10% runoff that has been estimated on the historic landscapes occurred while the ground was frozen. On the other hand, urbanized landscapes generally have runoff rates of up to 50% of any rainfall event and infiltrate only about 15% with the rest evaporating. The ―first flush" of the runoff is the most polluted with petroleum products, fertilizers, pesticides, heavy metals, chloride, and much more. In addition, the volume of water that is entering waterways is generally much more then the aquatic systems can handle due to the amount of pervious surfaces found in urban systems. This greater volume leads to eroded shorelines, de-vegetation of emergent and sub-emergent aquatic plants, and flooding. Heat is also a major issue with storm water from large sources of impervious surfaces. The heated storm water creates small dead zones at the outfalls where no life is usually sustained because of the great temperature fluctuation.

Ordinance and the implementation of those ordinances and Low Impact Development designs in urban developments are of major concern. New developments that are planned should have a better site design, which is based on working with the landscape rather than against it, using the counties soil survey for site design, and maximizing potential green space that will work to clean storm water. In the case of new or existing developments, which are not already connected to the sanitary sewer, steps should be taken to connect to the central sanitary sewer system. Septic systems are known to be large nutrient and bacteria contributors to watersheds.

History of Urban Conservation in the Iowa Great Lakes Watershed

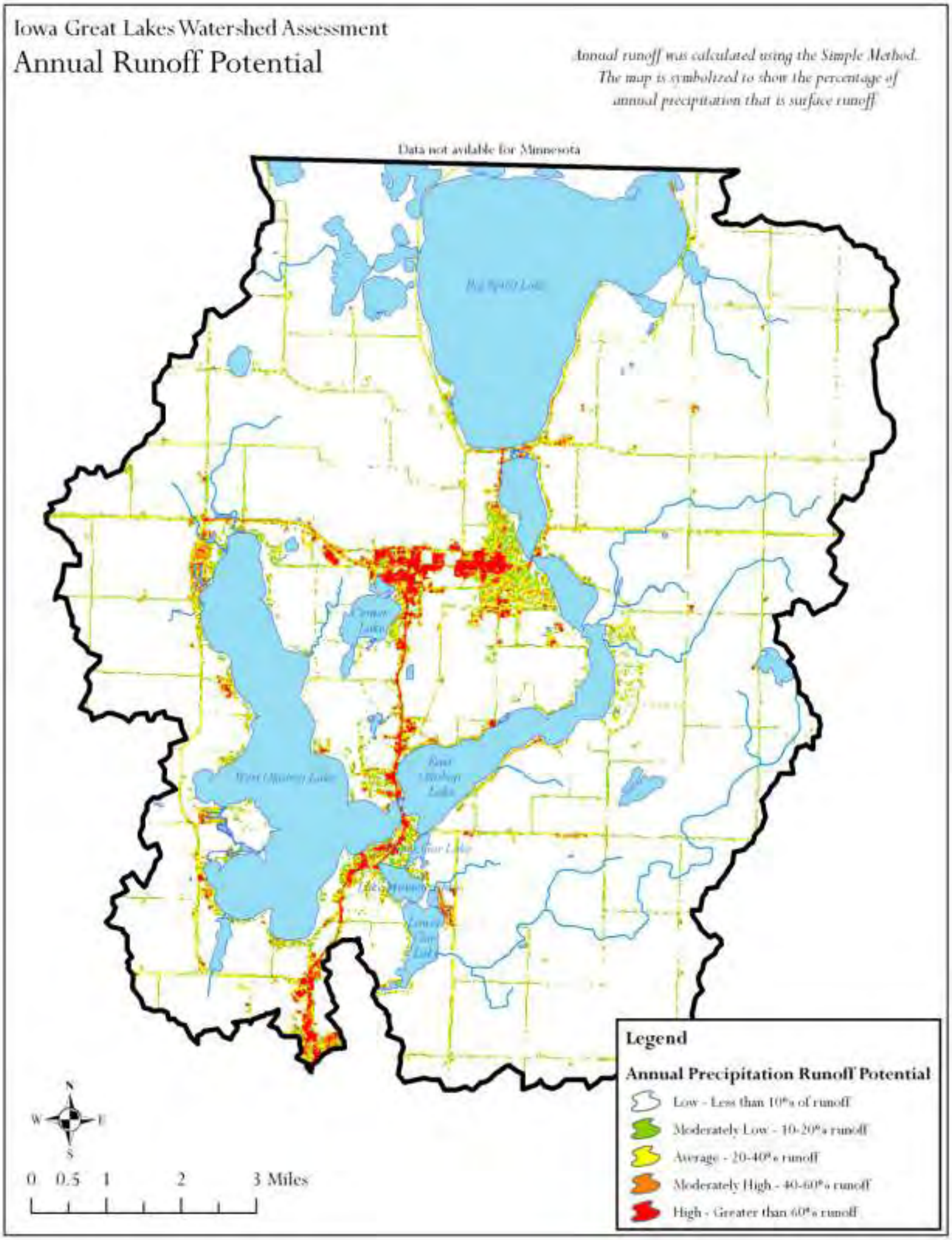
The urban component of the Iowa Great Lakes watershed has only recently taken on a larger share of attention for water quality protection in the Iowa Great Lakes. Until 20 years ago, the urban areas of the watershed, outside of the sanitary sewer, took a smaller portion of the effort used toward watershed work. Work started through the grass root efforts of the lake protective associations to address the sediment loading entering the lakes originating from urbanized areas. These improvements started in the early 1980's with the introduction of silt removal structures at the end of storm sewer intakes within the cities. The most notable project would be the large structure at the end of 15th street in Spirit Lake. These silt removal structures help to reduce sediment when cleaned out on regular bases.

The lake protective associations were instrumental in passing the first construction site and sediment control regulations. The original problem that was identified with urban sites and sediment was shown to be urban developments along the lakeshore that utilized no sediment or erosion reducing practices. Precipitation events readily eroded the soil on these sites and their proximity to the lakes allowed almost direct entry of sediment into the water. The first ordinances, which were passed in the mid-1980, were adopted by all the cities and the county. All of the ordinances required only silt fence and did not address erosion prevention.

A primary component of the Iowa Great Lakes Clean Water Project, which ran from 1989 through 2002, was public education of the urban residents around the lakes, teaching them that what they did affected the watershed and how the watershed was affected. Labeling storm sewers with spray painted decals on the storm sewers started during this time. A rubberized decal was placed on all storm sewer intakes in 2002 to remove the annual trips to all the storm sewer intakes. Another project that was completed by the Iowa Great Lakes Clean Water Project was education about lawn fertilizer. Working with the Iowa Great Lakes RC&D the project coordinator did lawn testing with landowners to show a need for phosphorous. This was followed up by the Iowa Great Lakes RC&D getting a locally made phosphorous free lawn fertilizer marketed. Through this education, many people started asking their lawn care provider if phosphorous was being applied to their lawns.

In 2002, the Dickinson County Clean Water Alliance introduced urban conservation to the county. The Natural Resources Conservation Service, State Urban Conservationist came to the Iowa Great Lakes and started to educate the public about how better ways to protect the lakes. This lead to a series of seminars that were funded by 319 and local Water Quality Commission funds to bring national experts to the county to explain how Low Impact Development and Smart Growth practices and policies work. These seminars were followed by demonstration projects in 2005 that show the public how Low Impact Development can work in the county. The success of the demonstration projects led to the passing of the first Low Impact Development Ordinance in the state of Iowa by the City of Okoboji in 2006.

Annual Runoff Potential has been determined for all urban areas within the Iowa Great Lakes Watershed. Those areas three concentrations have been identified with a greater than 60% runoff potential for these three locations. These three areas are already developed and it has been shown that very little rainwater infiltrates in these locations. Map 8.1 shows the locations very clearly with the highest density being North and East of Center Lake (Polaris area), a second the West side of Spirit Lake (Lakes Mall area), and a third Highway 71 from Arnolds Park to Milford (Hwy 71 area).



Map 8.1: Annual Runoff Potential, courtesy IA DNR.

Construction Site Erosion
Water quality issues from the urban areas of the watershed are due sedimentation from improperly protected construction sites for erosion and sediment control. Although locally there is a silt fence (sediment control) ordinance in place, enforcement usually occurs on a complaint basis only. Federal rules come into play and can be enforced for construction sites of over an acre in size. These rules are enforced by the Iowa DNR field office in Spencer, but with minimal staff time allowed these regulations are enforced but typically only by complaint basis. Due to the limited enforcement and the lack of subsequent follow up by contractors, developers and engineers erosion and sediment from construction sites is causing water quality violations in the lakes. As found by the EPA in a national study, on average the largest soil loss comes from the construction sites.

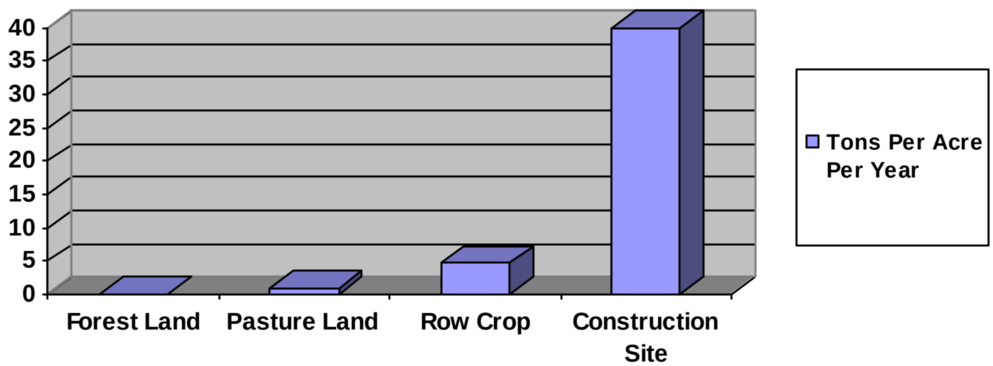


Table 8.1: Site Erosion. Courtesy of EPA January 2007.

This sedimentation from construction sites is leaving the site as sheet and rill erosion, tracking off site and dewatering. This sedimentation is a violation of ordinances and state and federal law but usually occur unchecked and this short fall should be picked up by the local jurisdictions. A compounding problem is the multiple jurisdictions within the watershed and how they enforce or interpret erosion and sediment control regulations.

Sanitary Sewage Management
In the Iowa Great Lakes watershed, the Iowa Great Lakes Sanitary District (IGLSD) has a very large collection system that covers all the shoreline and the majority of the urbanized areas within the watershed. The Iowa Great Lakes Sanitary District (IGLSD) has over 65 lift stations throughout the watershed. The district has done a good job of preventing untreated sewage from getting into the lakes. The lift stations have backed up generators, alarm systems and phone systems to help prevent discharge to the lakes. There is possible need for public education about all the work that is done by the IGLSD, the preventive measures taken by the IGLSD to prevent discharge into the lakes and what citizens need to do if they hear or see an alarm going off at one of the lift stations. The sooner a lift station that is not functioning correctly can be identified, the better the chances are that it will not discharge untreated wastewater onto the ground, into the lakes or into a building. Another educational program that is needed is to teach private citizens and businesses what should not be put into the sanitary system. Things like cooking grease can building up in pipes or lift stations and reduce its ability to function properly.

Items like petroleum or other volatile products should not be placed in the system due to explosion hazards.

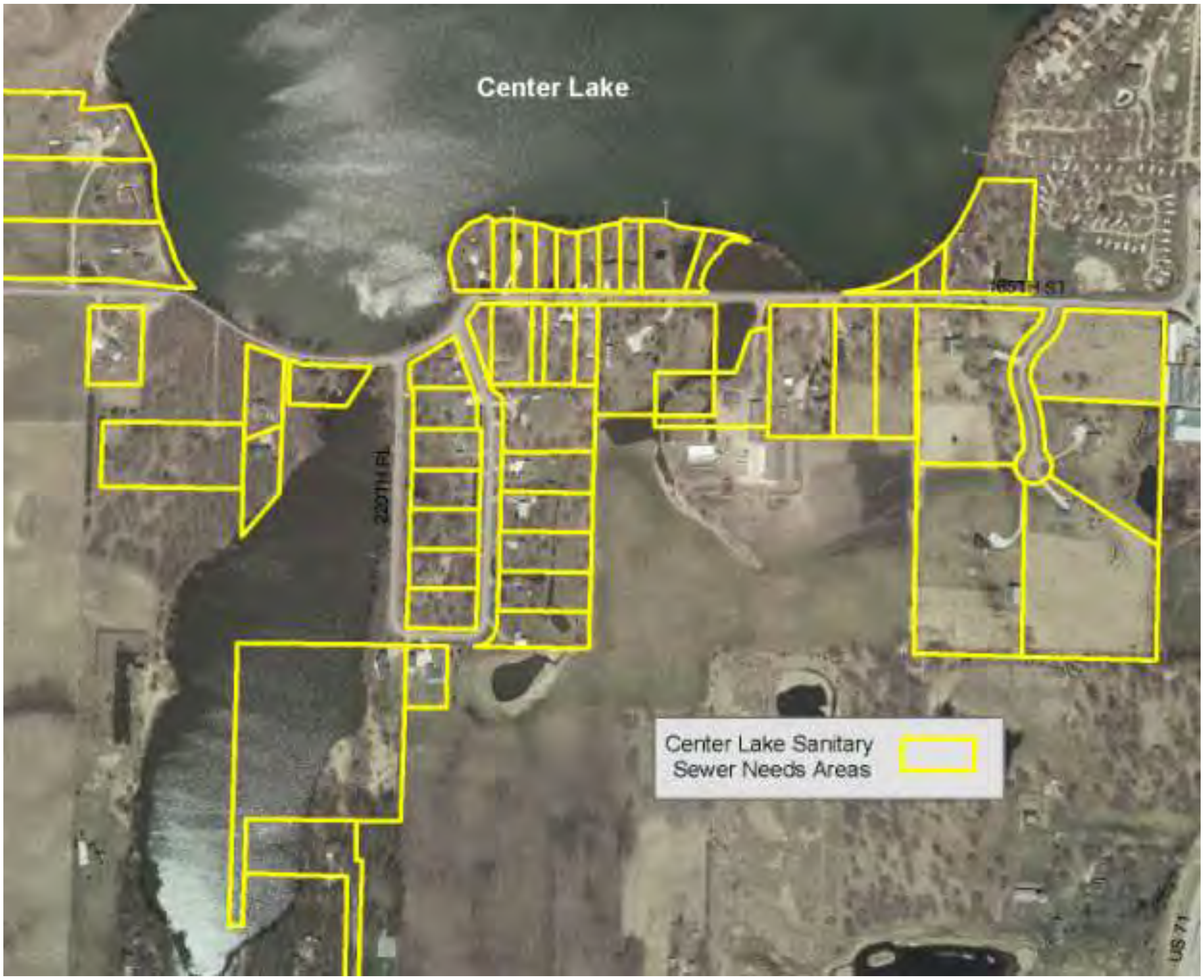
The entire collection system within the Iowa Great Lakes watershed is not owned or managed by the IGLSD. Some cities have ownership of the collection system within their jurisdiction. With some of these systems originally installed in the 1930's and 1940's the piping is old and out dated. The City of Spirit Lake had a problem with infiltration through these old lines and was passing wastewater into private residences. To prevent this the city would pump the wastewater out of the city collection system and into a storm sewer drain to the lake. Many believed that the cause was due to sump pumps illegally connected to the sanitary collection system. The city worked on finding sump pumps illegally connected, but also worked on cleaning and lining the collection pipes. After the lining, work was completed in the area the discharges have gone away.

Although there is an extensive sanitary collection system, there are still areas with septic systems within the Iowa Great Lakes watershed. Four areas are identified and have yet to be connected to the IGLSD collection system. Many of these areas have been identified in the past but due to local political issues have not been connected to the IGLSD collection system. Questions exist about the homes that are not currently connected to the system and who will pay for expansion of the system to the areas that are not connected.

Four locations within the Iowa Great Lakes Watershed are urbanized, which have not been connected to the Sanitary District. Those areas are the South end of Center Lake, an area West of Emerson Bay, and two areas on Little Spirit Lake. Many of the political problems with determining who will pay for these sewer connections are evident with the first site we will examine the area just to the South of Center Lake. On the south end of the Center Lake, many of the homes have septic systems in an area with a water table that is controlled by the lake level. With this area south of Center Lake under county jurisdiction, however, the closest collection system is operated by the City of Spirit Lake. In order for the IGLSD to connect these homes, they would have to run a trunk line to the area. To expand the system from Spirit Lake is the most likely option but to properly plan for the future to the line would be oversized for current users in order to account for future development and connection.

The second site with a need for septic systems to be attached to the sanitary district is West of Emerson Bay State Park. This area has a few privates systems, at least one commercial system and a joint system with several trailer homes connected. This site has been identified as one of the possible sources of bacteria for the Emerson Bay impairment. There is at least one private well in this area that has had issues with e-coli found in the water in the past. Water from a stream, which delivers water into Emerson Bay, has recently been diverted away from the beach. This temporary solution has controlled the bacteria on the beach but has not solved the bacteria problem. In order to resolve the bacteria problem at Emerson Bay two things need to occur as soon as is possible. First, the area needs to be connected to the IGLSD collection system and second, the current sanitary district lines to the lift station need to be inspected to ensure they are not leaking into the streambed and causing the problems.

Map 8.2: Center Lake Sanitary Sewer.



Map 8.3: Close up of the sanitary sewer needs on the south end of Center Lake.
Courtesy USDA, NRCS

Map 8.4: Close up of the sanitary sewer needs for the Emerson Bay area on West Okoboji. Courtesy USDA, NRCS

The third and fourth areas are located on Little Spirit Lake. The first area is on the south side of Little Spirit Lake were there are 3 or 5 lots that need to be connected to the IGLSD system. Homes in this area are newer and have modern septic systems that should be operating properly. In the future, these lots will need to be upgraded and maintenance and at that time connection to the IGLSD collection system should be offered as an option. The fourth and final location in the watershed, which needs to be connected to the sanitary sewer, is on the east side of Little Spirit Lake, the Leisure Beach area.

This area has recently been connected to the IGLSD collection system but it only goes to the state line. There are homes in Minnesota that are now on individual septic systems and not part of the joint collection system. The IGLSD has decided not to go into Minnesota because of the concern that they could not collect user fees. This is only a paper work concern because the Leisure Beach area in Minnesota receives all its services trash collection, fire protection, and police protection from Iowa through taxes collected in Minnesota and given to the proper agencies in Dickinson County.

Other areas that are not currently connected to the IGLSD should be researched to find out what it would take to get these sites connected to the system. If there are viable options or funds to assist to connect these systems to the IGLSD system, it should be done instead of rebuilding a septic system.

Map 8.5: Septic Systems on Little Spirit Lake

Map 8.6: Close up of the south sanitary sewer needs area on Little Spirit Lake. Courtesy USDA, NRCS

Storm Water Management

Management of storm water in the area has been focused primarily on flood control. In the past few years, however, a few cities and the county have been addressing water quality concerns through ordinances within their boundaries. The focus of these ordinances has been on management of storm water using the Iowa Storm Water Management Manual. Dickinson County is the first county in the state that is requiring post construction storm water management for water quality or LID storm water management. These ordinances need to keep the core standards and specifications for definitions and design as stated by the Iowa Storm Water Management Manual.

Many of the existing urban construction sites need to be retrofitted with Low Impact Development practices to reduce storm water run off. Ordinances are addressing existing structures when additional construction is built in an area but there is no standard to guide the ordinances and there is no standard from jurisdiction to jurisdiction. The built out areas can be modeled using GIS. The models show which areas will produce the highest volumes of water that will be generated for the water quality volume WQv or 1.25 inches of rain. There is also the Watershed Forestry Management Information System that can help prioritize areas for water quality concerns.

The areas that generate the most storm water runoff are located in three areas; the City of Spirit Lake, the Cities of Okoboji through Arnolds Park, and the South end of West Okoboji, encompassing the cities of West Okoboji, Wahpeton, and Milford. The areas with the highest runoff volume rates are the highest priority for storm water management. By treating these areas with practices such as Low Impact Development (LID), the large volumes of water going quickly to the lakes can be reduced. The LID practices include but are not limited to rain gardens, pervious pavement systems, soil quality restoration, infiltration trenches and green roofs. These LID practices reduce run off and cool the runoff down prior to it getting to the storm sewer and finally into the lakes.

The existing sub-divisions that do not have hard surface roads are another major source of sediment loading that needs significant attention. These sub-divisions are primarily found on the east side of East Okoboji Lake with steep hills and gravel roads. These areas are hard to properly model with computer modeling and GIS due to the continued maintenance they need to stay functional and safe for public use. The primary concern is the roads in this area as they have gullies that form but are continually maintained. Many of these roads can have up to 2 foot wide and 1-foot deep gullies that will start up towards the top of the hill and run to the lakeshore. These gullies next to the road are not safe for the public so they are refilled and then allowed to erode back into the lake during the next rain event. What is needed is alternative drainage systems that infiltrate the water from these gravel roads or to pave the roads and use infiltration based storm water management practices.

Shoreline Stabilization

The native shoreline around the lakes has been impacted dramatically by urban growth throughout the watershed. The IGL Lakes Watershed once had native prairie almost entirely except a few areas that had an oak savannah on the upland parts of the shoreline. In the lake, there were native emergent plants like bulrushes, sedges, and burr reeds, among other aquatic plants. The majority of these plants have been removed, destroyed, sprayed or displaced from the shoreline. This has led to more shoreline erosion less lake bottom stabilization, and less aquatic plant diversity. Ultimately, this has led to a reduction in water quality. The lack of these aquatic plants leads to stirring of the bottom muck, wave action on the shoreline, and excess nutrients left available for algal use.

The easiest place to do these restorations would be in areas of the lake that have public access to the lake. These plants can be restored on points, in shallow areas, and in low boat traffic areas as well as areas like state parks. On Big Spirit Lake and West Okoboji Lake, there is possibility of up to eight sites per lake. East Okoboji Lake will be limited to about four sites and the lower chain of lakes would only have one or two areas. The restoration of these vegetative species would help repopulate the plants that are so vital to the health of the lakes. By re-vegetating these plants, they may have the opportunity to spread and disperse seeds into the lake. The re-vegetation of the shoreline may be something that can occur on private lands but in doing so, there needs to be very specific guidelines on how the work is done. Any work on lakeshore vegetation restoration should be done only with local eco-type plants. These sites can be good educational tools to show the public the benefit of native plants to water quality in the lakes.

According to Henderson, in *Lakescaping for Wildlife and Water Quality*, ―Biological, chemical, and physical factors of a lake are interdependent. When one part, such as shoreline vegetation or surface runoff to the lake, is altered, the others change. Understanding the importance of each component in a lakes ecosystem is essential for us to understand how our actions can affect a lake‘s wildlife habitat and water quality." (Henderson, 2008)

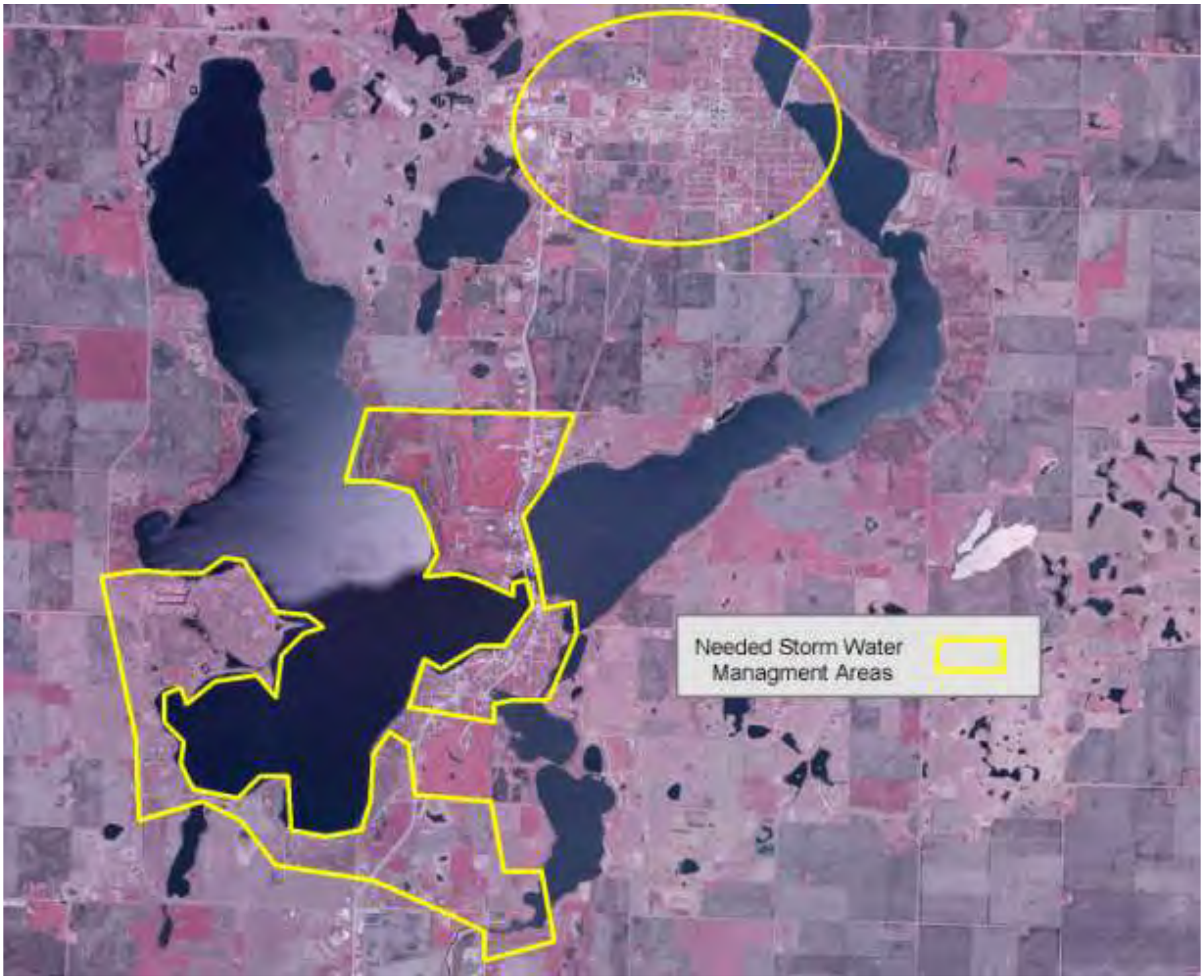
On the upland shorelines there needs to be work done to restore shorelines back to native plants. This is a key component to educating the public on why native plants are needed, to show them how to plant native prairie plants and how to maintain these plants. This should be started on slopes greater then 3:1 and steeper. That would get some of the steepest slopes that can have highest soil loss rates under control.

Map 8.7: Shows an overview of all the urban gully areas. Courtesy USDA, NRCS

Map 8.8: Shows known gully erosion areas in the Echo Bay Area on West Okoboji Lake.
Courtesy USDA, NRCS

Map 8.9: Shows known gully erosion areas in the Maywood Area on West Okoboji Lake. Courtesy USDA, NRCS

Map 8.10: Shows known gully erosion areas in the Camp Foster to Arthur Heights on East Okoboji Lake. Courtesy USDA, NRCS



Map 8.11: Shows the areas that are in need of Storm Water Management practices.
Courtesy USDA, NRCS

MANAGEMENT PLAN

The management of the Iowa Great Lakes for protecting and preserving its water quality has to be a multi-faceted approach. The Iowa Great Lakes is one of the most diverse watersheds in the State of Iowa with a strong agricultural influence, the largest concentration of publicly owned lands in the State, and one of the fastest growing urban areas in the state. The water quality assessment portion of this report clearly shows that nutrients, primarily phosphorous, are the primary concern in the Iowa Great Lakes Watershed.

The formation in the early 90's of the Clean Water Alliance was a unifying move on the part of many partners in the Iowa Great Lakes. The Clean Water Alliance has been a leader in providing guidance and communication to its members since its formation. The formation in the early 2000's of the Dickinson County Water Quality Commission was another step toward beginning to manage the Iowa Great Lakes. The Water Quality Commission has up to $200,000 each year that is directed for water quality projects in the Iowa Great Lakes, Silver Lake, and Swan Lake. This money has been used for development of management plans, actual conservation on the ground, and other uses to improve the water quality of the Iowa Great Lakes. In the last 8 years, the Water Quality Commission has invested 1.4 million dollars toward water quality projects and leveraged that money against 16.4 million dollars. In other words for every 1 dollar of local money spent, 16 has been brought into the county from private, local, state, and federal sources.

The primary problem in the Iowa Great Lakes Watershed is excess nutrients which in turn causes excess algae growth and in some occasions Cyanobacteria growth that can cause toxic results. The two major pollution sources in the Iowa Great Lakes include urban development areas and the agricultural production areas. While the agricultural lands are the majority land use, urban areas often have an equal amount of sediment and nutrient delivery because of the nature of urban development and the location of the urban areas in close proximity to a lake.

The Iowa Great Lakes cannot be managed in one simple way because of the diverse nature of the watershed. In addition to the two priority areas, urban and agriculture, the Iowa Great Lakes has the highest concentration of publicly owned lands and natural areas in the state. While this seems to be a good thing, it brings with it its own set of problems.

The management of the Iowa Great Lakes for water quality has to be a multifaceted approach dealing with both the urban and agriculture using different practices. The natural areas of the county will present different challenges, mainly in the form of animal waste. One problem, especially on smaller bodies of water is the influx of waterfowl feces at certain times of the year.

To achieve the biggest results, quickly, work should begin in the areas supplying the most sediment and nutrients to the Iowa Great Lakes. In the Chapter on Agricultural Assessment, the areas with the highest sediment delivery have been identified. The most ―bang for the buck" would be achieved by working in the areas that have shown to produce the most sediment and nutrient loading to the lakes. Appendix Four shows the procedures and processes that were arrived at to determine the sediment delivery to the lake. The Map 7.36 shows areas with the highest sediment delivery in the IGL Watershed. Those areas identified on Map 7.36 are the highest priority areas for watershed restoration work and the greatest effort should go to those areas. There are three main ―clusters" of sub-watersheds where work should be performed and those are: Triboji Beach Cluster, Marble Beach Cluster, and Reeds Run Cluster.

AGRICULTURE

To manage sediment runoff and nutrient runoff on agricultural areas construction of sediment control ―structures" such as waterways, wetlands, modified terraces, grade stabilization structures and sediment basins can be combined with nutrient and pesticide management and reduced tillage to prevent non-point source pollution.

All land under cultivation needs conservation cover such as mulch-till, no-till, and ridge-till to guard against erosion from rainfall and runoff as well as wind erosion. In addition, some areas within the Iowa Great Lakes should be seeded to a permanent ground cover and not be tilled due to its erosive nature.

Conservation structures that would be of great benefit in the Iowa Great Lakes and a description of that structure include:

- Grassed Waterway: A natural or constructed channel that is shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff.
- Grade Stabilization Structure: A structure used to control the channel grade in natural or constructed watercourses.
- Sediment Basin: A basin constructed to collect and store debris or sediment.
- Structure for water control: A structure in a water management system that conveys water, controls the direction or rate of flow, maintains a desired water surface elevation, or measures water.
- Terrace or modified terrace: An earth embankment, or a combination ridge and channel, constructed across the field slope.
- Wetland Restoration: The rehabilitation of a degraded wetland or the reestablishment of a wetland so that soils, hydrology, vegetative community, and habitat are a close approximation of the original natural condition that existed prior to modification to the extent practicable. The protection of existing, natural wetlands should be given priority.

Conservation cover that would be of great benefit in the Iowa Great Lakes Watershed and a description of that cover include:

- Conservation Cover: Establishing and maintaining perennial vegetative cover on the land using native vegetation.
- Critical Area Planting: Establishing permanent vegetation on sites that have or are expected to have high erosion rates, and on sites that have physical, chemical,

or biological conditions that prevent the establishment of vegetation with normal practices.

- Filter Strip: A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater.
- Shoreline Protection: Treatment(s) used to stabilize and protect banks of streams or constructed channels, and shorelines of lakes.
- Upland wildlife habitat: Creating, maintaining, or enhancing areas using native grasses and forbs, including wetland, for food and cover for upland wildlife.
- Windbreak/Shelterbelt establishment: Linear plantings of multiple rows of trees or shrubs established for environmental purposes.
- Lakeshore vegetative re-establishment using local eco-type, native species of plants.

Cultural Practices that would benefit the Iowa Great Lakes Watershed and a description of that practice include:

- Cross slope farming: when farming operations and planting rows are generally aligned perpendicular to the dominant slope of the field and when in-row grade does not exceed one-half of the dominant slope.
- Nutrient Management: Managing the amount, source, placement, form and timing of the application of plant nutrients and soil amendments.
- Pest Management: Utilizing environmentally sensitive prevention, avoidance, monitoring and suppression strategies, to manage weeds, insects, diseases, animals, and other organisms (including invasive and noninvasive species), that directly or indirect cause damage or annoyance.
- Prescribed Burning: Applying controlled fire to a predetermined area.
- Residue tillage management: Manage the amount, orientation, and distribution of crop and other plant residue on the soil surface year round while limiting the soil-disturbing activities used to grow crops in systems where the entire field surface is tilled prior to planting. Residue tillage management includes mulch-tillage, no-tillage, ridge-tillage, and reduced-tillage.

(Natural Resource Conservation Service (2009))

The practices listed above are a laundry list of practices that will benefit the water quality of the Iowa Great Lakes and the watershed of the Iowa Great Lakes. Some practices will give a greater benefit than others will. Those practices should be the priority practices; however, by having all “tools” available to the planner there is a greater possibility of affecting change in the watershed.

Priority practices or the ones that will give the greatest benefit to the Iowa Great Lakes quickly include grassed waterways, Sediment basins, wetland restoration, conservation cover, and critical area planting; filter strips, shoreline protection, lakeshore re-vegetation, nutrient and pesticide management, and reduced-tillage, no-till, and ridge-till farming. These practices have the greatest chance of being immediately accepted by the landowners and operators within the watershed and have a proven record of accomplishment of stopping sediment and nutrients from moving to a water body. The other practices listed above should not be left out of the ―toolbox" as each situation could call for a different application.

The listed practices should be prioritized in any treatment plan but a cookie cutter approach assuming that one practice is better than any other should not be used. Each situation in the Iowa Great Lakes should be evaluated independently based on cultural as well as practical applications. The more important prioritization can be seen when looking at Map 7.8. This map shows us the sub-watershed basins that produce the most sediment delivery to a water body.

According to modeling done by the Iowa DNR using RUSLE, the Iowa Great Lakes produces approximately 65,302 tons of sediment per year through sheet and rill erosion. Not all of that sediment reaches a lake or basin however. There are natural stoppages, roads, and conservation practices that stop a portion of this sediment and the nutrient that often accompanies it. Map 7.8 shows us the areas in the Iowa Great Lakes, using MUSLE that produce the greatest amount of sediment that is delivered to a basin during a 2-inch storm event. This map is one of the greatest tools in producing an actual doable management plan for the Iowa Great Lakes than any other in this assessment.

By using this map as a planning and a treatment tool, the conservation practices listed here (and other experimental practices) can be targeted in the most likely areas that will produce the most sediment. By targeting the conservation practices in the most sediment producing areas, we can affect the greatest change in the Iowa Great Lakes in a longer lasting and more effective manner.

It is important to note, Map 7.8 does not include the all sub-basins within the watershed. The limitation of this new technology is that the finer the information the greater computing power is needed and to complete the entire watershed in this manner would ―outpace" almost all but the most up to date computers. In Map 7.8, our limitation was each sub-basin had to be larger than 10-acres in size. It is recognized there are small sub-basins of less than 10-acres, which produce and deliver huge amounts of sediment at times.

There are approximately 33 sub-basins in the Iowa portion of the Iowa Great Lakes Watershed that produce 60 to 80% of the sediment that is delivered to a basin. Those basins should receive the greatest attention when programs are developed to treat sedimentation and nutrient problems on the agricultural portion of the Iowa Great Lakes.

URBAN

Low Impact Development, a buzzword in today‘s urban conservation field, is nothing more than urban agricultural practices with a twist. The bottom line is the impact of low impact development (LID) is simply the desire to treat storm water in the urban areas not as wastewater to be gotten rid of but rather as a resource to be used and integrated into the community planning process. The goal of a good LID plan is to contain or use 100% of the water that arrives in the form of rainfall or runoff on a property.

Low Impact Development guidelines are outlined in the Statewide Urban Design Standards Manual (SUDAS). The purpose of this manual is:

"The Urban Design Standards Manual for new public improvements has been prepared as a mechanism to implement uniform design standards, procedures, and regulations for the preparation of public improvements. Public improvements are those that meet any of the following:

1. Are initiated, designed and constructed by or under the supervision of the Jurisdiction as a public improvement and maintained by the Jurisdiction.
2. Are initiated, designed and constructed by the private owner/developer's private engineer and contractor. Upon acceptance of the improvements in the local Jurisdiction system the improvements are maintained by the Jurisdiction.

3. Those improvements that require review and approval by the Jurisdiction, but will remain under private ownership, may be required to follow the design standards described herein. Each Jurisdiction will decide on their own if these types of improvements are to follow the design standards". (Iowa Statewide Urban Design Standards Manual, 2008)

Construction Site Erosion
Construction sites typically have the greatest concentration of sediment and pollutants associated with them per acre than any other type of pollutant source in the State of Iowa. By using the erosion control measures discussed below, construction site erosion can be minimized and in some cases eliminated from storm sewer runoff and direct access to the lake or water bodies. The normal disturbance and the nature of construction has great consequences to erosion and sediment loss from construction sites. Unless pre-planning and sediment control measures are used during the construction process there will be pollution leaving the construction site at every rain event.

The easiest way to avoid construction site erosion and pollution is to plan prior to construction beginning and then to implement the erosion control measures. The plan should be easy to implement. There is no cookie-cutter approach for erosion control on construction sites. Each site must be evaluated independently and a plan for erosion control measures needs to be arrived at long before construction begins. If the plan is done quickly and as an afterthought then erosion control measures, will not be emplaced properly nor will the people emplacing them view them as important. Rather the measures will be viewed as just another hurdle and expense that has to be done.

Construction site erosion control measures include; Vegetative & Soil Stabilization Erosion Control Measures, Structural Erosion Control Measures, and Sediment Control Measures. A partial listing of erosion control measures that should be used in the Iowa Great lakes Watershed includes:

Vegetative and Soil Stabilization Erosion Control Measures

- Compost Blanket
- Dust Control

- Grass Channel
- Mulching
- Permanent Seeding
- Temporary Rolled Erosion Control Products
- Sodding
- Surface Roughening
- Temporary Seeding
- Turf Reinforcement Mats
- Vegetative Filter Strip

Structural Erosion Control Measures

- Check Dam
- Diversion Structure
- Level Spreader
- Rock Chutes and Flumes
- Rock Outlet Protection
- Flow Transition Mat
- Temporary Slope Drain

Sediment Control Measures

- Filter Berm
- Filter Sock
- Wattle
- Flocculants
- Floatation Silt Curtain
- Inlet Protection
- Sediment Basin
- Sediment Trap
- Silt Fence
- Stabilized Construction Entrance

(Iowa Statewide Urban Design Standards Manual, 2008)

Storm Water Management

Storm water management is the key ingredient in controlling the amount and type of water that is entering the Iowa Great Lakes nearly directly. Part of the Iowa Statewide Urban Design Standards Manual calls for the reduction or the elimination of water leaving a construction site by using storm water management practices. These practices, typically referred to as Low Impact Development (LID) are tried and tested in many areas of the country but are actually new to the State of Iowa.

By using storm water management and properly placing LID Practices within a development with the idea of slowing the release of storm water, or in some cases eliminating it, the impact that storm water has on a water body is greatly reduced. The primary Low Impact Development practices that will be used in the Iowa Great Lakes Watershed for new construction and for retrofit of existing construction areas include:

- Bioretention Cells: are small landscaped basins intended to provide water quality management by filtering stormwater runoff before release into storm drain systems or allowing the water to infiltrate into the grounds ground water system. This work shall consist of installing bioretention facilities as specified in the Contract Documents, including all materials, equipment, labor and services required to perform the work. Bioretention cells are a family of Low Impact Development, which includes bio-cells, rain gardens, and modified detention ponds.
- Bioretention Swales: designed to remove silt and pollution from surface runoff water. Swales are a drainage course with gently sloped sides (less than six percent) and filled with vegetation, compost and/or riprap. The water's flow path, along with the wide and shallow ditch, is designed to maximize the time water spends in the swale, which aids the trapping of pollutants and silt. The swale can be modified to include soil amendments, soil matrix similar to rain gardens, or simply left with the natural soil profile.
- Permeable Paver Systems: Construction of permeable interlocking concrete pavers on a permeable, open-graded crushed stone bedding layer (typically No. 8 stone). This layer is placed over an open-graded base (typically No. 57 stone) and sub-base (typically No. 2 stone). The pavers and bedding layer are placed over an open-graded crushed stone base with ex-filtration to the soil sub grade. In low infiltration soils or installations with impermeable liners, some or all drainage is directed to an outlet via perforated drainpipes in the sub base.
- Soil Amendments: This work shall consist of incorporating compost within the root zone to improve soil quality, plant viability and soil hydraulic conductivity.

(Iowa Statewide Urban Design Standards Manual, 2008)

Shoreline Stabilization and Re-vegetation
Shoreline stabilization and re-vegetation should be completed where feasible to reduce the potential for shoreline erosion, increase the amount of native aquatic vegetation in the IGL, and decrease the amount of free nutrients that are present in the water bodies. Shoreline stabilization and flood protection planning should be undertaken in a coordinated manner among affected property owners and public agencies. Those who are planning the shoreline stabilization and re-vegetation should consider entire systems or sizable stretches of shoreline where possible.

1) Shoreline stabilization and flood protection work should be located, designed, constructed and maintained to provide the following:

(a) Protection of the physical integrity of the shore process corridor and other properties which may be damaged by interruptions of the geo-hydraulic system;

(b) Protection of water quality and natural ground water movement;

(c) Protection of valuable fish and other life forms and their habitat vital to the aquatic food chain;

(d) Protection of valuable recreation resources and aesthetic values such as point and channel bars, islands and other shore features and scenery.

2) In design of publicly financed or subsidized works, consideration should be given to providing public pedestrian access to the shoreline for low-intensity outdoor recreation.

As stated in *Lakescaping for Wildlife and Water Quality*, ―Shoreline erosion is one of the most common problems experienced by lakeshore property owners." (Henderson, 2008) In a recent survey of Anglers Bay on Big Spirit Lake, 28 species of aquatic plants were observed inhabiting that portion of the Lake. This location on Big Spirit Lake is thought to be the most natural portion of the Iowa Great Lakes that yet remains. (Phillips, 2008)

Sanitary Sewage Management
The US Environmental Protection Agency estimates that from 10 to 30% of all septic tanks fail in any given year. The problems associated with septic tank failure include:

* Drinking water can contain excess nutrients or pathogens which would pose a serious health problem to humans drinking the water;
* Sewage on the ground would pose a serious public health danger because exposure could cause human disease to those exposed, especially children;
* Nearby lakes, streams, ponds or the ocean would have excess pathogens that could cause human disease to those exposed to the water;
* Fish caught from nearby waters exposed to contamination could carry diseases and create a public health problem if eaten; and
* Nearby surface waters would have excess nutrients that could cause algae, fish kills, and other undesirable aesthetic effects.

(Septic Tank Failures, 2004)

While sanitary sewer is the most desired way to rid a household of sanitary wastes, in some cases it is not cost effective due to the distance to an acceptable site hook-up. In the Iowa Great Lakes, however, the Iowa Great Lakes Sanitary Sewer is located within reasonable distance of all known owners of septic tank on the lakeshore.

In the maps above it is easy to identify the three principal locations in the Iowa Great Lakes where septic tanks are still prevalent in locations that cause significant problems for the Lakes. In two of the three septic-tanked areas the lakeshore (beach) area near the septic-tanked area are on the 2008 Impaired Waters in Iowa List. The Emerson Bay public beach on West Okoboji has been listed because of bacteria and Marble Beach on Big Spirit Lake has recently been added due to bacteria as well.

The recent additions of these two areas on the State‘s Impaired Waters List and their location to septic tanked areas indicates that, in all likelihood, the bacteria problem stems from older and failed septic tanks. In most instances, recommendation to improve or fix those tanks would be a key to correcting this problem. In this case, however the sanitary sewer runs near each of the three locations and a recommendation to remove the tanks and have each landowner become part of the Iowa Great Lakes sanitary sewer.

Other Urban Erosion Concerns

There are areas where urban storm water is concentrating and creating gullies, in some instances 20-feet deep or more and 40-feet wide. These gullies have formed over years of constant erosion but are a significant source of pollution to the lakes especially localized to the areas where the gullies are located. The use of forestry management in these areas could prove to be useful. The natural vegetation in these areas was historically savannah or prairie. These two ecotypes are also more stable than a bare topsoil forest area. As water runs across the forest floor it typically brings with it sediment and leaf litter. Some sites may need grade stabilization structures or other conservation practices in the gullies and watershed work to reduce sediment loading and polluted water from entering the lakes. Three areas in the IGL are known to have problems. The three areas are East Okoboji (Camp Foster YMCA North to the south end of East Okoboji Beach), West Okoboji (Echo Bay and Lime Kiln Point) and West Okoboji (Greens Beach).

WORKS CITED

Bachman, Roger, Jones, John. (1974) Water Quality in the Iowa Great Lakes. Iowa State University, Ames, IA

Carlson, Roy. Copper Compounds and Algae. (2008). http://www.bassresource.com/fish_biology/algae_copper.html. Accessed July 16, 2008.

Dankert, Wayne (Ed.). (1980). *Soil Survey of Dickinson County, Iowa*. National Cooperative Soil Survey.

Dickinson County Comprehensive Planning and Development Plan. (2006) http://www.co.dickinson.ia.us/Department/Zoning/pdf/2006%20Dickinson%20Co%20Comp%20Plan.pdf accessed August 15, 2008.

Downing, John A. (2008). Iowa Lakes Survey. Retrieved July 2, 2008, from Iowa Lakes Information System Web site: http://limnology.eeob.iastate.edu/lakereport/chemical_report.aspx

Natural Resource Conservation Service (NRCS). Electronic Field Office Technical Guide. (2009) Web site: http://efotg.nrcs.usda.gov/treemenuFS.aspx. Accessed January 8, 2009.

Graham, Jennifer (2005). USGS Science for a Changing World. Retrieved June 2, 2008, from Preliminary Assessment of Cyanobacteria Occurrence in Lakes and Reservoirs in the United States Web site: http://ks.water.usgs.gov/studies/qw/cyanobacteria/prilasscyano2008.ppt#257,1,Slide 1

Henderson, Carrol L., Dindorf, Carolyn J., Rozumalski, Fred J. 2008. Lakescaping for Wildlife and Water Quality. Saint Paul, Minnesota, State of Minnesota, Department of Natural Resources.

Hickok, Eugene A.. *Management Plan for Water Quality Iowa Great Lakes.* 1 ed. Wayzata, Minnesota: Hickok and Associates, 1974.

Iowa Department of Natural Resources

IA DNR, (2005). Plan for the Management of Aquatic Nuisance Species in Iowa. Retrieved August 2, 2008, from Plan for the Management of Aquatic Nuisance Species in Iowa Web site: http://www.anstaskforce.gov/Iowa-ANS-Mangement-Plan.pdf

Iowa Great Lakes and Dickinson Clean Water Alliance.

Iowa Statewide Urban Design Standards Manual, (2008), SUDAS, Retrieved January 13, 2009, from http://www.iowasudas.org/design.cfm.

Jackson County Planning and Environmental Services. November 28, 2007

Lakes Information System, Iowa DNR (2005) http://limnology.eeob.iastate.edu/lakereport/class_trends_in_water_quality.aspx?Lake_ID=001&bk=1#1 Accessed (July 15, 2008)

Limnology Laboratory, (2007). Cooperative Lakes Area Monitoring Project (CLAMP). Retrieved December 2, 2008, from Iowa Lakes Information System Web site: http://limnology.eeob.iastate.edu/clamp/default.aspx

Ractliffe, Robert. "www.bioremediate.com." October 15, 2002. http://www.bioremediate.com/algae.htm (accessed July 16, 2008).

Phillips, Gary S., 2008. Aquatic Vegetation Inventory of Anglers Bay, Spirit Lake, Dickinson County, IA, 2006 – 2007. Estherville, IA. Iowa DNR.

Protect Your Waters, http://www.protectyourwaters.net/news/ and http://www.newwest.net/index.php/citjo/article/10009/C38/L38. accessed April 12, 2007.

Septic Tank Failures (2004). Kent County Public Works. Accessed January 13, 2009. http://co.kent.de.us/Departments/PublicWorks/SepticTankFailures.htm

Starinchak, Joe (2006, July 18). Protect Your Waters. Retrieved April 12, 2007, from Protect Your Waters Web site: http://www.protectyourwaters.net/news/

Securing a Future for Wildlife, (2005). *Iowa Wildlife Action Plan*, Retrieved June 15, 2008, from http://www.iowadnr.com/wildlife/diversity/files/iwap_part1.pdf

Sperling's Best Places, (2008). Dickinson County, Iowa climate. Retrieved December 12, 2008. from http://www.bestplaces.net/County/Dickinson_IA-CLIMATE-41905900060.aspx

Stenback, (2005). Quantification of Nutrient Inputs into the Iowa Great Lakes. U.S. EPA.

University of Missouri The, sampled the Iowa Great Lakes for algal toxins from 1999-2004 (J. Graham).

USDA, (2007). National Invasive Species Management Plan. Retrieved July 2, 2008, from Invasive Species Web site: http://www.csrees.usda.gov/nea/pest/in_focus/invasive_if_plan.html

U.S. Census Bureau, (2000). U.S. Census Bureau. Retrieved July 8, 2008, from Iowa -- County Web site: http://factfinder.census.gov/servlet/GCTTable?_bm=y&-geo_id=04000US19&-_box_head_nbr=GCT-PH1&-ds_name=DEC_2000_SF1_U&-format=ST-2

Vacation Okoboji, http://www.vacationokoboji.com/2002/09_living/09_01area.html, accessed May 4, 2007.

APPENDIX ONE
TOURISM IN THE LATE 19TH & EARLY 20TH CENTURY

The first white men to arrive at the Iowa Great Lakes were trappers who did not leave any trace of their time here, except to tell others that this was indeed a wondrous and prosperous region. In 1838 a surveyor, Joseph N. Nicolett, was sent by the U.S. Government to assess and map this area.

White men did migrate to the lakes to homestead in 1856. Six cabins were constructed by the approximately 40 settlers. It was in 1856 that the Spirit Lake Massacre occurred. People thought it would cause all the settlers to leave; however, the opposite happened, nearly 900 people flocked to the lakes in 1857. Elections were held, and a sawmill was erected that year. The settlers were here to stay, for better or worse.

A fort was constructed at the site of the future town of Spirit Lake to protect against any further Indian intrusions. Today's St. Mary's Catholic Church sits on the ground of the old fort.

Then, in 1858 there was an invasion of the lakes from an unlikely source. Blackbirds swarmed the area and completely devoured the crops. This was a disaster for settlers who had counted on that first crop for their survival. Many of the first settlers pulled out of the lakes region and went elsewhere because they had no way of surviving the Iowa winter without a harvest. This setback severely curtailed the growth of the lakes.

During the late 1860s and the 1870s there was continued development of our region. The lakes were quite popular as a hunting and fishing Mecca. The immediate problem faced by potential visitors was transportation to the lakes. There were no roads worthy of the name, only wagon trails across the prairie. Yet people came to the lakes to hunt the "bountiful game" and to "catch fish by the barrel full." There were no roads around the lakes; the best travel was by rowboat or sailboat. Accommodations for these visitors were nonexistent, so the sportsmen brought their tents and supplies with them.

By the early 1870s several rustic lodges were constructed. W. B. Arnold built his lodge just east of the present day Arnolds Park Amusement Park. Three other lodges were constructed on Big Spirit Lake: Crandall's, Lillywhite's and Sampson's. The main camping areas were the Hawkeye Camp on the north shore of Big Spirit Lake and another camp near Pillsbury Point on West Okoboji Lake. The passenger sailboats Foam, Falcon, and Golden Rule went into service as a convenient form of transportation in this road-poor area.

In 1873 another catastrophic setback affected the local economy. One spring day the sky darkened in the west from an immense swarm of billions of grasshoppers. The insects ate everything. They stayed two years and no crops were harvested. The insects were so thick that they would sit on the sun-warmed train tracks and actually make the tracks so slippery that they could stop the trains from going uphill. The grasshoppers were an economic disaster that again drove many farmers and businesses away from the lakes.

The 1880s was a time of growth. The lakes were connected to two train lines in 1883. The Burlington, Cedar Rapids and Northern opened Big Spirit Lake as a vacation destination. The Chicago, Milwaukee and St. Paul developed the Okoboji Lakes. The trains also insured a continuous market for our farmers, who also prospered. Vacationers flocked to the beautiful lakes on the fast and comfortable trains. The Iowa Great Lakes were the vacation destination for the Midwest.

The steamboat era dawned in the early 1880s out of the necessity of moving visitors from the train depots to the various points around the lakes. The steamboats ran on a schedule that coincided with the arrival and departure of the trains. Some of the steamboats were owned by the train companies. Well-known steamers of the fleet would have been the Queen, Ben Lennox, Iowa and Hiawatha. The 1880s also saw the development of the fish hatchery, the first summer cottages, the swing bridges on the Okoboji lakes and the growth of the Chautauqua's.

The 1890s brought a mixture of development and disaster at the lakes. Again Mother Nature intervened to decide the winners and losers in tourism and the effects are still with us today. The 1890 era was the decade of the drought. The lakes fell nine feet below the high water mark. Navigation on the shallow lakes ceased as those lakes nearly dried up, except for the deeper pools of water.

The magnificent Orleans hotel was torn down by its owner, the B.C.R. &N. Railroad, when the structure was only 16 years old. There was no need for such an opulent building when the lake was going dry. Tourism on Big Spirit was devastated by the decade-long drought and most developers would continue to be wary of any long-term development of that lake.

The decline in Big Spirit Lake as the premier vacation destination at the lakes gave rise to the development of the West Okoboji grand hotels. The Inn and the Manhattan were both constructed in the late l890s as the Orleans was being taken down. There was a definite shift in the tourism base at the turn of the century. Steamboats were still operating and carrying passengers to most points over the deep waters of West Okoboji Lake. The largest steamer of the day, the Okoboji, was constructed in 1899. The new entertainment of the 1890s was the water slide at Arnolds Park.

Between 1900 and 1920 another stabilization of the region and a period of growth occurred. Big Spirit Lake and the other shallow lakes did not dry up as expected, but recovered completely from the drought. A new-Orleans hotel was constructed, but on a much smaller scale. Templar Park grew tremendously as a meeting place for the Knights Templar organization.

West Okoboji Lake continued its growth as the lakes benefited from the development of hard-surfaced roads around the state. This period of time was known as the heyday of the steamboat. The "fleet" would consist of from 6 to 10 boats in any given year, as they were needed to transport vacationers to the hotels, campgrounds and cottages in the road-deficient lakes region.

Mr. Arnolds' family continued to develop what is known today as the Arnolds Park Amusement Park. A quote of the day describing Arnolds Park was that "anything and everything that tends to attract and interest a promiscuous crowd is found here in abundance."

The 1920's continued as a period of growth. Dance pavilions like the Roof Garden and the Casino were added and everyone flocked to the lakes for a good time.

Another invasion overwhelmed the Iowa Great Lakes in the early 1920's that again completely changed the economics of the region. The invader was none other than the automobile, and it arrived in large numbers as the road system extended to and around the Iowa Great Lakes. Now everyone could come to the lakes in their family car. The immediate casualty was the passenger steamboat that had been a mainstay of transportation. Almost overnight all the passenger steamboats were scrapped. Only the Queen survived to become an excursion boat on West Okoboji Lake. The passenger trains were also affected, but their demise at the lakes would not occur completely until the early 1950s.

The swing bridges were replaced by permanent structures as road travel took precedence over water travel.

Then the Great Depression swept over the lakes with all the force and destruction of a blackbird and grasshopper invasion combined. The tourism base evaporated and all businesses suffered. The 1930s saw the downsizing of the grand hotels and a carefree way of life. No one had money to spend on a vacation. Yet in the downfall of one way of life another took its place. We saw the development of the fishing cottage, the "mom and pop" resort. A hundred or more of these resorts provided an economic way for vacationers to enjoy the lakes. One such example of this movement is Fillenwarth Beach.

The combination of the depression and the growth of the road system brought us larger numbers of visitors who also needed less expensive housing and entertainment. The 1930s saw the arrival of the Big Bands at the several pavilions around the lakes. This was the era of "10 cents a dance," and only the men were charged the fee.

The 1930s was the era that the Civilian Conservation Corp, better known as the C.C.C., who assisted on public works projects at the newly acquired State Parks around the lakes. The CCC put unemployed men and boys back to work.

During the 1940s the United States and the Iowa Great Lakes were consumed by World War II. The lakes still served as a vacation spot for those who lived nearby and could get here without using all their gas-rationing cards. The Queen ruled the waves and provided a much-needed boost in the morale of those lucky enough to visit the lakes.

After World War II and through the 1970's the lakes experienced a period of growth and prosperity unequaled before or since. The hard surfaced gravel roads were replaced by paved roads to and around the lakes. This led to the final death of the passenger trains. During this period of unprecedented growth the area saw tourism evolve again. The "mom and pop" fishing cottages started to give way to larger family resort facilities such as Vacation Village and Manhattan Beach. A more affluent public demanded more amenities on their vacation. The Lodge of Okoboji and other larger facilities included a pool and restaurant. They were favorites of the era. We also saw the corresponding growth of our restaurants and entertainment centers. During this period the typical vacationing family would come to the lakes and stay at least a week and maybe two.

This period saw the continued demise of the resorts on Big Spirit Lake. The last Orleans hotel closed, as did Crandall's Lodge and Templar Park. Outdoor movie theaters and "car hops" at the drive-ins became a thing of the past. Even the Queen lost her steam engine in favor of a new diesel plant. Eventually the Queen was retired from the lakes. The Empress attempted to replace the Queen.

The early 1980s brought the "farm crisis" and a deep recession. Again the area witnessed an outward migration of the bedrock population to areas where people conceivably could make a living. The 1980s saw the demise of the Arnolds Park Amusement Park, although it was to be replaced quickly. The Empress left West Okoboji Lake for Arkansas and a longer season.

The era saw growth and change too. Fast food outlets and more entertainment facilities developed. Video stores replaced movie theaters. The Queen II was constructed and helped to forget the recession years. Village West, Village East, Manhattan Beach Resort and others were constructed or remodeled to provide even more elegant facilities. These facilities would remind one of the original grand hotels of an earlier day.

The new phenomenon of the late 1980's and early 1990's would be the condominium and time-share facilities. An older population of "empty nesters" had decided to "invest in their vacation destination." As these new facilities grew, the smaller resorts continued their general decline in numbers.

Today, the Iowa Great Lakes Region is still undergoing changes that occurred earlier at other lake vacation areas in the Midwest. Lake Minnetonka in Minnesota and Clear Lake in Iowa all made the change from vacation resort facilities to an "ownership" concept of condominiums and time-shares. These lakes had entertainment areas similar to our dance pavilions and amusement park but lost them through this general transition. Lake Minnetonka is restoring an old excursion boat that was raised from the bottom of the lake to recreate their steamboat era, and Clear Lake has imported an excursion boat.

We are again witnessing a definite change in the way people are utilizing their vacation opportunities at the Iowa Great Lakes. Twenty-five years ago, a three-month season existed where families would rent a cottage or motel room for a week. Today the ever-expanding encroachment of the school year has shortened the season for families to a two-month period from about June 15 to August 15. The one-week family vacation is nearly a thing of the past. Year-round school appears to be on the horizon.

Another pressure has been put on our tourism base, and that has come from the uncontrolled expansion of gambling in Iowa and neighboring states. Every discretionary dollar lost at a gambling casino, racetrack or in the lottery is one less dollar available to be spent on a family vacation. The 21^{st} Century is an exciting but unknown time.

APPENDIX TWO

ENVIRONMENTAL FACTORS INFLUENCING MICROCYSTIN DISTRIBUTION AND CONCENTRATION IN THE MIDWESTERN UNITED STATES

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Environmental factors influencing microcystin distribution and concentration in the Midwestern United States

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Abstract

During May–September 2000–2001, physicochemical data were collected from 241 lakes in Missouri, Iowa, northeastern Kansas, and southern Minnesota U.S.A., to determine the environmental variables associated with high concentrations of the cyanobacterial hepatotoxin microcystin (MC). The study region represents a south–north latitudinal gradient in increasing trophic status, with total phosphorus (TP) and total nitrogen (TN) values ranging between 2–995 and 90–15870 μg/L, respectively. Particulate MC values, measured by ELISA, ranged from undetectable to 4500 ng/L and increased with increasing latitude. Despite latitudinal trends, environmental variables explained <50% of the variation in MC values. Inspection of MC–TN and MC–Secchi bivariate plots revealed distinctly nonlinear trends, suggesting optima for maximum MC values. Nonlinear interval maxima regression indicated that MC–TN maxima were characterized by a unimodal curve, with maximal (>2000 ng/L) MC values occurring between 1500 and 4000 μg/L TN. Above 8000 μg/L TN all MC values were <150 ng/L. MC–Secchi maxima were characterized by exponential decline, with maximal MC values occurring at Secchi depths <2.5 m. The development of empirical relationships between environmental variables and MC values is critical to effective lake management and minimization of human health risks associated with the toxin. This study indicates MC values are linked to the physicochemical environment; however, the relationships are not traditional linear models.

Keywords: Microcystin; Cyanotoxin; Cyanobacteria; Midwest; ELISA; Nonlinear

1. Introduction

Cyanobacteria cause a multitude of water quality concerns, including the potential for toxin production. Implicated in human and animal illness and death in over twenty countries worldwide, the hepatotoxin microcystin is more common than other cyanotoxins.

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Over fifty microcystin variants have been isolated from thirteen cyanobacterial genera, likely contributing to the global occurrence of the toxin (Carmichael, 1997; Chorus, 2001).

Knowledge of microcystin occurrence and understanding factors associated with high concentrations are critical to effective lake management and minimization of health risks associated with the hepatotoxin. Current studies indicate a complex range of physicochemical variables influence microcystin production, and no one variable stands out as an unequivocal link to toxicity. Cyanobacterial blooms are often composed of both toxic and nontoxic strains (Vézie et al., 1998), and laboratory experiments have demonstrated that environmental influences on microcystin production are strain dependent (Sivonen, 1990; Vézie et al., 2002). Environmental variables are therefore likely to influence microcystin concentrations directly, by influencing cellular microcystin production and content (Orr and Jones, 1998; Long et al., 2001), and indirectly, by influencing cyanobacterial species and strain composition (Chorus, 2001; Vézie et al., 2002). Regional studies of microcystin in relation to physicochemical variables provide valuable information on what environmental conditions are most likely to result in high microcystin concentrations (Chorus, 2001); however, relative to the number of regional studies that have been conducted, empirical relationships between microcystin and environmental factors have seldom been developed.

Cyanotoxic incidents have been reported in the Midwestern United States for over a century, but little research has been done in the region (Yoo et al., 1995). Surveys in Wisconsin and Kansas indicate microcystin is common (McDermott et al., 1995; Dodds, 1996), and the toxin has been detected in finished drinking water (Chu and Wedepohl, 1994). Thus, microcystin represents a potential health risk in Midwestern water resources. Lakes in Missouri, Iowa, northeastern Kansas, and southern Minnesota were sampled during summers 2000–2001 to document microcystin occurrence and develop empirical relationships between the physicochemical environment and microcystin concentration.

2. Materials and methods

2.1. Study area

Lakes ($n = 241$) were located within four physiographic provinces: the Ozark Highlands, Osage Plains, Dissected Till Plains, and Western Lake Section (Fenneman, 1938, Fig. 1). Limnological differences among provinces have been well characterized and are associated with geology and land use. Due to rich glacial soils and a landscape dominated by row-crop agriculture the Western Lake Section has nutrient enriched lakes that support high levels of algal biomass. In contrast, the Ozark Highlands, with poor quality soils and little row-crop agriculture, tends to have lakes with low nutrient levels and algal biomass. Lakes in the Osage and Dissected Till Plains are intermediate between lakes

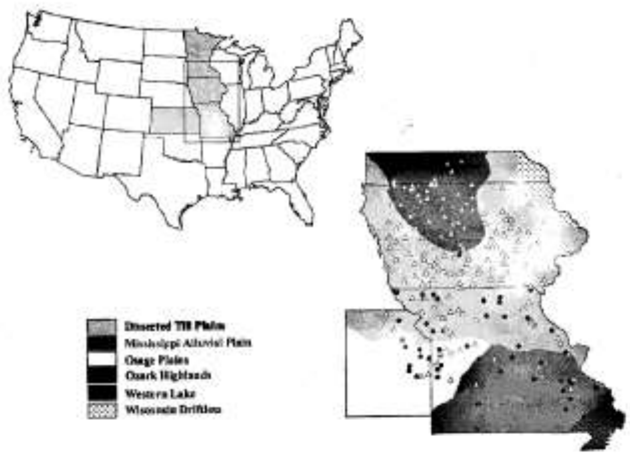

Fig. 1. Physiographic location of lakes sampled and regional trends in microcystin occurrence. Open triangles indicate lakes where microcystin (MC) was detected. Closed circles indicate lakes where MC was not detected.

located in the southern- and northern-most provinces (Jones and Bachmann, 1978; Jones and Knowlton, 1993). Generally, the region represents a south–north gradient in increasing trophic status, with lakes located farther north having many characteristics conducive to cyanobacterial dominance.

2.2. Sample collection

A total of 800 lake visits were made during May–September 2000–2001; most lakes were sampled 2–4 times during one or both years. Six University of Missouri (MU) studies and an Iowa State University (ISU) study collected algal samples for particulate microcystin (MC) analysis. All studies measured Secchi transparency and surface temperature (°C) and analyzed composite surface or integrated epilimnetic samples for total phosphorus (TP), total nitrogen (TN), TN:TP ratio, volatile (VSS), nonvolatile (NVSS), and total suspended solids (TSS), chlorophyll (Chl), and Chl:TP ratio. Additionally, ISU (lake $n = 132$) determined phytoplankton community structure.

At MU, TP was determined using ascorbic acid (Eaton et al., 1995), and TN by persulfate oxidation (Crumpton et al., 1992). Suspended solids were collected on 1.2 μm Whatman GF/C filters; VSS was calculated by taking the difference between TSS and NVSS (Eaton et al., 1995). Chl was collected on 1.0 μm Pall A/E filters, extracted in heated ethanol and analyzed fluorometrically (Knowlton, 1984; Sartory and Grobbelar, 1986). Detailed ISU methods are given in Downing and Ramstack (2000).

Though produced by cyanobacteria of all size classes, toxic incidents involving MC are most frequently associated with large, surface bloom forming genera (Chorus and Bartram, 1999; Chorus, 2001). Thus, when algal cells > 64 μm were present, 20 L of surface water was concentrated for particulate MC analysis using a 64 μm plankton net (Kotak et al., 2000; Chorus, 2001). Samples were frozen, then lyophilized and stored at −80 °C. ISU sent samples to MU for analysis. The mass of seston > 64 μm (μg/L, dry weight) was measured and MC was extracted from 10 mg sub-samples using deionized water. Envirogard® ELISA kits (detection limit: 100 ng/L) were used to determine MC concentration in seston extracts. MC measured by ELISA includes the variants -LR, -RR, and -YR, as well as nodularian. Particulate MC values were expressed volumetrically by multiplying the seston mass (μg/L d.w.) by the MC content of the seston (μg/g seston d.w., Chorus, 2001); values were re-expressed as ng/L.

2.3. Statistical analyses

Relationships between particulate MC values and environmental variables were developed using non-parametric Spearman–Rank correlation ($\alpha = 0.05$).

Bivariate plots of the relationships between particulate MC and environmental variables showed non-linear trends that were not linearized through transformation. MC was undetectable across the range of all variables; therefore, the shape of any given relationship was defined by the upper limits created by MC maxima. To characterize the relationships between MC and environmental variables we used interval maxima regression (IMR). Each variable was divided into equal increments, resulting in 6–16 intervals. The maximum MC value and the associated environmental variable value were obtained from each interval and used in nonlinear regression analysis (Blackburn et al., 1992; Scharf et al., 1998).

Nonlinear regression is an iterative fitting analysis in which the form of the relationship between variables must be specified (Snedecor and Cochran, 1989). Inspection of bivariate plots revealed two relationships, which we defined as log-normal 3-parameter

$$y = ae^{[-0.5(\ln(x/x0)/b)^{\wedge}2]} \qquad (1)$$

and inverse first-order polynomial

$$y = y_0 + a/x, \qquad (2)$$

where x = the value of the environmental variable and a, b, x_0, and y_0 are estimated coefficients. A curve fitter (SigmaPlot® 2001) employing a least-squares method was used to fit equations and estimate coefficients (tolerance = 0.0001, step size = 100, and iterations = 100). This is a parametric analysis and the assumptions of normality and heteroscedasticity were generally met. IMR relationships were considered significant at $\alpha = 0.05$.

3. Results

3.1. Descriptive limnology

A diverse range of lake conditions was encountered in the study region wherein TP (2–955 μg/L), TN (90–15870 μg/L), and Chl (1–546 μg/L) values spanned 2–3 orders of magnitude (Table 1). Nutrient values were lowest in the Ozark Highlands and increased moving northward through the Osage Plains and into the Dissected Till Plains and Western Lake Section, with median values nearly doubling between each province, respectively (Table 1). The majority of lakes in the Ozark Highlands (73%) were classified as oligo- or mesotrophic, while in all other provinces most lakes (> 85%) were either eu- or hypereutrophic (Nürnberg, 1996).

TN:TP ratios ranged from 1 to 429, and varied widely within provinces (Table 1). Based on TN:TP ratios, the majority of lakes in the study region were potentially P-limited (46%, TN:TP > 17) or co-limited (30%,

Table 1
Provincial medians (med) and ranges of limnological variables

Variable	Ozark Highlands			Osage Plains			Dissected Till Plains			Western Lake Section		
	n	Med	Range	*n*	Med	Range	*n*	Med	Range	*n*	Med	Range
Z_{mean} (m)	22	7.1	2.4–20.7	25	2.9	1.9–7.3	88	3.1	0.9–14.9	43	2.9	0.9–11.6
Area (ha)	22	72	12–20755	18	42	10–21733	132	27.9	4–7689	47	153	6–2300
TP (μg/L)	92	12	2–182	111	45	17–178	435	79	5–721	157	141	12–995
TN (μg/L)	92	405	90–1080	111	730	360–2670	434	1091	290–9445	158	1956	236–15870
TN:TP	92	26	5–97	111	16	5–35	431	14	3–227	157	14	1–429
Chl (μg/L)	92	5	1–105	111	22	3–106	431	18	<1–286	152	37	1–546
TSS (mg/L)	92	2.6	0.6–17.7	111	10.0	2.5–39.3	419	8.6	0.1–177.9	153	19.0	1.5–295.0
Chl:TP	92	0.4	0.1–1.9	111	0.5	<0.1–1.1	426	0.3	<0.1–2.5	159	0.3	<0.1–2.3
NVSS (mg/L)	92	1.1	0.1–10.2	111	5.3	0.1–31.7	419	3.9	0.1–151.2	153	7.9	0.1–207.0
VSS (mg/L)	92	1.3	0.2–13.3	111	4.3	1.0–16.3	419	4.0	0.1–70.0	153	9.0	0.2–120.0
Secchi (m)	92	2.2	0.4–8.6	111	0.8	0.1–3.0	437	0.8	0.1–4.3	156	0.5	0.1–6.3
°C	92	28.0	19.9–34.4	111	27.2	8.3–34.3	432	27.4	16.7–32.9	153	24.6	14.1–38.9
CBV (μm³/L)	0			0			218	5.8e9	0–1.0e^{12}	84	7.3e9	0–4.7e^{11}

n indicates the number of lake visits in which each variable was measured, with the exception of Z_{mean} and area, where *n* indicates number of lakes. Cyanobacterial biovolume (CBV) was not measured for all lake visits.

17<TN:TP>10) by P and N; only 24% of lakes were potentially N-limited (TN:TP<10, Forsberg and Ryding, 1980). Chl:TP ratios ≪1 indicate algae are not P-limited, while ratios ≅ 1 are indicative of potential P-limitation (White, 1989). In the study region, Chl:TP ratios ranged from <0.01–2.5 (Table 1); however, only 10% of lakes considered P-limited by the TN:TP ratio had Chl:TP ratios>0.8, suggesting factors other than nutrients may commonly limit algal growth.

Cyanobacterial community structure was assessed for 302 lake visits in the Dissected Till Plains and Western Lake Section. Four genera known to produce MC, *Anabaena*, *Coelosphaerium*, *Microcystis*, and *Oscillatoria* (Yoo et al., 1995), were present in 91% of lake visits. Cyanobacterial biovolume (CBV) was generally dominated (>50% total CBV) by the MC producing genera (81% of lake visits), with *Oscillatoria* dominating most frequently (48%), followed by *Microcystis* (17%), *Coelosphaerium* (11%), and *Anabaena* (5%).

3.2. Microcystin occurrence and concentration

Algae>64 μm were collected for particulate MC analysis during 58% of lake visits; of the algal samples collected, 98% had detectable MC. Overall, MC was detected at least once in 78% of lakes sampled. But, in northern provinces there was a greater incidence of MC: 85% of Dissected Till Plain and 100% of Western Lake Section lakes had detectable MC, compared to 26% in the Ozark Highlands and 44% in the Osage Plains (Fig. 1).

Table 2
Regional medians and ranges of microcystin values

Region	Microcystin (ng/L)		
	n	Median	Range
Ozark Highlands	92	0[a]	0–43
Osage Plains	111	0[a]	0–189
Dissected Till Plains	439	2[b]	0–2933
Western Lake Section	158	27[c]	0–4501

n indicates the number of lake visits in each region. Letters indicate significant differences in median concentrations (Kruskal–Wallis, $p<0.01$).

Particulate MC values ranged from undetectable to 4501 ng/L. Although spanning a wide range, 75% of MC values were <26 ng/L and only 2% of values were>1000 ng/L. Median MC values were significantly greater in northern provinces (Kruskal–Wallis: $H = 237$, $df = 3$, $p<0.01$), increasing from 0 ng/L in the Ozark Highlands and Osage Plains to 27 ng/L in the Western Lake Section (Table 2). Likewise, maximal MC values in the Dissected Till Plains and Western Lake Section were an order of magnitude greater than in the Osage Plains and two orders of magnitude greater than in the Ozark Highlands (Table 2).

3.3. Correlation analysis

Particulate MC was significantly correlated with latitude, nutrients, TN:TP ratio, Chl, Chl:TP ratio, suspended solids, Secchi depth, °C, and Z_{mean} (Table 3). Latitude ($r = 0.66$), TN ($r = 0.59$), and TP ($r = 0.46$) were most highly correlated with MC. In lakes where cyanobacterial biovolume was assessed, MC was positively correlated with CBV ($r = 0.32$). Latitude was also significantly correlated with environmental variables (Table 3), suggesting the latitudinal increase in MC values was related to changing environmental conditions.

3.4. Interval maxima regression (IMR)

The strong latitudinal gradients in environmental variables and MC presence and concentration, indicate there is a relationship between MC and the physicochemical environment. Despite significant correlations, environmental variables explained <50% of the variation in MC values (Table 3). Correlation analysis measures the closeness of linear relationship between two variables (Snedecor and Cochran, 1989); however, inspection of the maxima in MC–TN and MC–Secchi bivariate plots showed two distinctly non-linear trends.

The MC–TN maxima were characterized by a unimodal curve ($r^2 = 0.84$, $n = 14$, $p < 0.01$). Along the TN gradient the greatest MC values (>2000 ng/L) occurred between 1500 and 4000 µg/L; MC values were <150 ng/L above 8000 µg/L TN (Fig. 2a). By comparison, MC–Secchi maxima were characterized by exponential decline ($r^2 = 0.75$, $n = 16$, $p < 0.01$)(Fig. 2b). MC values were <150 ng/L above Secchi depths of 2.5 m. The relationships observed along the regional TN and Secchi gradients were reflected in individual lakes. For example, in Beeds Lake, Iowa, TN values ranged from

Table 3
Spearman Rank correlations (r_s) between microcystin (MC), latitude (LAT), and environmental variables

Variable	n	MC		LAT	
		r_s	p	r_s	p
Latitude	800	0.66	<0.01	—	—
TN (µg/L)	795	0.58	<0.01	0.66	<0.01
TP (µg/L)	795	0.46	<0.01	0.56	<0.01
VSS (mg/L)	775	0.36	<0.01	0.35	<0.01
CBV (µm^3/L)	302	0.32	<0.01	0.14	0.01
Chl (µg/L)	786	0.30	<0.01	0.21	<0.01
Z_{mean} (m)	621	−0.30	<0.01	−0.27	<0.01
TSS (mg/L)	775	0.29	<0.01	0.31	<0.01
Secchi (m)	796	−0.27	<0.01	−0.26	<0.01
NVSS (mg/L)	775	0.17	<0.01	0.23	<0.01
TN:TP	791	−0.15	<0.01	−0.20	<0.01
°C	788	−0.10	<0.01	−0.19	<0.01
Chl:TP	781	−0.07	0.03	−0.26	<0.01
Area (Ha)	716	0.02	0.52	0.07	0.06

1800 to 12700 µg/L ($n = 8$), but maximal MC values were only observed at TN values ≤4000 µg/L (Fig. 3a). And, in West Okoboji, Iowa, where Secchi values ranged from 0.6 to 6.2m, MC maxima were observed at Secchi depths <2.5 m (Fig. 3b).

IMR analysis was also performed using CBV. CBV–TN ($r^2 = 0.94$, $n = 15$, $p < 0.01$), and CBV–Secchi ($r^2 = 0.76$, $n = 11$, $p < 0.01$) relationships were strikingly similar to MC relationships. Like MC, the greatest CBV values (>2^{11} µm^3/L) occurred within a TN range of 1500–4000 µg/L and at Secchi depths <2.5 m (Fig. 2c and d). The subset of MC values in lakes where CBV was measured show similar upper limit trends as the overall relationship (Fig. 2a and b), but MC and CBV values were not tightly coupled ($r = 0.32$).

Other bivariate plots between MC, CBV, and environmental variables had maxima described by either exponential decline or unimodal curves. For example, the TN:TP relationship was characterized by exponential decline. And, the TP relationship could be fitted with a unimodal curve, although the curve was not significant ($p = 0.17$). Peak MC and CBV values occurred when TN:TP<50 and within a TP range of 200–600 µg/L (Fig. 4).

While cyanobacterial community composition did not change markedly along the environmental gradients, overall phytoplankton community structure changed substantially. At TN values <8000 µg/L the Cyanophyta dominated (>50% of total phytoplankton biovolume) 71% of lake visits ($n = 280$), compared to only 24% at TN values>8000 µg/L ($n = 17$). Similar trends were observed along the Secchi and TN:TP gradients, with ~70% of lake visits dominated by Cyanophyta at Secchi <2.5 m ($n = 278$) and TN:TP <50 ($n = 264$), compared to only ~50% at Secchi>2.5 m ($n = 21$) and TN:TP>50 ($n = 30$). At TN>8000 µg/L, Secchi>2.5 m, and TN:TP>50 Bacillariophyta and Chlorophyta were the dominant phytoplankton groups. Unlike TN, Secchi, and TN:TP, the Cyanophyta remained dominant along the entire TP gradient.

4. Discussion

The study region represents a latitudinal gradient in trophic status (Table 1), thereby providing a unique context in which to examine MC concentration with respect to the physicochemical environment. MC presence, and median and maximum values, increased along the trophic gradient (Table 2, Fig. 1), indicating environmental factors play a role in determining MC occurrence and maxima. Nutrient values were greater, and Secchi depths shallower in the Dissected Till Plains and Western Lake Section, where MC was detected most frequently (Table 1, Fig. 1), conditions known to favor cyanobacteria (Reynolds, 1998). MC is

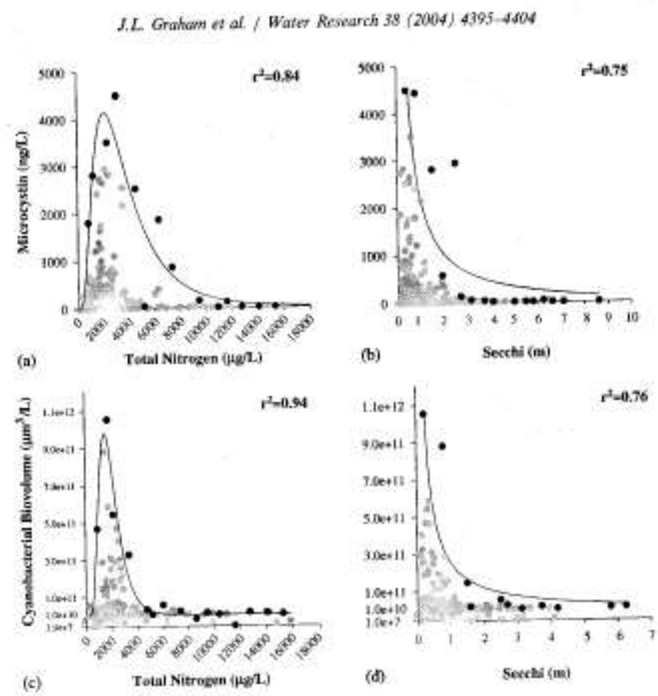

Fig. 2. Microcystin (MC), cyanobacterial biovolume (CBV), total nitrogen (TN), and Secchi bivariate relationships. Curves were estimated using interval maxima regression (IMR). Black points indicate the data used for IMR analysis ($n = 11$–16); r^2 values are for this fitted line only (all $p < 0.01$). (a) The MC–TN relationship ($n = 795$), (b) The MC–Secchi relationship ($n = 796$), (c) The CBV–TN relationship ($n = 299$), (d) The total cyanobacterial biovolume–Secchi relationship ($n = 301$).

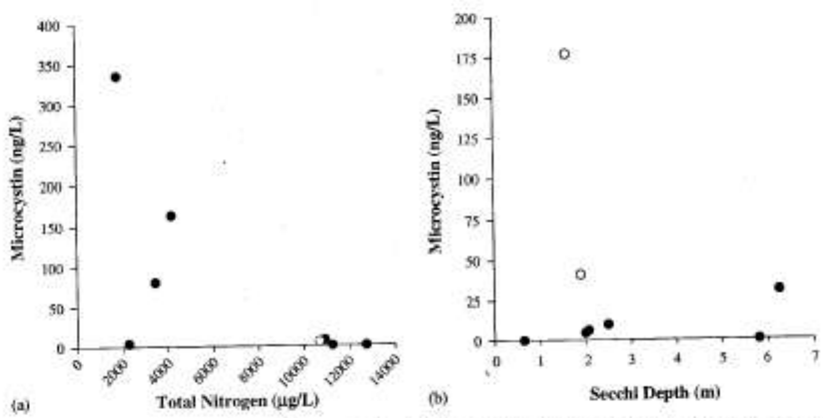

Fig. 3. The microcystin–total nitrogen (a) and microcystin–Secchi (b) relationships in individual lakes. (a) Beeds Lake, Iowa, was sampled 7 times during May–September, 2000 (closed circles), and once in August 2001 (open circle), (b) West Okoboji, Iowa, was sampled 6 times during May–September 2000 (closed circles) and twice (July and September) in 2001 (open circles).

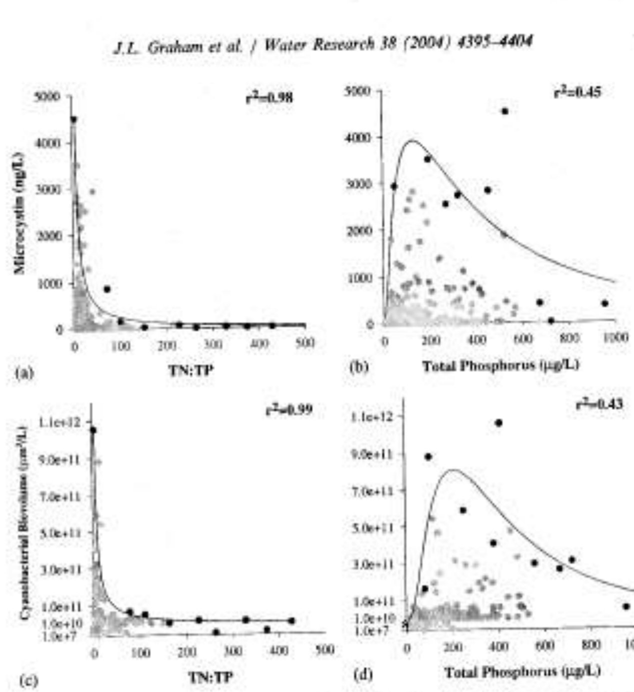

Fig. 4. Microcystin (MC), cyanobacterial biovolume (CBV), and TN:TP and total phosphorus (TP) bivariate relationships. Curves were estimated using interval maxima regression (IMR). Black points indicate the data used for IMR analysis (n = 6–9); r^2 values are for this fitted line only. (a) The MC–TN:TP relationship (n = 791, IMR $p<0.01$), (b) The MC–TP relationship (n = 795; IMR p = 0.17), (c) The CBV–TN:TP relationship (n = 296; IMR $p<0.01$), (d) The CBV–TP relationship (n = 299; IMR p = 0.18).

inextricably linked to cyanobacteria, and factors favoring cyanobacterial dominance are also expected to influence MC presence and concentration. Where data were available, particulate MC was significantly correlated with CBV (Table 3). Similarly, regional studies in Canada and Germany found significant correlations between particulate MC and CBV (Kotak et al., 2000; Chorus, 2001). Relationships between MC and environmental factors, however, are not consistent. For example, in the current study MC was strongly correlated with TN (Table 3), but in Canada and Germany the MC–TN relationship was not significant.

A diverse range of physical, chemical, and biological factors may potentially limit cyanobacterial growth (Reynolds, 1998). In the study region TN:TP and Chl:TP ratios suggest potential TN-, TP-, and nutrient co-limitation as well as limitation by other factors, such as light (Table 1). Field and laboratory studies have demonstrated that the relationship between cyanobacteria, MC concentration, and environmental factors is invariably complex. Cellular MC content is strain dependant, varying by several orders of magnitude between strains (Chorus, 2001). Individual strains also have different environmental optima for growth and MC production, and respond differently to changing environmental conditions (Sivonen, 1990; Vézie et al., 2002). Additionally, many strains may occur simultaneously in an individual lake (Vézie et al., 1998). Observed MC values are therefore the result of interactions between environmental influence on MC production and dominance of individual cyanobacterial strains (Chorus, 2001). Thus, the lack of consistent empirical relationships between MC and environmental variables is not surprising.

Because MC is toxic, maxima are of particular interest. Given the complexity of factors determining observed MC values, focusing exclusively on attributes of mean response along an environmental gradient excludes useful information contained in the maxima (Scharf et al., 1998). Definition of the upper limit of MC values along an environmental gradient represents the potential maximum given all conditions for MC production and MC producing cyanobacteria are optimal. MC values will often fall below the potential maxima because other undetermined abiotic and biotic factors are sub-optimal (Kaiser et al., 1994).

Relationships between particulate MC maxima, CBV maxima, and environmental variables were nearly identical. Along the TN and TP gradients maxima were characterized by unimodal curves, while maxima along the Secchi and TN:TP gradients were characterized by exponential decline (Figs. 2 and 4). CBV response along these gradients generally take the form expected based on current knowledge of cyanobacterial requirements, limits, and competitive abilities and therefore provide insight into the factors influencing MC values (Chorus, 2001). For example, exponential decline in MC values along the Secchi gradient reflects cyanobacterial adaptation to low light conditions (Chorus, 2001) and superior competitive ability at low nitrogen concentrations along the TN:TP gradient (Blomqvist et al., 1994).

Maximal particulate MC values increased along the TN gradient to a peak between 1500 and 4000 μg/L TN, with low values (< 150 ng/L) above 8000 μg/L (Fig. 2a). Along the TP gradient maximal MC values occurred between 100 and 600 μg/L (Fig. 3b). Lower MC maxima at TN < 1500 μg/L and TP < 600 μg/L may be due to nutrient limitation of phytoplankton biomass (Chorus, 2001); lower maxima at TN > 4000 μg/L and TP > 100 μg/L imply either excess nutrients limit MC producers or biological factors influence the shape of the curve. There is no indication nutrient enrichment negatively affects cyanobacterial growth or MC production (Vézie et al., 2002). Although it is commonly accepted that cyanobacteria are abundant in hypereutrophic lakes, cyanobacteria are poor competitors for both nitrogen and phosphorus in nutrient replete systems (Blomqvist et al., 1994; Jensen et al., 1994), even under low light conditions (Huisman et al., 1999). Cyanophytes do not necessarily dominate in hypereutrophic systems, as suggested by increased dominance by Bacillariophytes and Chlorophytes at TN > 8000 μg/L; thus, biotic factors such as competition may cause the decline in maximal MC values noted at higher nutrient levels.

IMR is limited by the range of MC values and environmental conditions encountered (Blackburn et al., 1992; Scharf et al., 1998). Although TN, TP, Secchi, and TN:TP values spanned a wide range, data were not uniformly distributed across the range (Figs. 2 and 4). When intervals were created for IMR, the uneven distribution of data resulted in the majority of points falling within 2–3 intervals. For example, TN values ranged between 90 and 15870 μg/L, but 75% of values were < 1800 μg/L; 16 TN intervals were created and the number of observations per interval ranged between 0 and 394, with a median of 3.5. Similar trends were noted in TP, Secchi, and TN:TP data and altering interval size did not rectify the uneven spread of the data. The greatest MC values observed within each interval may not have represented true maxima, but in intervals with fewer observations there is a greater chance true MC maxima were not observed (Blackburn et al., 1992; Scharf et al., 1998); thus, the overall shape of the MC-environmental variable relationships may be a result of the low number of observations at the extreme ends of the curves (Figs. 2 and 4). MC upper limits may actually be characterized by other linear or curvilinear relationships. The relationships were, however, consistent when interval maxima regression analysis was conducted using lake means or sub-maximal MC values (i.e., 2nd or 3rd ranking values). Observed regional relationships were also reflected in individual lakes (Fig. 3).

Unlike the TN, Secchi, and TN:TP relationships, the unimodal curve fitted to the TP interval maxima was not significant (Fig. 4b) and cyanobacteria dominated the phytoplankton along the entire TP gradient. In Danish lakes, Cyanophytes have been observed to dominate the phytoplankton at TP values < 800 μg/L, while Chlorophytes tended to dominate at TP values > 1000 μg/L (Jensen et al., 1994). Although TP values in the study region ranged from 2–995 μg/L, 75% of values were < 142 μg/L, and only ten values were > 500 μg/L. Therefore, the TP range encountered may not have been large enough to fully characterize the MC–TP relationship.

Despite the limitations imposed by the environmental conditions encountered, the overall trends defined by the IMR relationships are in accord with what is known about cyanobacterial ecology. Furthermore, these empirical relationships are strikingly similar to those noted elsewhere. The range of TN and TP values at which MC maxima were observed is similar to the range noted in Germany (TN: 1500–3000 μg/L, TP: 100–200 μg/L), where MC maxima are several orders of magnitude greater (Chorus, 2001). The German study also measured the Z_{eu}:Z_{mix} ratio, an indicator of light availability. Like the Secchi–MC relationship, the outer edge of the MC–Z_{eu}:Z_{mix} relationship was characterized by exponential decline (Chorus, 2001). Additionally, Canadian MC–TN:TP, MC–nitrate, and MC–ammonia relationships suggest edges characterized by exponential decline (Kotak et al., 2000).

As noted in many studies (Chorus and Bartram, 1999), MC was common in the study region, but generally detected in low concentrations with only a few high values (Table 2). Little published data from the U.S. is available for comparison; however, observed MC maxima were two orders of magnitude greater than maxima reported from Kansas (22 ng/L, Dodds, 1996) and within the range of maxima reported from Washington (total MC—3800 ng/L, Johnston and Jacoby, 2003) and Alberta, Canada (6200 ng/L, Kotak et al., 2000). Observed maxima were substantially lower than maxima reported from shoreline surface scums in Wisconsin (total MC—200 μg/L, McDermott et al., 1995) and Washington (total MC—43 μg/L, Johnston and Jacoby, 2003), but most lakes in our study were sampled at pelagic locations, thus avoiding extensive surface scums.

All of the lakes sampled are used for recreational purposes, and 45 of the lakes are also used as drinking water supplies. MC was detected in 98% of the algal samples collected; thus, there is a potential MC risk anytime algae > 64 μm are present. Particulate MC values in the study region never exceeded the low risk range (1–10 μg/L) for recreational exposure (Chorus and Bartram, 1999). Similarly, although several drinking water supplies had MC values in raw water near the WHO recommended 1 μg/L limit (Chorus and Bartram, 1999), MC was never detected in finished drinking water (data not presented). Therefore, in the study region, risk of acute MC toxicity appears relatively low and chronic exposure is a greater concern. Effects of chronic MC exposure are currently unknown, but MC is considered to be a tumor promoter (Chorus and Bartram, 1999).

The current study focused on large algae present at the surface; inclusion of subsurface, benthic, and picocyanobacteria in future studies would more accurately assess MC presence and concentration. Additionally, MC content of cyanobacteria strains has not been studied in the Midwest, and knowledge of the common MC producers in the region would be of great value in assessing potential maximum MC values. Although maximal values were below levels likely to cause acute toxicity, MC poses a potential chronic health risk in the Midwest. Efforts, such as monitoring programs for recreational lakes and adoption of drinking water guidelines, need to be taken to ensure MC exposure is minimized.

Knowledge of the environmental factors associated with high MC values is critical to effective lake management and minimization of human health risks. Our study demonstrates that MC concentrations are linked to the physicochemical environment; however, the relationships are not traditional linear models. Further empirical work must be conducted to validate the non-linear nature of the relationships between environmental factors and MC maxima. Studies addressing the interaction of biotic and abiotic components will elucidate conditions under which the greatest MC values are produced. Natural systems are characterized by a vast array of biotic and abiotic gradients coupled with multiple species interactions (Reynolds, 1998). As a product of these diverse systems, MC concentration along environmental gradients is similarly complex. Understanding that MC values are not linearly related to a single habitat component, but are rather the complex result of the interaction of many different factors, provides a novel approach to addressing environmental influences on MC concentrations.

5. Conclusions

1. Microcystin is common throughout the study region, but both presence and concentration increase moving northward along a gradient of increasing lake trophic status.
2. Microcystin values were typically low, with only 2% of values > 1000 ng/L; but, because microcystin is toxic, maxima are of particular interest.
3. The relationships between microcystin concentration and environmental factors are complex, and to date have largely been explored using traditional linear analyses. The development of nonlinear relationships provides a novel approach to defining the conditions under which high microcystin concentrations are most likely to occur.

Acknowledgements

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References

Blackburn, T.M., Lawton, J.H., Perry, J.N., 1992. A method of estimating the slope of upper bounds of plots of body size and abundance in natural animal assemblages. Oikos 65 (1), 107–112.

Blomqvist, P., Pettersson, A., Hyenstrand, P., 1994. Ammonium–nitrogen: a key regulatory factor causing dominance of non-nitrogen-fixing cyanobacteria in aquatic systems. Arch. Hydrobiol. 132 (2), 141–164.

Carmichael, W.W., 1997. The cyanotoxins. Adv. Bot. Res. 27, 211–256.

Chorus, I. (Ed.), 2001. Cyanotoxins: Occurrence, Causes, Consequences. Springer, Berlin.

Chorus, I., Bartram, J. (Eds.), 1999. Toxic Cyanobacteria in Water. WHO, E & FN Spon, London.

Chu, F.S., Wedepohl, R., 1994. Algal toxins in drinking water? Research in Wisconsin. Lake Line 14 (1), 41–42.

Crumpton, W.G., Isenhart, T.M., Mitchell, P.D., 1992. Nitrate and organic N analysis with second derivative spectroscopy. Limnol. Oceanograph. 37 (4), 907–913.

Dodds, W.K., 1996. Assessment of blue-green algal toxins in Kansas. Contribution Number G2020-02. Kansas Water Resources Research Institute, Lawrence, KS.

Downing, J.A., Ramstack, J.M., 2000. Iowa lakes survey summer 2001 data. Iowa State University, Ames, IA.

Eaton, A.D., Clesceri, L.S., Greenburg, A.E. (Eds.), 1995, Standard Methods for the Examination of Water and Wastewater, 19th Edition. American Public Health Association, Washington, DC.

Fenneman, N.M., 1938. Physiography of Eastern United States. McGraw-Hill Book Company, Inc., New York.

Forsberg, C., Ryding, S.-O., 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. Arch. Hydrobiol. 89, 189–207.

Huisman, J., Jonker, R.R., Zonneveld, C., Weissing, F.J., 1999. Competition for light between phytoplankton species: experimental tests of mechanistic theory. Ecology 80 (1), 211–222.

Jensen, J.P., Jeppesen, K.O., Kristensen, P., 1994. Impact of nutrients and physical factors on the shift from cyanobacterial to chlorophyte dominance in shallow Danish lakes. Canad. J. Fish. Aquat. Sci. 51 (8), 1692–1699.

Johnston, B.R., Jacoby, J.M., 2003. Cyanobacterial toxicity and migration in a mesotrophic lake in Western Washington, USA. Hydrobiologia 495 (1–3), 79–91.

Jones, J.R., Bachmann, R.W., 1978. Trophic status of Iowa lakes in relation to origin and glacial geology. Hydrobiologia 57 (3), 267–273.

Jones, J.R., Knowlton, M.F., 1993. Limnology of Missouri reservoirs: an analysis of regional patterns. Lake Reserv. Manage. 8 (1), 17–30.

Kaiser, M.S., Speckman, P.L., Jones, J.R., 1994. Statistical models for limiting nutrient relations in inland waters. J. Am. Stat. Assoc. 89 (426), 410–423.

Knowlton, M.F., 1984. Flow-through microcuvette for fluorometric determination of chlorophyll. Water Res. Bull. 20, 1198–1205.

Kotak, B.G., Lam, A.K.-Y., Prepas, E.E., Hrudey, S.E., 2000. Role of physical and chemical variables in regulating microcystin-LR concentration in phytoplankton of eutrophic lakes. Canad. J. Fish. Aquat. Sci. 57 (8), 1584–1593.

Long, B.M., Jones, G.J., Orr, P.T., 2001. Cellular microcystin content in N-limited *Microcystis aeruginosa* can be predicted from growth rate. Appl. Environ. Microbiol. 67 (1), 278–283.

McDermott, C.M., Feola, R., Plude, J., 1995. Detection of cyanobacterial toxins (microcystins) in waters of Northeastern Wisconsin by a new immunoassay technique. Toxicon 33 (11), 1433–1442.

Nürnberg, G.K., 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake Reserv. Manage. 12 (4), 432–447.

Orr, P.T., Jones, G.J., 1998. Relationship between microcystin production and cell division rates in nitrogen-limited *Microcystis aeruginosa* cultures. Limnol Oceanograph. 43 (7), 1604–1614.

Reynolds, C.S., 1998. What factors influence the species composition of phytoplankton in lakes of different trophic status? Hydrobiologia 369/370, 11–26.

Sartory, D.P., Grobbelar, J.U., 1986. Extraction of chlorophyll-a from freshwater phytoplankton for spectrophotometric analysis. Hydrobiologia 114, 117–187.

Scharf, F.S., Juanes, F., Sutherland, M., 1998. Inferring ecological relationships from the edges of scatter diagrams: comparison of regression techniques. Ecology 79 (2), 448–460.

Sivonen, K., 1990. Effects of light, temperature, nitrate, orthophosphate, and bacteria on growth of and hepatotoxin production by *Oscillatoria agardhii* strains. Appl. Environ. Microbiol. 56 (9), 2658–2666.

Snedecor, G.W., Cochran, W.G., 1989. Statistical Methods, 8th Edition. Iowa State University Press, Ames.

Vézie, C., Brient, L., Sivonen, K.G.B., Lefeuvre, J.-C., Salkinoja-Salonen, M., 1998. Variation of microcystin content of cyanobacterial blooms and isolated strains in Lake Grand-Lieu (France). Microb. Ecol. 35 (2), 126–135.

Vézie, C., Rapala, J., Vaitomaa, Seitsonen, J., Sivonen, K., 2002. Effect of nitrogen and phosphorus on growth of toxic and nontoxic *Microcystis* strains and on intracellular microcystin concentrations. Microb. Ecol. 43 (4), 443–454.

White, E., 1989. Utility of relationships between lake phosphorus and chlorophyll-a as predictive tool in eutrophication control studies. New Zeal. J. Mar. Fresh. Res. 23, 35–41.

Yoo, R.S., Carmichael, W.W., Hoehn, R.C., Hrudey, S.E., 1995. Cyanobacterial (blue-green algal) toxins: a resource guide. AWWA Foundation and the American Water Works Association, Denver, CO.

APPENDIX THREE

SHOVEL READY PROJECTS FOR THE IOWA GREAT LAKES WATERSHED

As of 02/10/2009

1. Septic tank renovation/repair on Emerson Bay, Center Lake, and Little Spirit: possibly have these properties installed on the IGL Sanitary Sewer System. The area on Emerson Bay is a direct reason for the Emerson Bay's listing on the State's List of threatened water bodies. Likely, the same thing is happening on Marble Beach as well. -- $300,000

2. Polaris Industry: Green Roof, rain gardens, wetland restoration, and parking lot paving. -- $200,000

3. Courtyard Gardens: A greenhouse and small business, which drains into Center Lake, for the most part. The owner would like to retrofit his entire business to a total containment LID system that would prevent the irrigation water (which has fertilizer in it) from going through the pea gravel floor of the green houses and to the lake. The owner would also like to capture as much rainwater as possible on run this water to a cistern type structure so it will not run to the lake and can be used in his business as irrigation water. -- $68,000

4. Lakeshore Re-vegetation: 2,500 feet of lakeshore have been identified as key in re-establishing the lakeshore vegetation that was once prominent in the Iowa Great Lakes. The word Okoboji comes from a Sioux word Okoboogi which means reed or rush. The Iowa Great Lakes were once populated with varying species of aquatic vegetation. Those plants are what the lakeshore needs to become stabilized and to use up some of the excess nutrients in the lakes. -- $40,000

5. Historic Arnolds Park Inc. (Bob's Hotdog Stand): Low Impact Development retrofit and improvement. The area has been consistently hit with high runoff volumes from non-permeable and permeable surfaces. The major problem is water coming off the bluegrass onto the double sidewalk and then running down the sidewalk picking up velocity along the way. – $58,000

6. Dickinson County Courthouse Parking lot LID project. – $70,000

7. IGL Land Trust Rain Garden/Paver project -- $28,000

8. Dam Road Rain Garden Project – $30,000

9. Clean out or repair of the Grade Stabilization structure on Conroy Johnson's property. This basin has been slowing water moving to East Okoboji for nearly 30 years and the depth of the basin is now only a few feet. When it was built, it was nearly 30 feet deep according to Conroy Johnson. This structure could help to clean the water moving toward East Okoboji for years to come if only it were revitalized. -- $35,000

10. Drainage District 22 water quality improvements: Shoreline stabilization and fish barriers to stabilize and reduce sediment deliver to East Okoboji. -- $100,000

11. Miscellaneous rain gardens and pervious paver systems that have designs but have not been built due to an early frost/freeze. – $20,000

12. Wetland Renovation: Wetlands have been gradually filled in due to agricultural sediment delivery. Those wetlands are no longer serving their purpose. By digging the sediment out of these wetlands we can once again achieve a level of protection from these wetlands. $20,000

13. Lutheran Church Easement, wetland restoration, upland restoration, and grade stabilization structure: This project will protect a major wetland, which filters water prior to it entering West Okoboji. The wetland below this area has become void of vegetation because of the mass fluctuations of water caused by the urban construction above it. A large gully has formed and needs to be ―fixed". -- $40,000

14. Silt Fence installation seminar for contractors. This seminar will be a multi-day program focusing on installation of silt fence correctly. It will target contractors who will actually help install silt fence on a construction site. -- $3,000

15. Grant program to help landscape architects in Dickinson County certified in designing rain gardens. This program will certify local landscape architects in the design and construction of Rain Gardens. – $3,000

16. Twelve Rock tile intakes installed, replacing the normal honeycomb (orange) intake. A reduction of 30% phosphorous is realized when using rock tile intakes versus the orange intakes that are normally seen. -- $12,400

Total $1,037,400 (estimated) in project costs currently

APPENDIX FOUR

Watershed Assessment Model produced by Mike Hawkins, Iowa DNR

Watershed Assessment Model produced by Mike Hawkins, Iowa DNR

In 2006 an on the ground land use inventory was created for the Iowa Great Lakes Watershed. During the spring of 2006, technicians visually inspected all agricultural fields to ascertain cropping and tillage practices. Other land use characterizations were made such as tree plantings, abandoned farmsteads, animal feeding operations, grasslands, urban and residential development, and other land use categories.

The land use data was then incorporated into sediment loss and delivery models for the watershed.

Sheet and Rill Erosion

The USDA Revised Soil Loss Equation (RUSLE) was used to create a GIS Surface for the entire watershed.

The RUSLE surface was created using a 1-meter grid cell derived from the following equation:

A=R*C*LS*K

Where:

A= annual soil loss from sheet and rill erosion (tons/acre/year)

R= rainfall erodibility factor

C= cropping factor

LS= Slope and length of slope

K= Soil erodibility index

For our purposes, the soil erodibility index (K) was derived from the SSURGO soils data from Dickinson County, Iowa and Jackson County, Minnesota. The rainfall erodibility factor (R) for Northwest Iowa and Southwest Minnesota was used. The slope and length of slope factor (LS) was derived from the high resolution DEM. The cropping factor (C) was created using cropping coefficients form the 2006 land use inventory and the USDA technical guide.

Annual Soil loss was estimated from the entire watershed (Figure 1).

Sub-watershed Delineation and Sediment Delivery

The IGL's have 216 sub-watersheds greater than 10 acres flowing into them. These areas have been delineated and identified as Tier 1 Watersheds (Figure 2). As discussed below, the Tier 1 watersheds were broken down further based on hydrology since they do not function as typical catchments. These sub-watersheds do, however, provide hydrological boundaries, which will be used to target general areas of concern identified through modeling.

The Iowa Great Lakes Watershed topography is not suited for traditional modeling methodology and several considerations were made to allow for accurate prioritization of key sub-watersheds, wetland restorations, and agricultural BMP's.

A high resolution (1-meter) LiDAR derived Digital Elevation Model (DEM) was created for the watershed. This high-resolution survey was necessary to model the non-dendritic drainage pattern and compensate for the poorly drained soils and pothole formations.

When modeling most watersheds, the first step to conditioning the DEM for hydrological modeling is to fill the sinks or closed basins. In a typical dendritic drainage pattern, these sinks are associated with artifacts inherent in the DEM and must be filled to connect upstream to downstream flow. In a poorly drained area such as the IGL watershed, many of these sinks are not artifacts and represent actual closed basins or glacial pothole formations. These are typically drained wetlands and correspond closely to wetlands soil types. By utilizing the conditioning routine during the hydrological modeling process, we were able to identify over 1,800 of these depressed pothole formations.

Since these depressed pothole formations do not typically outlet overland to a receiving body of water, typical modeling efforts were modified. We delineated catchments for each of the closed basins. This effort conversely resulted in delineation of areas of the watershed flowing directly into a receiving water body without passing through a depressed area.

The depressed areas cannot be eliminated from consideration, however. Most remain hydrologically connected to the watershed through sub-surface drainage tile and surface drainage intakes. For this reason, sediment delivery modeling was performed for sub-watersheds of depressed areas greater than 10-acres (staffing and technical limitations prevented modeling of catchments smaller than 10-acres). Sediment delivery was estimated for a 2-inch rainfall event using the Modified Universal Loss Equation (MUSLE) and the methods outlined in Zhang et al. 2008 were used.

We found a significant positive linear relationship between annual soil loss estimates and sediment delivery ($p=<0.001$, $R^2=0.4241$). Since sediment loss was calculated for the entire IGL watershed the relationship was used to predict sediment delivery in portions of the catchments of depressed areas not included in the original analysis (i.e. Sub-watersheds less than 10 acres).

Prioritization

Ideally, prioritization of wetland restorations and agricultural BMP's would be accomplished through a combination of sediment and nutrient delivery monitoring and modeling. In the case of the Iowa Great Lakes Watershed, water quality monitoring is part of a long-term plan, but not included in this assessment. Because of the complexity of the hydrological landscape of the IGL Watershed, modeling performed in this assessment was needed to focus future monitoring efforts.

Priority areas identified in this plan have been developed by using the above process and through discussions with project partners. This assessment should be used as a guide for watershed protection and enhancement efforts.

Prioritization follows three steps:

1. Identification of the priority, Tier 1 sub-watersheds based on high average sheet and rill erosion values.

2. Targeting of wetland restoration and agricultural BMP‘s within the priority Tier 1 sub-watersheds using sediment delivery modeling.
3. Identification of high delivery and sediment loss areas within direct contribution zones that are immediately adjacent to the lake or a water body.

Tier 1 Sub-watersheds

Several Tier 1 watersheds have been identified as having high average soil loss estimates (figure 3). These areas are sub-watersheds that have a higher than normal sediment delivery to a lake. These sub-watersheds should be considered ―low hanging fruit" and some protection activity begun as soon as is possible. These priority Tier 1 Sub-watersheds correspond well with the known problem areas in the watershed. Sediment delivery modeling completed within these priority sub-watersheds will be used to identify key wetland restoration priorities and placement of BMP‘s (figure 4).

Direct Contribution Zone

Those areas of the IGL Watershed not flowing to a depression area or existing wetland are considered to be directly contributing to a receiving waters body (figure 5). Areas within this zone are typically near a lakeshore or waterway draining to a lakeshore and should be considered as a high priority. Sediment loss calculations have been completed for this entire zone. Sediment delivery has been calculated for some of these areas.

The three largest ―clusters of sub-watersheds" have been broken out into individual maps to show detail in the predicted sediment delivery. From these breakout maps, we can begin to pinpoint locations where potential erosion control practices can be installed to ensure the biggest benefit for the dollars spent has occurred.

Triboji Beach Cluster:

The Triboji Beach Cluster of Sub-watersheds is located on West Okoboji Lake and consists of approximately 2629 acres of land adjacent to the Triboji Beach/Harbor area (Figure 6).

Marble Lake Cluster:

The Marble Lake Cluster of Sub-watersheds is located South of Marble Lake and West of Big Spirit Lake. The cluster consists of approximately 2145 acres of land (Figure 7).

Reeds Run Cluster:

The Reeds Run Cluster of Sub-watersheds is located on Big Spirit Lake and consists of approximately 3447 acres of land East of Big Spirit Lake on the southern edge of Anglers Bay (Figure 8).

Other Sub-watersheds:

In addition to the three sub-watersheds listed above, the top 25% sediment delivery producing areas have been delineated in the Iowa Great Lakes Watershed. Figure 4 shows all the top 25% sediment delivery-producing sub-watersheds in addition to the three big clusters mentioned above. All of the top 25% sub-watersheds should be considered a priority but for the purposes of logistics, the three-clustered areas will offer a bigger opportunity for actionable success.

Figure 1


Iowa Great Lakes Watershed Assessment
Estimated Sheet & Rill Erosion
Watershed Size: 89,691 acres
Land Area of Watershed: 71,761 acres
Average Sheet & Rill Erosion: 0.91
Legend
Subwatersheds
Lakes
Streams
Sheet & Rill Erosion
No Data
Spirit Lake Subwatershed
23965 acres
West Okoboji Subwatershed
19344 acres
East Okoboji Subwatershed
13705 acres
Center Lake Subwatershed
892 acres
Gar Chain Subwatershed
0
1
2
4
6 Miles

Figure 2

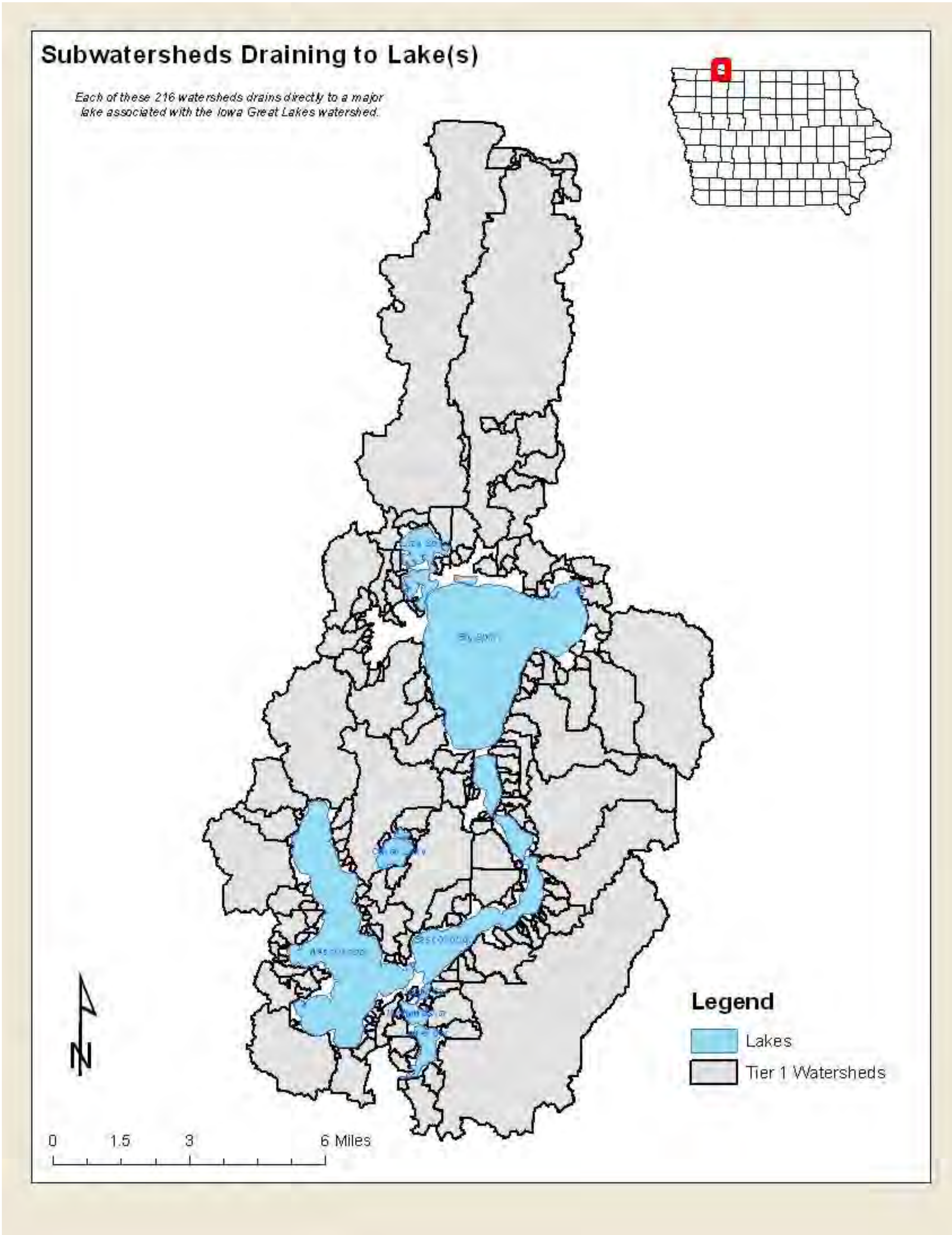

Subwatersheds Draining to Lake(s)
Each of these 216 watersheds drains directly to a major lake associated with the Iowa Great Lakes watershed.
Legend
Lakes
Tier 1 Watersheds
N
0 1.5 3 6 Miles

Figure 3

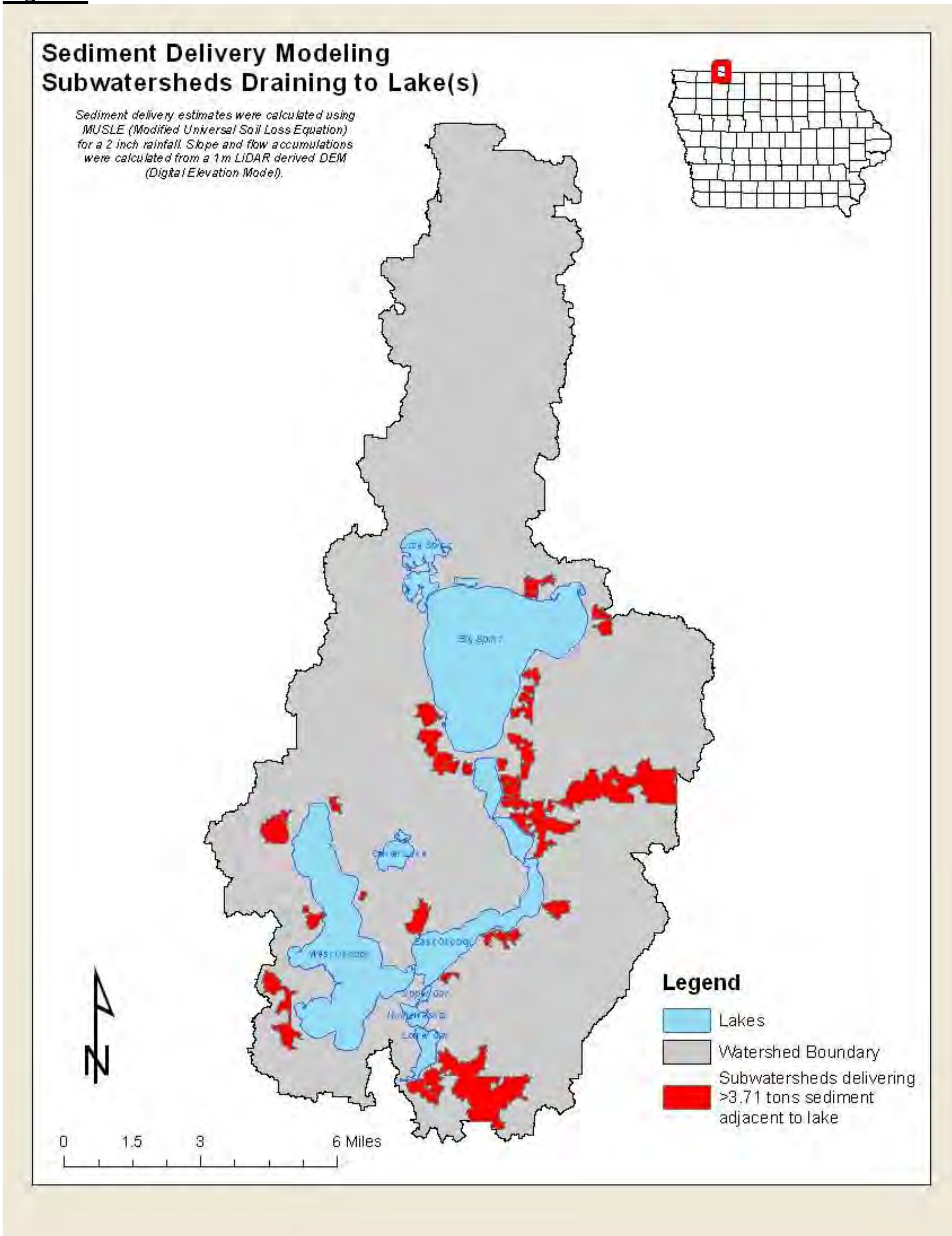

Sediment Delivery Modeling
Subwatersheds Draining to Lake(s)
Sediment delivery estimates were calculated using MUSLE (Modified Universal Soil Loss Equation) for a 2 inch rainfall. Slope and flow accumulations were calculated from a 1m LiDAR derived DEM (Digital Elevation Model).
Legend
Lakes
Watershed Boundary
Subwatersheds delivering >3.71 tons sediment adjacent to lake
0
1.5
3
6 Miles
N

Figure 4

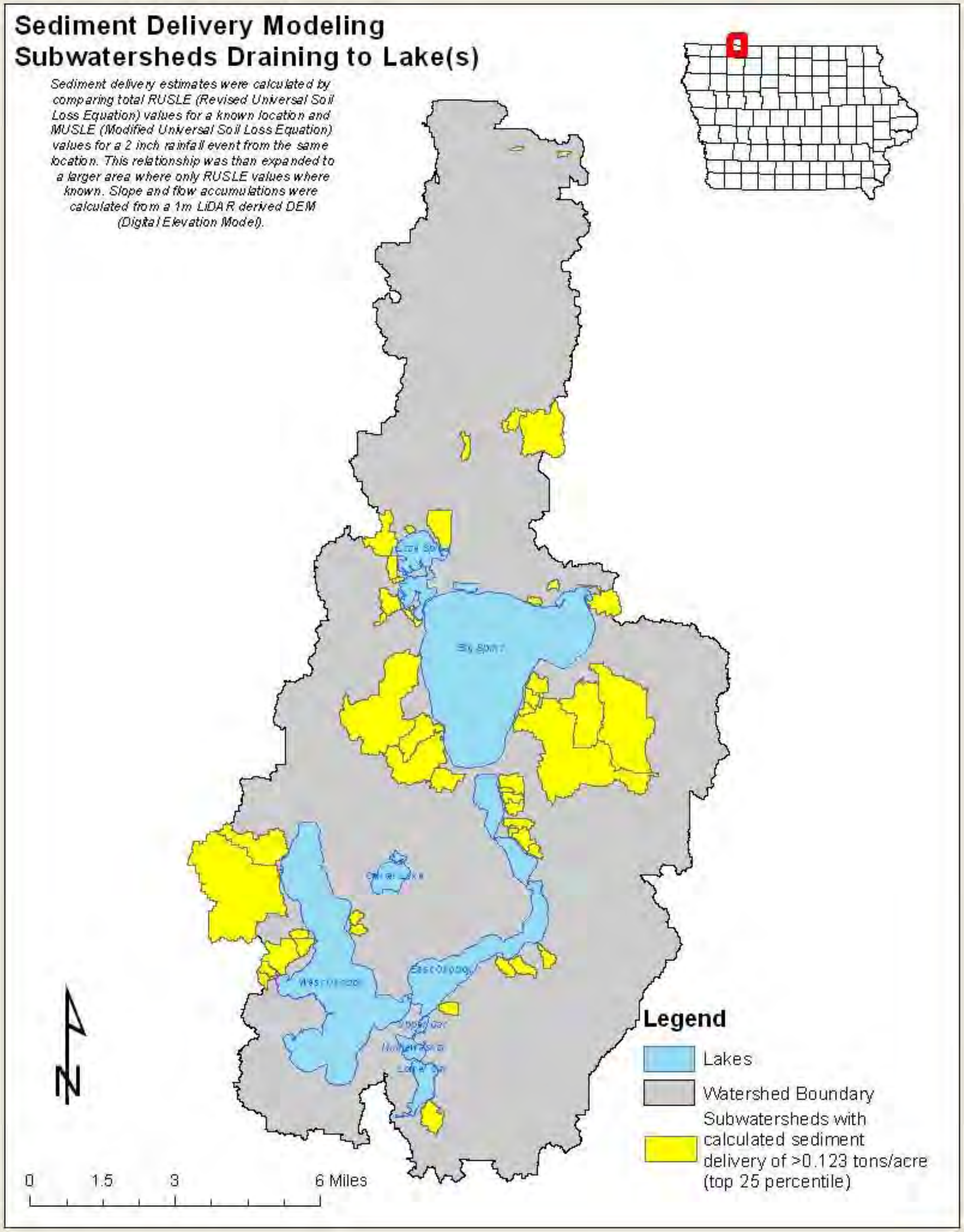

Sediment Delivery Modeling
Subwatersheds Draining to Lake(s)
Sediment delivery estimates were calculated by comparing total RUSLE (Revised Universal Soil Loss Equation) values for a known location and MUSLE (Modified Universal Soil Loss Equation) values for a 2 inch rainfall event from the same location. This relationship was than expanded to a larger area where only RUSLE values where known. Slope and flow accumulations were calculated from a 1m LiDAR derived DEM (Digital Elevation Model).
N
0
1.5
3
6 Miles
Legend
Lakes
Watershed Boundary
Subwatersheds with calculated sediment delivery of >0.123 tons/acre (top 25 percentile)

Figure 5

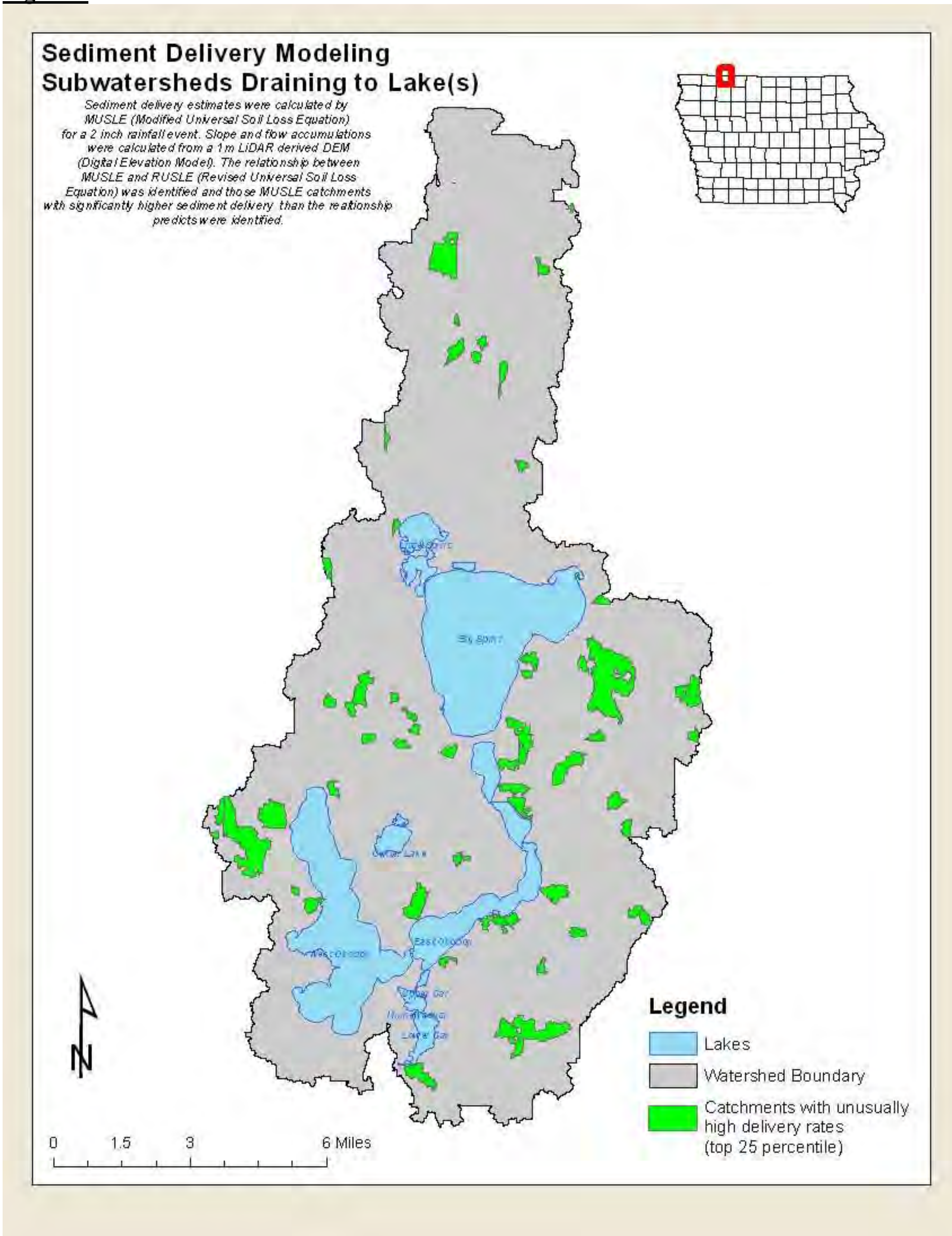

Sediment Delivery Modeling
Subwatersheds Draining to Lake(s)
Sediment delivery estimates were calculated by MUSLE (Modified Universal Soil Loss Equation) for a 2 inch rainfall event. Slope and flow accumulations were calculated from a 1m LiDAR derived DEM (Digital Elevation Model). The relationship between MUSLE and RUSLE (Revised Universal Soil Loss Equation) was identified and those MUSLE catchments with significantly higher sediment delivery than the realtionship predicts were identified.
Legend
Lakes
Watershed Boundary
Catchments with unusually high delivery rates (top 25 percentile)
0
1.5
3
6 Miles
N

Figure 6

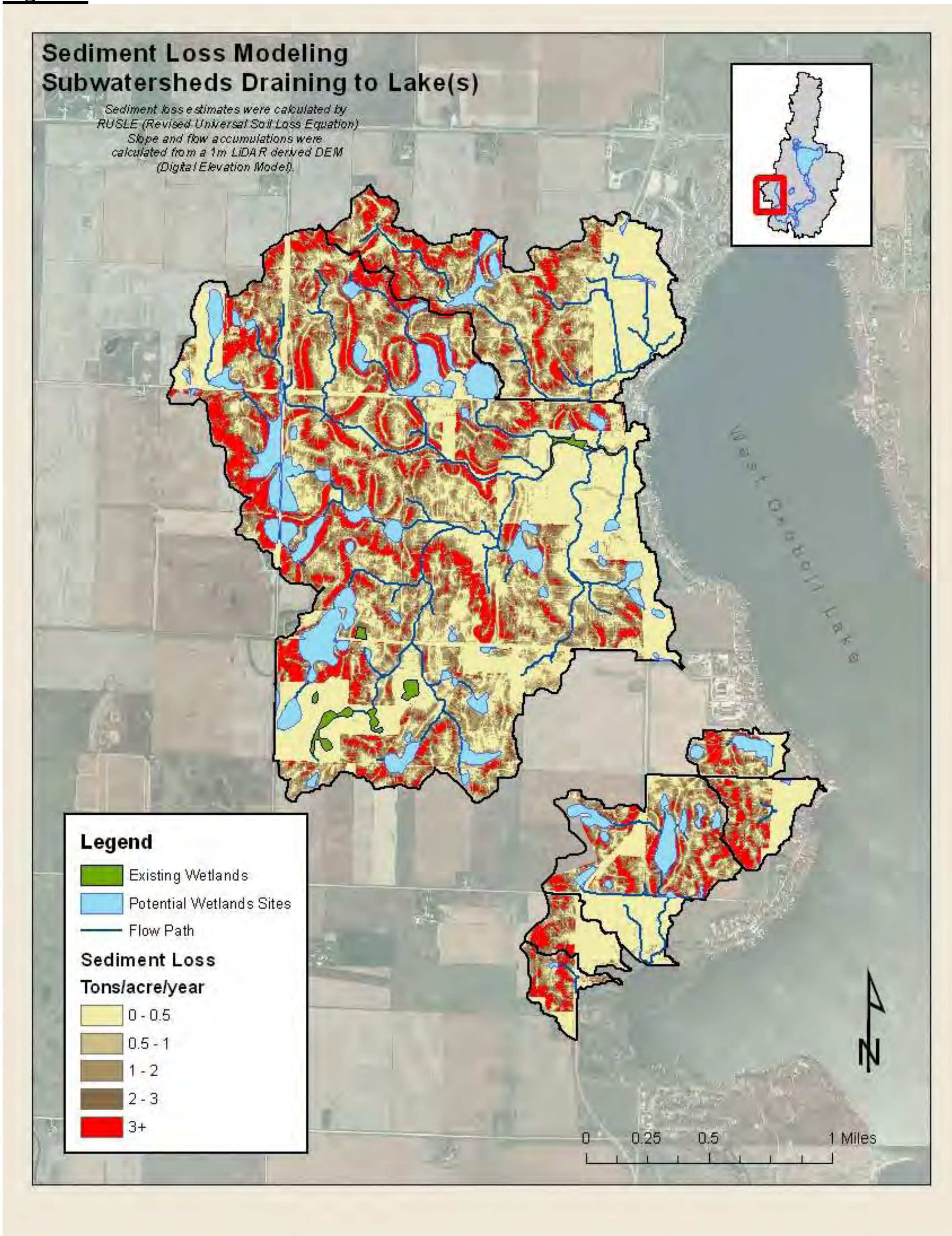

Sediment Loss Modeling
Subwatersheds Draining to Lake(s)
Sediment loss estimates were calculated by RUSLE (Revised Universal Soil Loss Equation). Slope and flow accumulations were calculated from a 1m LiDAR derived DEM (Digital Elevation Model).
West Okoboji Lake
Legend
Existing Wetlands
Potential Wetlands Sites
Flow Path
Sediment Loss
Tons/acre/year
0 - 0.5
0.5 - 1
1 - 2
2 - 3
3+
0
0.25
0.5
1 Miles
N

Figure 7

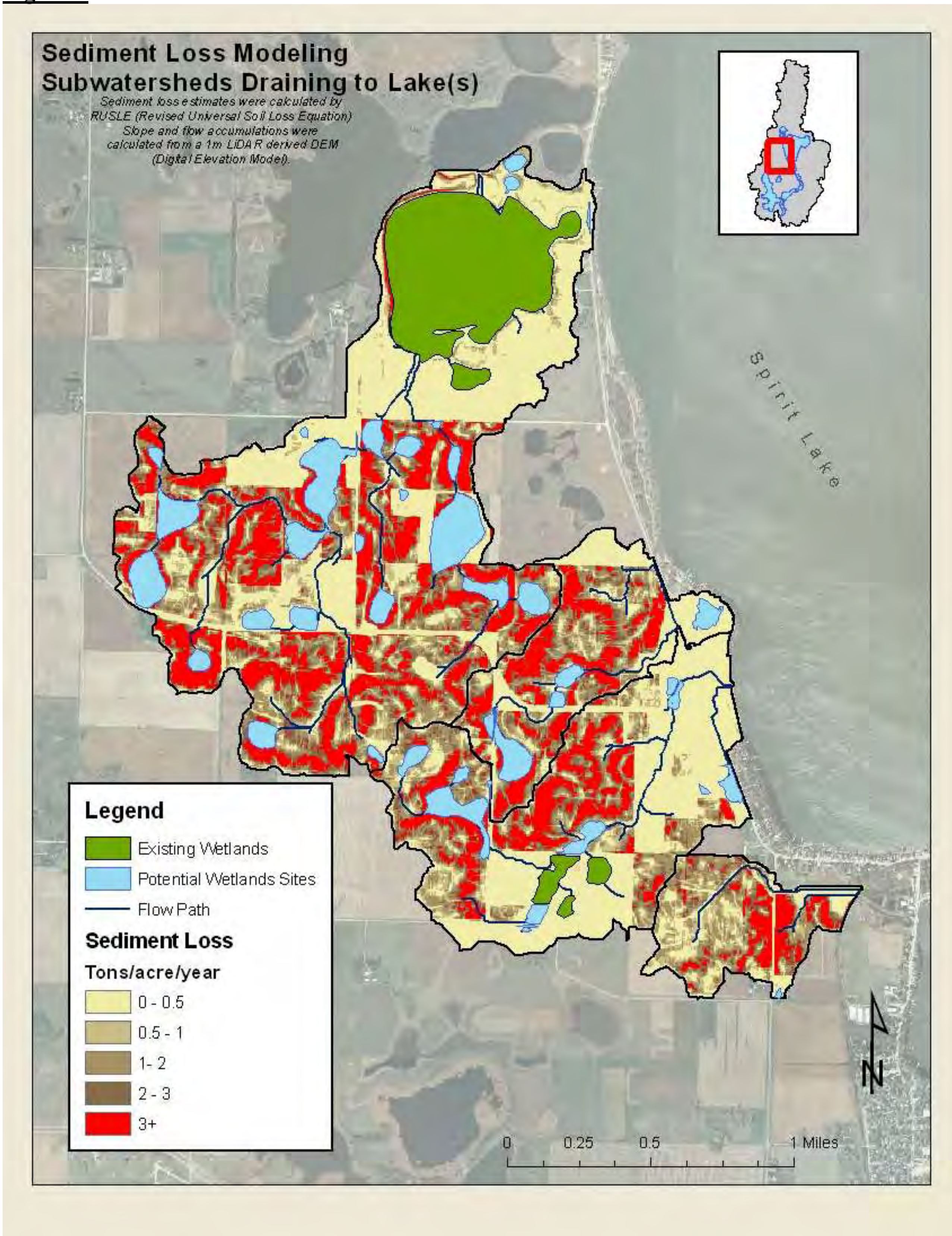
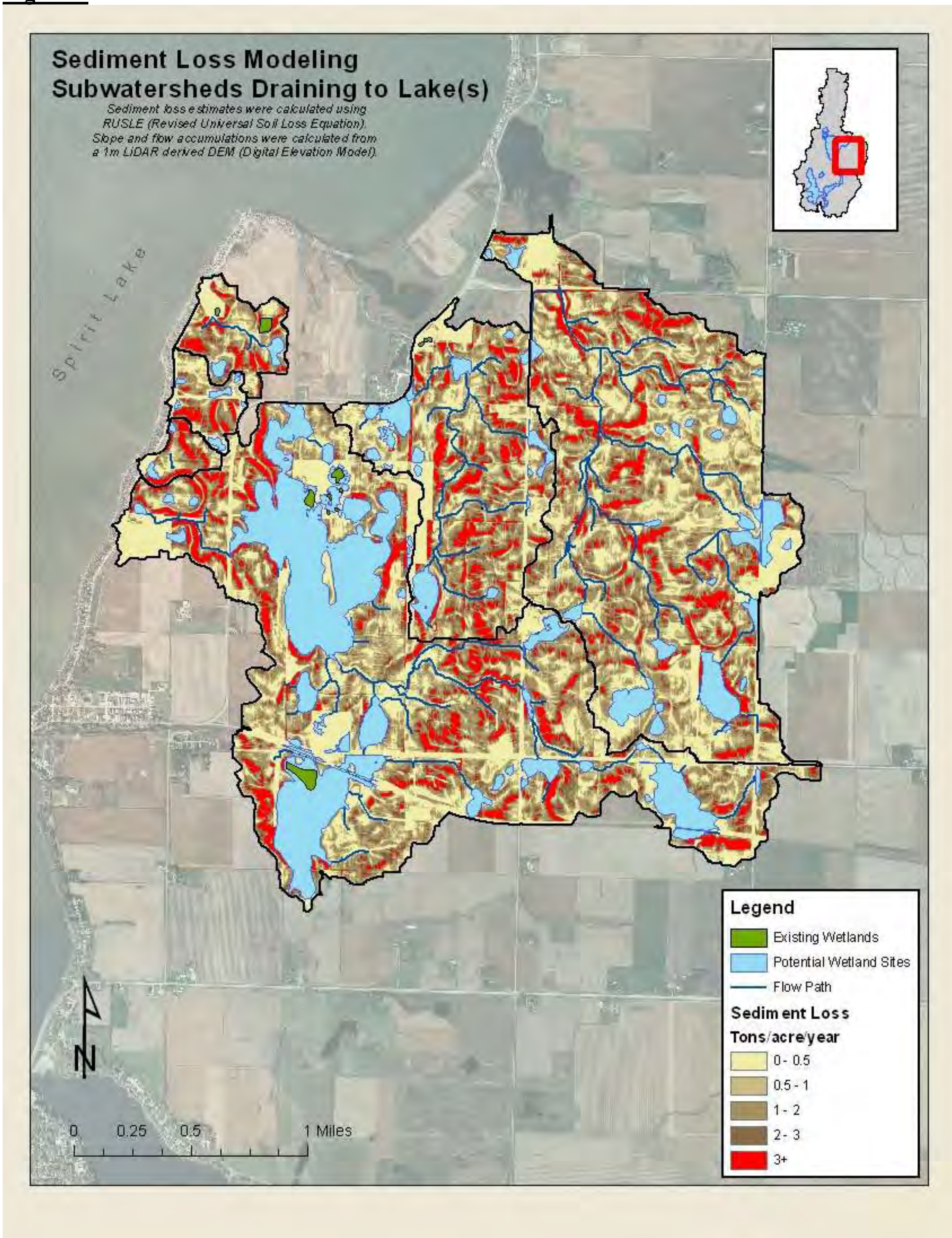

Sediment Loss Modeling
Subwatersheds Draining to Lake(s)
Sediment loss estimates were calculated by
RUSLE (Revised Universal Soil Loss Equation)
Slope and flow accumulations were
calculated from a 1m LiDAR derived DEM
(Digital Elevation Model).
Spirit Lake
Legend
Existing Wetlands
Potential Wetlands Sites
Flow Path
Sediment Loss
Tons/acre/year
0 - 0.5
0.5 - 1
1- 2
2 - 3
3+
0
0.25
0.5
1 Miles
N

Figure 8



Sediment Loss Modeling
Subwatersheds Draining to Lake(s)
Sediment loss estimates were calculated using RUSLE (Revised Universal Soil Loss Equation). Slope and flow accumulations were calculated from a 1m LiDAR derived DEM (Digital Elevation Model).
Spirit Lake
Legend
Existing Wetlands
Potential Wetland Sites
Flow Path
Sediment Loss
Tons/acre/year
0 - 0.5
0.5 - 1
1 - 2
2 - 3
3+
N
0
0.25
0.5
1 Miles