4. Lake Characteristics

The Origin and Nature of Crooked Lake

Crooked Lake is the result of the partial filling of a glacial drainageway left by the Superior lobe of the Wisconsin glaciation. Channels such as the one occupied by Crooked Lake are conspicuous by the general alignment to the north and northeast of most of the lakes in Anoka County.

4.1 Morphology and Bathymetry

Crooked Lake is approximately 114 acres in size with a mean depth of 9 feet. It is elongated in the north-south direction and is almost four times long as wide. Crooked Lake is a shallow lake with 73 percent of the lake classified as littoral zone (<15 feet). The deepest area has been measured at 26 feet in the central southeast portion of the lake. It has a meandered shoreline length of 2.9 miles and one small ½-acre island in the southwest which is separated from the shore by a narrow channel.

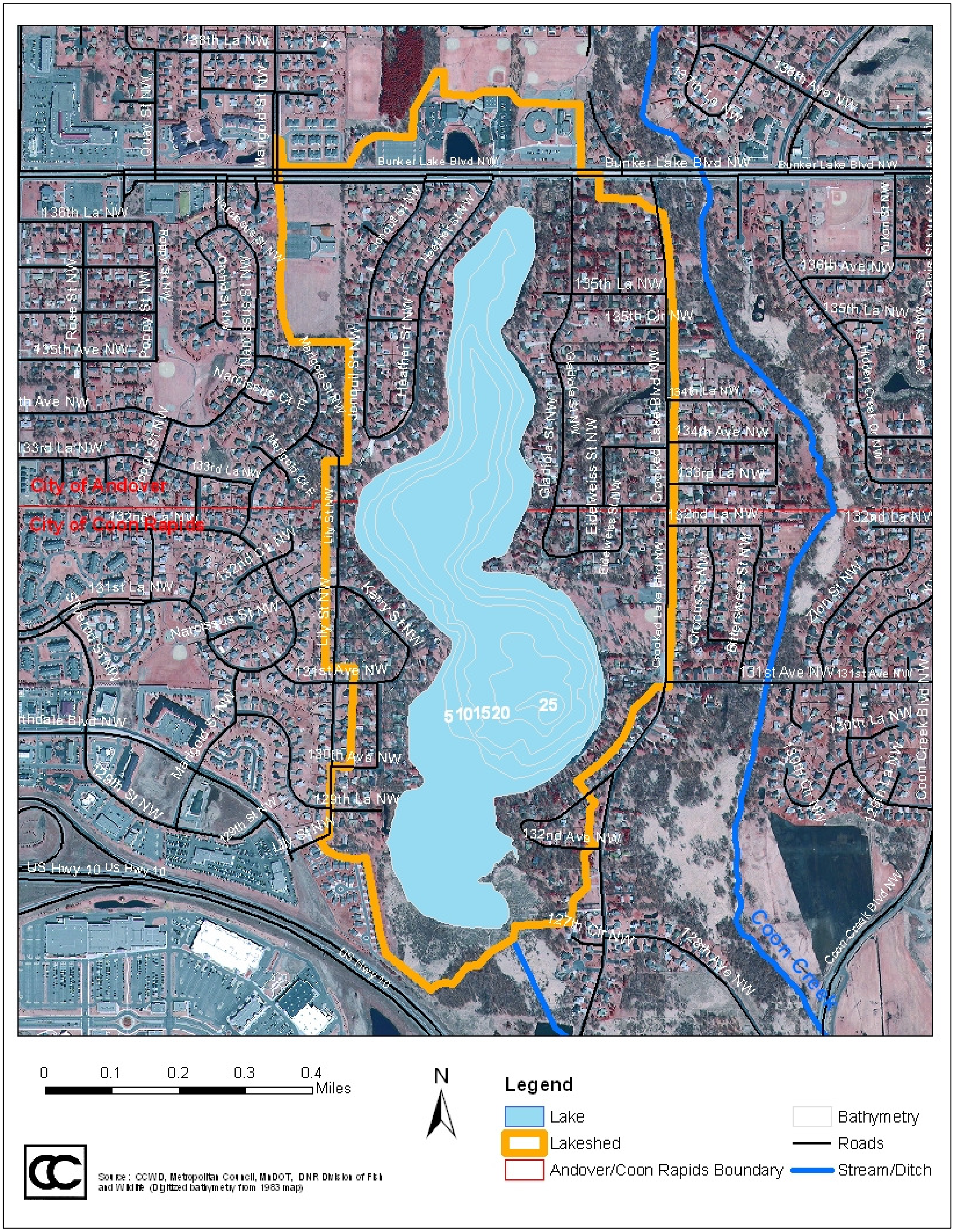
Table 4.1.1 Crooked Lake Morphology

Lake Feature	Measurement
Lake Surface Area	114 acres
Watershed Area	236 acres
Littoral Zone Area (depth <15 feet)	83 acres
Percent Littoral Area	73%
Maximum Depth	26 feet
Mean Depth	9.0 feet
Relative Depth	1.0%
Average Slope	0.02%
Maximum Lake Length	1.08 miles
Maximum Lake Width	0.29 miles
Length to Width Ratio	3.7
Maximum Fetch Distance	1.07 miles
Lake Perimeter (Shoreline Length)	2.9 miles

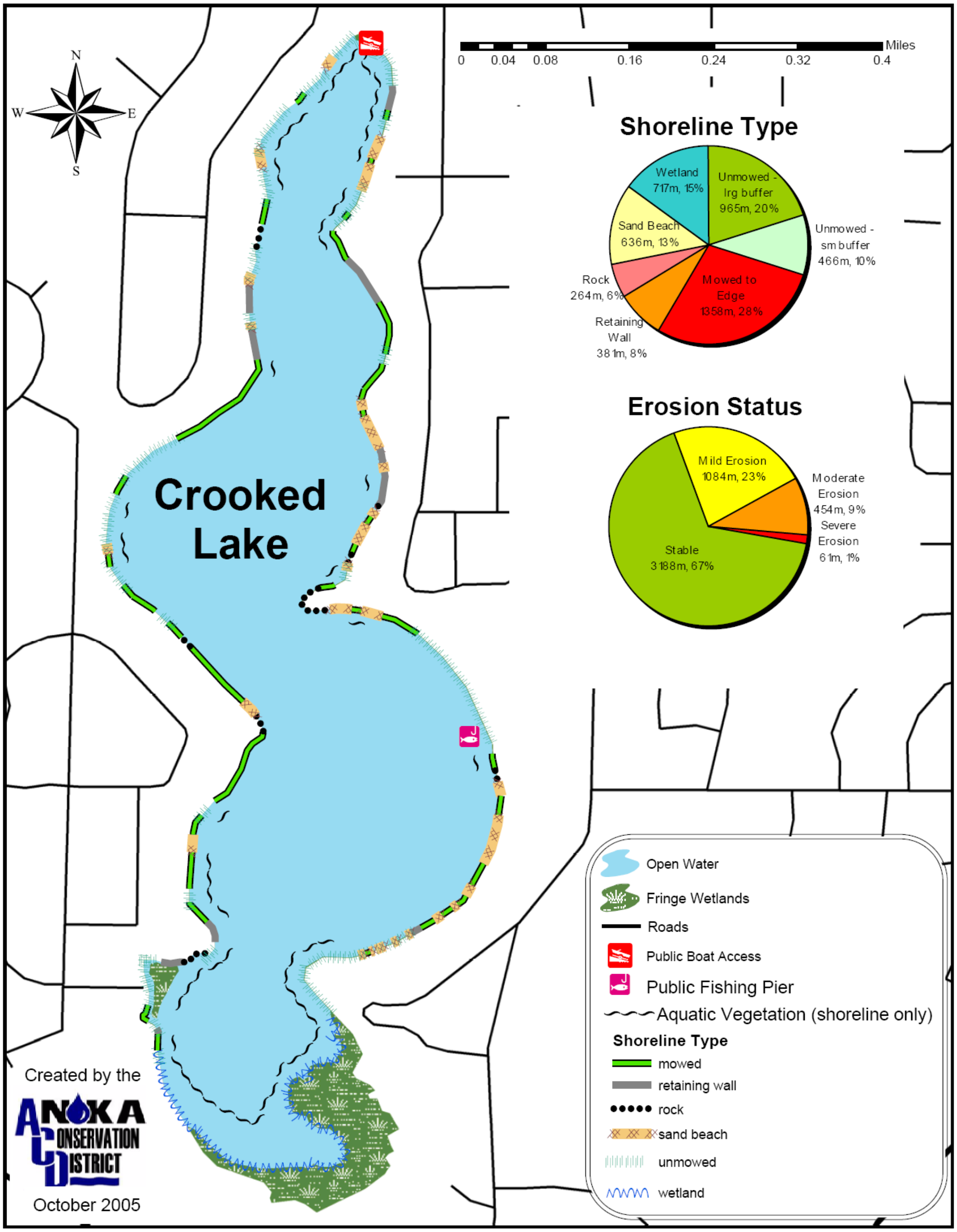
Table 4.1.2 Crooked Lake Bathymetry

Depth [ft]	Area (acres)	Volume (ac-ft)	Bottom Area	% Lake Area
surface	114	1,021		100.0
5	65	441	49.0	43.0
10	47	278	17.8	15.7
15	31	192	16.5	14.5
20	8	90	22.8	20.0
25	1	20	6.7	5.9

Figure 4.1 Crooked Lake Morphology and Bathymetry



4.2 Crooked Lake Shoreline

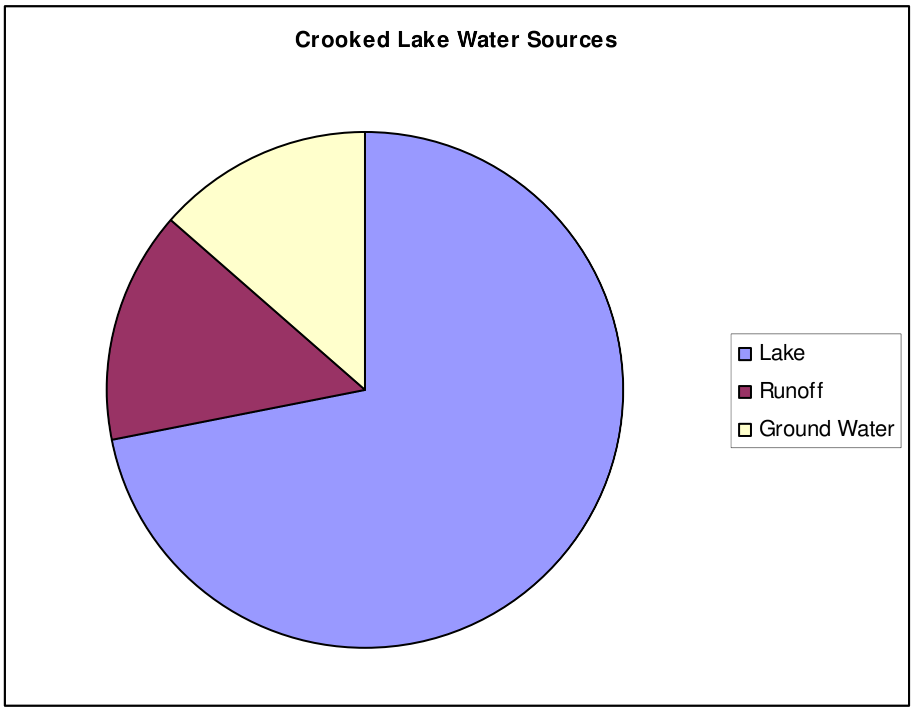


4.3 Water

Crooked Lake has no natural inlets and is supported by ground water and a relatively small watershed area of approximately 236 acres. Consequently only 29% of the water in the lake comes from the watershed (15%) and groundwater (14%).

There is a culvert outlet through an earthen dam at the southern end of the lake where water can flow to a channel (County Ditch 54-1) to confluence with Coon Creek to the southeast. Inspection of the dam and outlet in fall, 2008 showed that the lake has not discharged in a very long time.

Lake Feature	Measurement
Lake Volume (acre-feet)	1,021 acre-feet



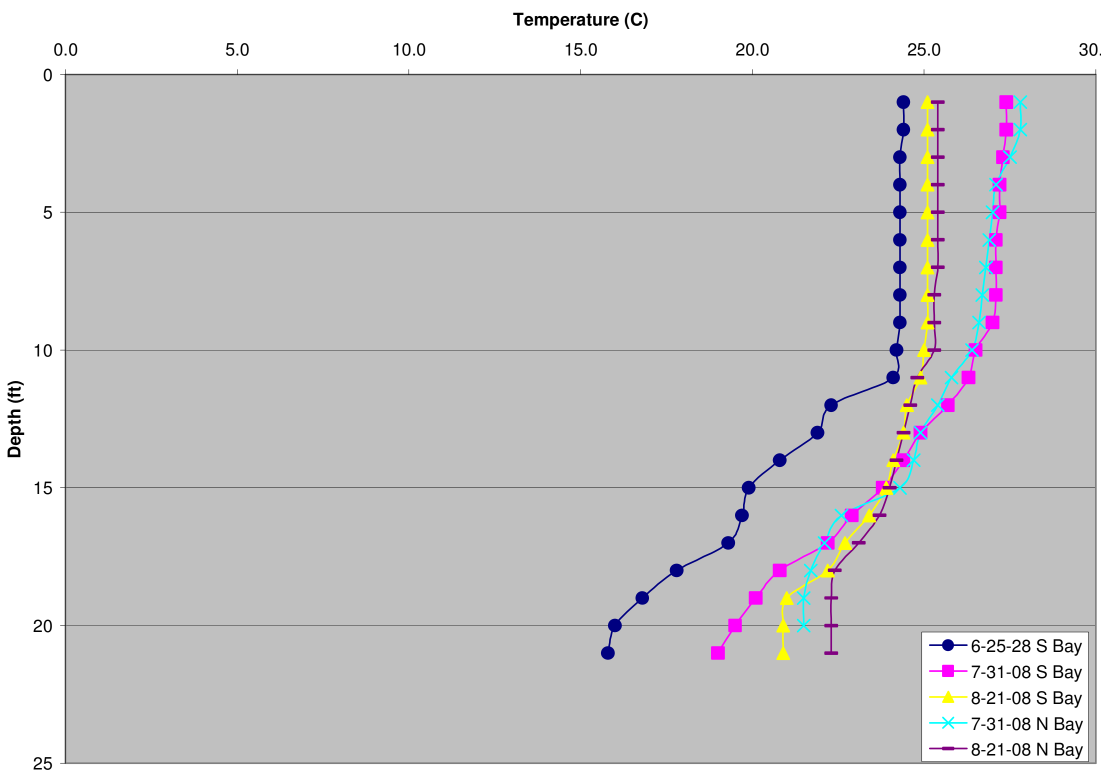
Hydraulic Residence

It is estimated that Crooked Lake requires 7.4 years to renew the lake water volume. The residence time is a function of the volume of water entering or leaving the lake relative to the volume of the lake and is a determinant in how a lake responds to various inputs. The length of time for Crooked Lake is a function of its relatively small watershed.

4.4 Mixing and Temperature

Lake mixing and thermal stratification play important roles in lake ecology including nutrient recycling. Water stratifies based upon temperature differences, unless mixing by wind occurs to the bottom. The extent of mixing is observed by taking measurements of dissolved oxygen and temperature at various depths

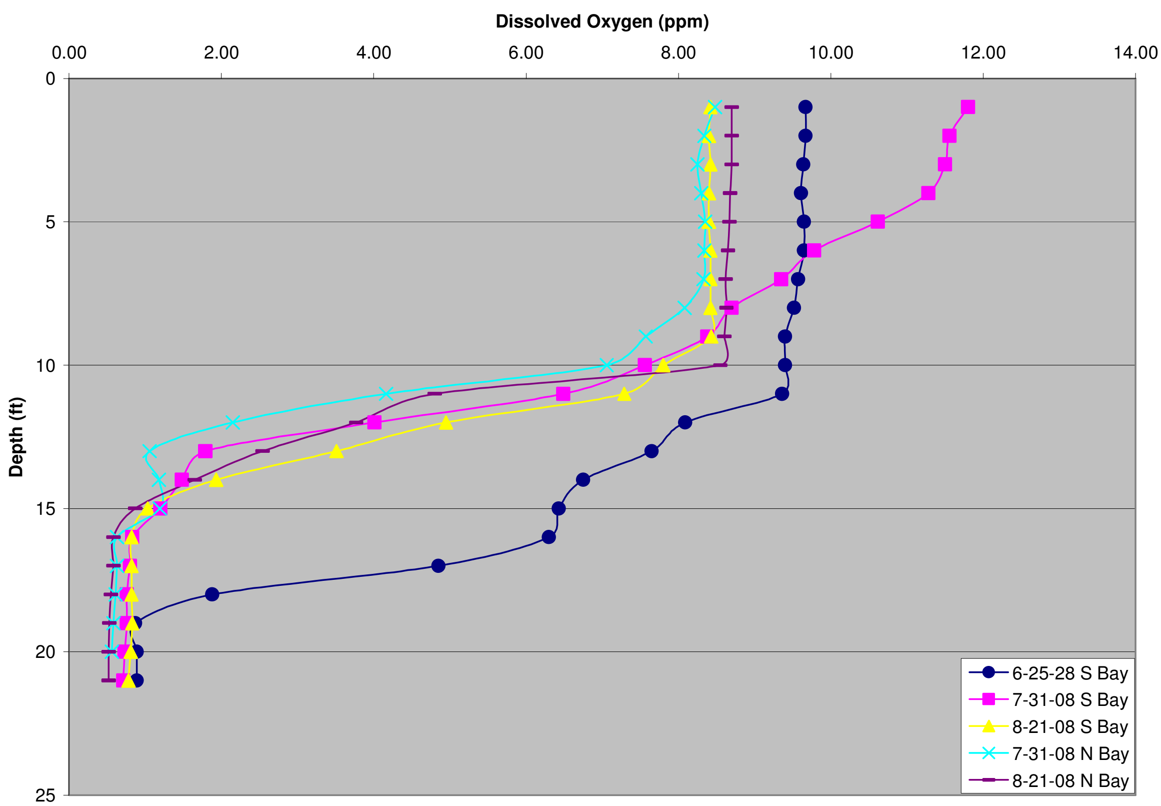
Crooked Lake is polymictic, meaning it is nearly continuously mixed to the bottom by wind and wave action. The relative lack of stratification compared to many lakes is due to a somewhat shallow basin and broad north-south expanse over which wind can create turbulence by wave action. Relatively homogenous water column temperatures are indicated by the vertical isotherm graph to a depth of approximately 10 feet (15.7% of lake area). Approximately 15% of Crooked Lake thermally stratifies during the summer months, restricted to areas of the lake deeper than 12 feet.



4.5 Dissolved Oxygen for Crooked Lake

The minimum amount of dissolved oxygen (D.O.) needed for most fish to survive and grow is 5 mg/L. In Crooked Lake, summertime (May-Sep) dissolved oxygen amounts are almost always above this level, averaging 8.5 mg/L (readings at 1 m depth, 2000-2008). The only time low summertime dissolved oxygen levels have been recorded was a single reading of 4.23 mg/L in August 2000. Lower oxygen levels are commonly found at depths greater than 12 feet due to decomposition on the lake bottom and lack of wind mixing.

Wintertime dissolved oxygen has been more problematic because ice eliminates wind mixing and plant photosynthesis is reduced. Fish kills have occurred in the winters of 1950-51, 1955-56, 1964-65, 1969-70 and 1978-79. A winter aeration system, first installed in 1988, has eliminated winterkills.

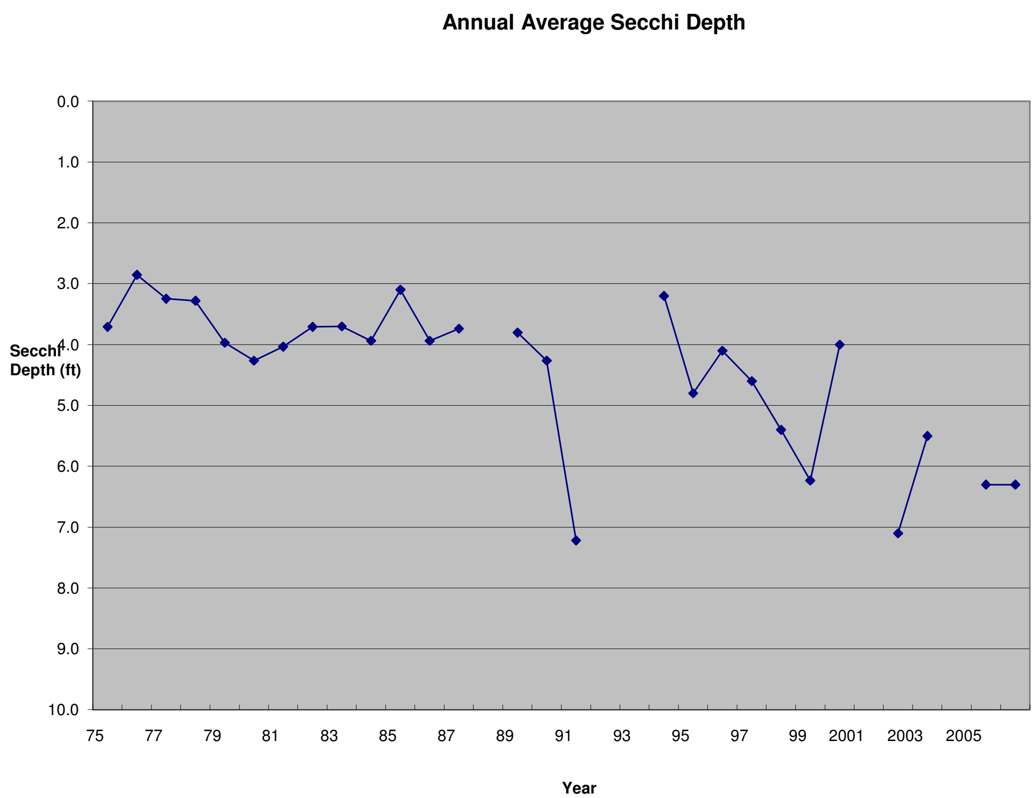


4.6 The pH of Crooked Lake

The data indicate daily fluctuations in pH primarily due to variations in the amount of primary productivity occurring in the lake. The pH ranges from 7.68 to 9.42 and the average pH is 8.6.

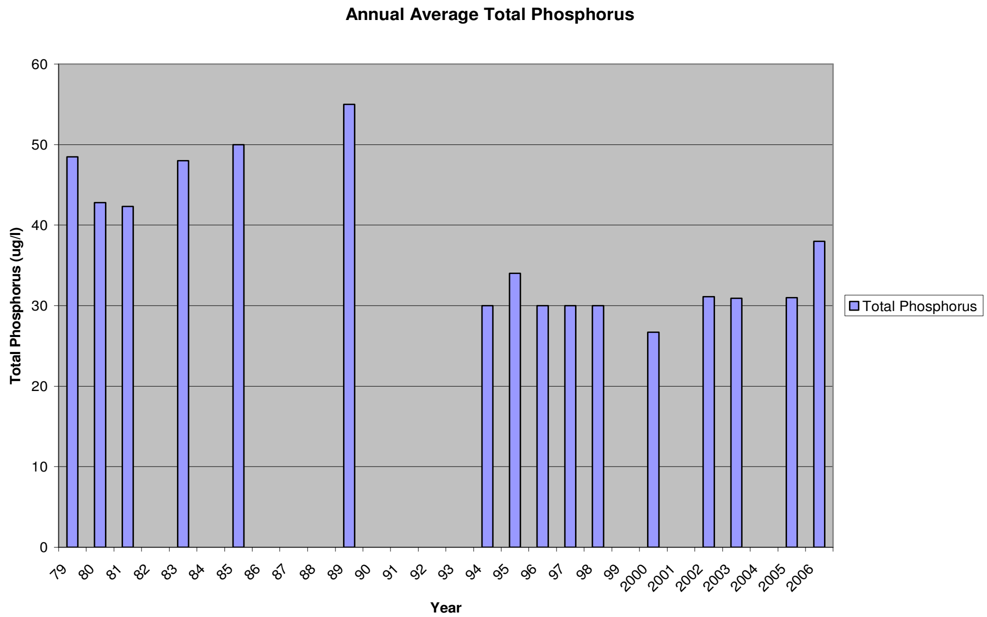
4.7 Transparency in Crooked Lake

Water clarity has improved since the 1980s. The annual average secchi depth for the 1980s is 3.78 feet. The annual average from 1990-2006 is 5.3 feet.



4.8 Total Phosphorus in Crooked Lake

Phosphorus concentrations have significantly decreased from 1983 to 2006. During the 1980s the annual average phosphorus concentration was 50 µg/L. From 1995 until the present the annual average phosphorus concentration is 30 µg/L.



4.9 Current Phosphorus Budget Components

The phosphorus budget for Crooked Lake includes atmospheric load, internal load from lake sediments, and watershed loads from stormwater runoff.

Atmospheric Load

Atmospheric loads were estimated using published literature values for aerial loading rates in Minnesota (14.91 kg/km^2-yr for an average precipitation year; Barr Engineering, 2004). Aerial loading rates were multiplied by lake surface area to determine the annual loading rate (kg/yr) for atmospheric deposition.

Internal Load

Internal loading for Crooked Lake was calculated by Equation 1:
Equation 1: (Lake Area) * (Anoxic Factor) * (Internal Total Phosphorus Release Rate)

The predicted anoxic factor was estimated based on research of shallow lakes conducted by Nürnberg (2005). Multiple regression analysis of multi-year Total Phosphorus (TP) data sets were used to develop an equation to predict the anoxic factor (AF_{pred}) for shallow lakes and is given by Equation 2:

Equation 2: AF_{pred} (days) = $-35.4 + 44.2 \log(TP) + 0.95\, z/A^{0.5}$ (Nürnberg 2005)

Where TP is the average measured water column TP (µg/L) of the lake, z is the mean depth in meters, and A is the lake surface area in hectares. The release rate (mg/m^2-day) was estimated from literature values.

Watershed Loads

Pollutant load generation and delivery to Crooked Lake were estimated using the P8 computer model (Walker 2007, Version 3.2). P8 inputs include devices (detention ponds and pipes) and watershed information (area, percent impervious and pervious curve number.)

Using 2-foot contours and storm sewer information obtained from the Cities of Andover and Coon Rapids along with construction plans from Coon Creek Watershed District permits, the Crooked Lake watershed was divided into 11 subwatersheds. Ten of these subwatersheds are point source discharges that enter the lake through stormsewer pipes, and the 11th subwatershed has overland flow direct drainage.

Two subwatersheds, approximately 25% of the Crooked Lake watershed, contain water quality treatment. One is located north of Crooked Lake: a stormwater pond treating 25 acres of roadway and public/semi-public buildings. The other is on the east side of the lake: an old ditch currently acting as a stormwater pond for 29 acres. Both of these detention basins have been incorporated into the P8 model.

Table 4.9.1

Subwatershed ID	Avg. Runoff Volume (ac. ft./yr)	Avg. TP Load (lbs./yr)
1	2.3	1.1
2	3.2	1.6
3	8.8	4.2
4	5.3	2.5
5	8.8	4.2
6	23.3	11.0
7	17.0	3.2
8	44.3	21.0
9	12.0	5.7
10	18.0	3.3
11	3.1	1.5

The percent impervious and pervious curve numbers were estimated by current land use. Based on literature values and LANDSAT imagery, an impervious percent was assessed to each land use type. All pervious undeveloped areas were assigned a curve number of 60. All pervious developed areas were assigned a curve number of 74 (Wenck 2007).

Table 4.9.2 summarizes the land uses, total areas, impervious fractions, and curve numbers used:

Table 4.9.2

Land Use	Area (ac)	Impervious fractions	Pervious Curve Number
Single Family Residential	181	0.25	74
Multi-Family Residential	3	0.40	74
Parks and Recreation	9	0.05	60
Public/Semi-Public	22	0.30	74
Vacant	16	0.05	60
NWI Types 1,2,6,7,8	6	0.00	60
Totals (weighted average*)	236	0.23*	72*

Water quality data collected in 2000, 2002, 2003, 2005 and 2006 were used to verify the P8 model simulation of pollutant load generation and delivery (water quality data was not available for years 2001 and 2004). The P8 model was calibrated so that the BATHTUB model equations approximately matched the in-lake monitored phosphorus concentrations. The calibration was conducted by modifying the scale factor for particle loads in the P8 model.

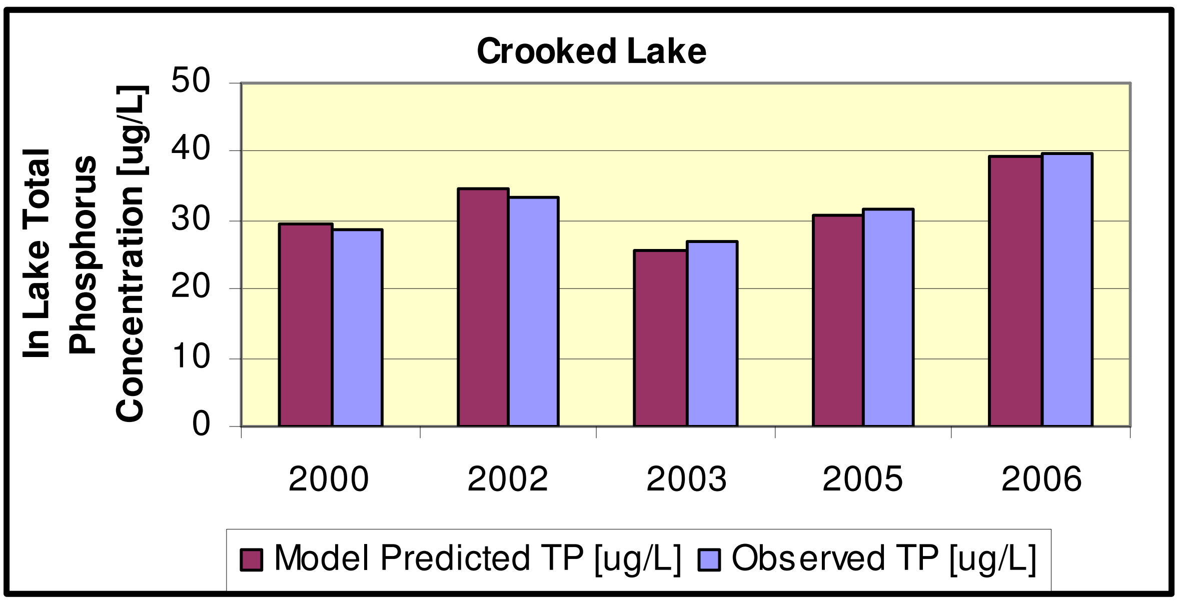
4.10 Water Quality Response Modeling

Model equations from BATHTUB were used to estimate the in-lake response to hydraulic and pollutant loads in 2000, 2002, 2003, 2005 and 2006 in Crooked Lake. Several models are available within the BATHTUB model. The Canfield-Bachmann model for natural lakes was used to estimate lake response for phosphorus.

BATHTUB was used to estimate chlorophyll-a concentrations as a function of phosphorus, light, and flushing rate. BATHTUB was also used to estimate Secchi depth as a function of chlorophyll-a and non-algal turbidity. The coefficient for chlorophyll-a concentration was modified from 0.025 to 0.015 to represent shallow lakes more accurately (Steve Heiskary, pers. comm.).

Model Validation: The results from the in-lake phosphorus response model are compared to measured in-lake phosphorus concentrations (TP) as shown in Figure 4.10. This model performed well for the modeled years and is considered a reasonable representation of the nutrient dynamics in the lake and watershed.

Figure 4.10



4.11 Current Phosphorus Budget

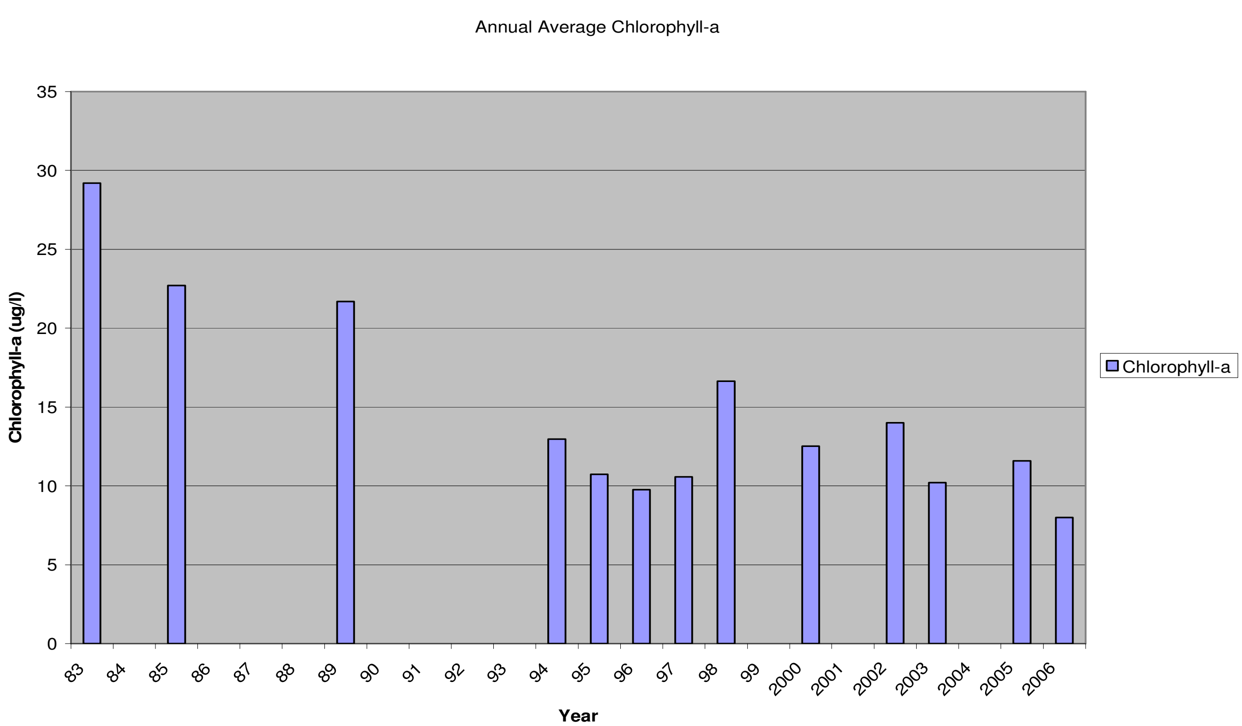
Modeled and monitored data from 2000, 2002, 2003, 2005, and 2006 were used to estimate the current sources of phosphorus to Crooked Lake. It is assumed that 100% of the hydraulic loading for Crooked Lake is contributed by its watershed. For the years considered in this study the phosphorus loading is distributed on average as follows: 6% from atmospheric deposition, 18% from internal loading, and 76% from the watershed. The hydrologic and phosphorus budget for Crooked Lake is presented in Table 4.11:

Table 4.11

	2000	2002	2003	2005	2006
Annual Total Phosphorus Load [lb]					
Watershed	48	82	35	55	90
Atmosphere	5	5	4	5	5
Internal (1 mg/m^2-day)	15	12	12	16	18
TOTAL	68	99	51	76	113

4.12 Chlorophyll-a in Crooked Lake

Chlorophyll-a concentrations have significantly improved since the early 1980s. The annual average chlorophyll-a concentration for the 1980s was 24 µg/L. The annual average from 1995-2006 was 11.6 µg/L.



4.13 Aquatic Macrophyte Plants

Crooked Lake has a diverse aquatic plant community that is comprised of numerous native species plus two invasive species, Eurasian watermilfoil and Curly leaf pondweed. In some areas plants grow densely and to the surface, both native and invasive species. Given the water clarity and diverse plant community, dense plant numbers are expected especially in shallow areas; this is not unhealthy. A map of nuisance vegetation conditions and invasive species has not been created for the lake yet; it is scheduled into this Plan. In recent years staff from the Anoka Conservation District have noted that dense vegetation at or near the surface occurs in limited areas, mostly in shallow areas near shore, with a few exceptions. Lake managers generally strive for healthy, diverse aquatic plant communities with invasive species below nuisance levels (if present at all).

Invasive Species

Crooked Lake contains two invasive plant species which have reached nuisance conditions on the lake:

Genus	Species	Common Name
Myriophyllum	spicatum	Eurasian watermilfoil
Potamogeton	crispus	Curly leaf pondweed

Eurasian watermilfoil: Eurasian watermilfoil was first discovered in 1990 and whole-lake treatments have occurred in 1992 and 2002 to control Eurasian watermilfoil. Eurasian watermilfoil is an extremely adaptable plant that is able to tolerate and thrive in a variety of environmental conditions. It grows in water depths from one to 10 meters (three to 33 feet). Eurasian watermilfoil grows best on fine textured, inorganic sediments, and relatively poorly on highly organic sediments. Eurasian watermilfoil requires high light, has a high photosynthetic rate, and can grow over a broad temperature range. Eurasian watermilfoil exhibits an annual pattern of growth. In the spring, shoots begin to grow rapidly as water temperatures approach 59 degrees Fahrenheit. Shoots branch profusely when near the surface, forming a dense canopy. Below one meter in depth, leaves senesce in response to self-shading. Typically, plants flower upon reaching the surface (usually mid to late July). During fall, plants die back to the root crowns, which sprout again in the spring.

Curly leaf pondweed: Curly leaf pondweed, another highly productive aquatic macrophyte, has a life cycle that can significantly impact summertime phytoplankton productivity. Curly leaf pondweed reproduces by forming vegetative propagules called turions. Turions will remain dormant in the summer and then most will germinate in the fall and continue to grow slowly through the winter. These young plants will grow rapidly in the spring and by early summer the entire crop senesces. The density of growth and the timing of senescence for Curly leaf pondweed can have significant impacts on productivity because the release of phosphorus occurs at a time when growth conditions are ideal for phytoplankton. A heavy nuisance level of Curly leaf pondweed biomass (~400 stems/m^2) can potentially contribute 6.7 pounds phosphorus per acre.

Management of Invasive Plants: In 1992 Crooked Lake was subjected to a whole lake treatment with 15 ppb fluridone. The treatment reduced the milfoil population to below detectable levels for four years but also caused unacceptable damage to the native aquatic plant community (Crowell 2002). By 1998 Eurasian watermilfoil was back to nuisance levels. In 2002 Crooked Lake was chosen along with two other Minnesota lakes to determine if a lower concentration of fluridone (4-5 ppb) would effectively control Eurasian watermilfoil without causing unacceptable harm to native vegetation. The fluridone treatment reduced the frequency of Eurasian watermilfoil to zero. The treatment also reduced the total number of native plant taxa in the lake. By 2003 the number of taxa had rebounded to pretreatment levels.

Native Plant Species

Approximately 34 aquatic plant species occur in Crooked Lake. The following species were found during DNR aquatic plant inventories of 2001 to 2005, and are classified by physical similarity.

Table 4.13

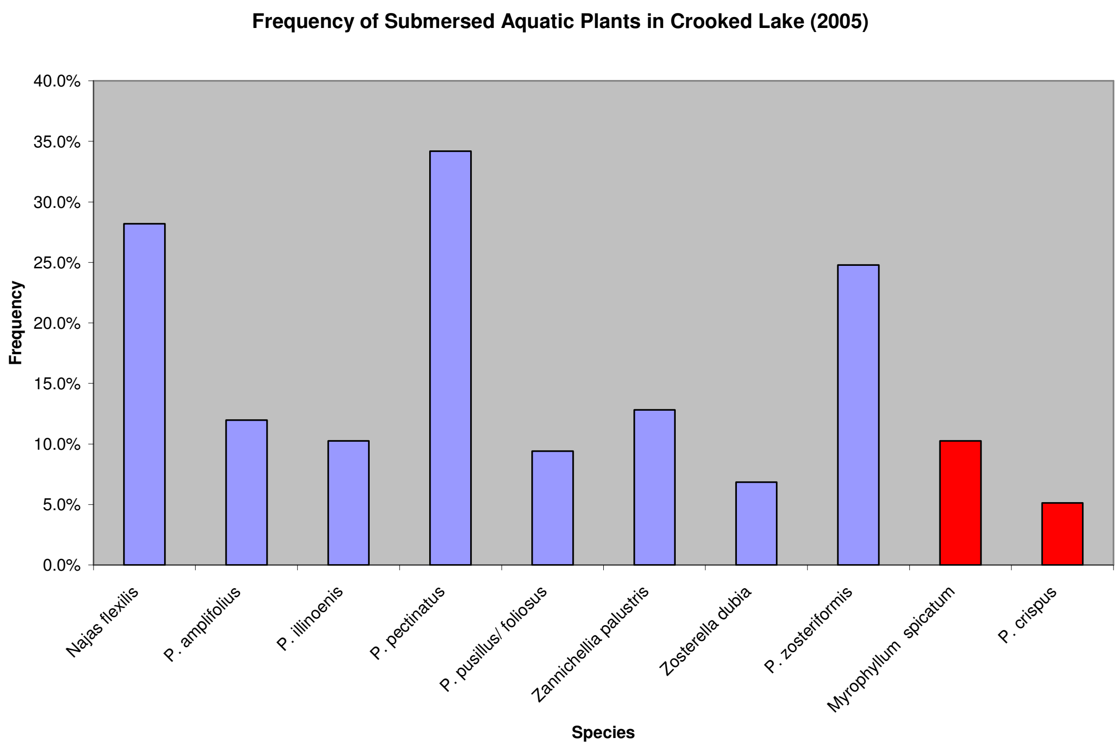
Plant Group	**Genus**	**Species**	**Common Name**
Trees	Populus	sp.	Poplar/Cottonwood
	Salix	sp.	Willow
Emergent			
Cattail	Typha	sp.	Cattail
	Eleocharis	sp.	Hairgrass
Rush	Juncus	sp.	Rush
	Scirpus	americanus	American bulrush
	Scirpus	validus	soft-stem bulrush
Lily & Lotus	Nuphar	sp	Water-lily
	Nymphaea	sp.	Water-lily
	Cicuta	maculata	Spotted water hemlock
	Rumex	crispus	Curled dock
	Sagittaria	sagittifolia	Arrowhead
Free Floating			
	Lemna	minor	Common Duckweed
	Ricciocarpus	natans	Purple-fringed riccia
	Spirodella	polyrhiza	Common Duckweed
	Wolffia	sp	Watermeal

Table 4.13
Continued

Plant Group Submergent	**Genus**	**Species**	**Common Name**
Broadleaf	Potamogetan	amplifolius	Largeleaf pondweed
	Potamogetan	illinoensis	Illinois pondweed
	Potamogetan	natans	Broad-leaved pondweed
Curled Pondweed	Potamogeton	crispus	Curly leaf pondweed
Fine-leaf	Certaophyllum	demersum	Coontail
	Myriophyllum	spicatum	Eurasian watermilfoil
	Myriophylum	sibiricum	Northern watermilfoil
	Najas	sp.	Bushy pondweed
Low Growth	Chara	spp.	Stonewart / muskgrass
	Utriculalria	vulgaris	Common bladderwort
	Vallisneria	americana	Wild celery
	Zannichellia	palustris	Horned pondweed
	Zosterella	dubia	water stargrass
Narrowleaf	Potamogeton	pectinatus	Sago pondweed
	Potamogeton	pusillus	Small pondweed
	Potamogeton	foliosus	Leafy pondweed
	Potamogeton	zosteriformis	flat-stem or eelgrass pondweed

Aquatic Plant Frequency Distribution – 2005

The most recent DNR aquatic plant survey in 2005 found 10 species that were widespread enough to be present in >5% of the samples. Eurasian watermilfoil was present in <10% of locations sampled and curly leaf pondweed in <15%. The density of these plants at each location is not known. Sago pondweed, bushy pondweed, and flat-stem pondweed were the most frequently encountered, all at >25% of locations sampled. The figure below summarizes the frequency of the remaining five species:



4.14 Fish Community Structure and Health

The fish community of Crooked Lake is in a stable, healthy state.

The first fish survey for Crooked Lake was conducted in 1951. There have been 11 total fish surveys conducted on Crooked Lake with the most recent fisheries survey conducted in 2004. The next scheduled survey is in 2009.

Table 4.14.1 Prominent species found in Crooked Lake

Trophic Guild	Common name	Genus	species
Forage Species	White Sucker	Catostomus	commersonii
	Channel Catfish	Ictalurus	punctatus
Pan Fish	Bluegill	Lepomis	macrochirus
	Smallmouth Bass	Microterus	dolomieui
	Yellow Perch	Perca	flavescens
	Black Crappie	Pomoxis	annularis
Rough Fish	Common Carp	Cyprinus	carpio
	Yellow Bullhead	Ameiurus	natalis
Top Predator	Northern Pike	Esox	lucius
	Largemouth Bass	Microterus	salmoides
	Walleye	Sander	vitreus

Based on the DNR surveys bluegills are the most abundant fish in Crooked Lake, comprising the largest percentage of total fish collected in each of the 11 surveys. Additional species that comprised a significant portion of the total catch include black crappie, black bullhead, northern pike, and yellow perch.

Fish community data was summarized by trophic groups for Crooked Lake. Species within the same trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community. Trophic group summaries of abundance and biomass are presented in Figures 4.14.1 and 4.14.2, respectively.

Based on trophic group analysis, panfish are the dominant group in Crooked Lake in terms of both abundance and biomass. The rough fish and top predator groups make up a relatively small percentage of the total fish abundance in Crooked Lake during most survey years. However, in terms of abundance the top predator group comprises a significant portion of the total lake biomass during most surveys. Additionally, large mouth bass are known to be present in the lake in moderate to large numbers. Largemouth bass are not well represented in DNR surveys. Combining this information of the top predator biomass with the known occurrence of largemouth bass indicates that three is a good mechanism for top-down control in the fish community.

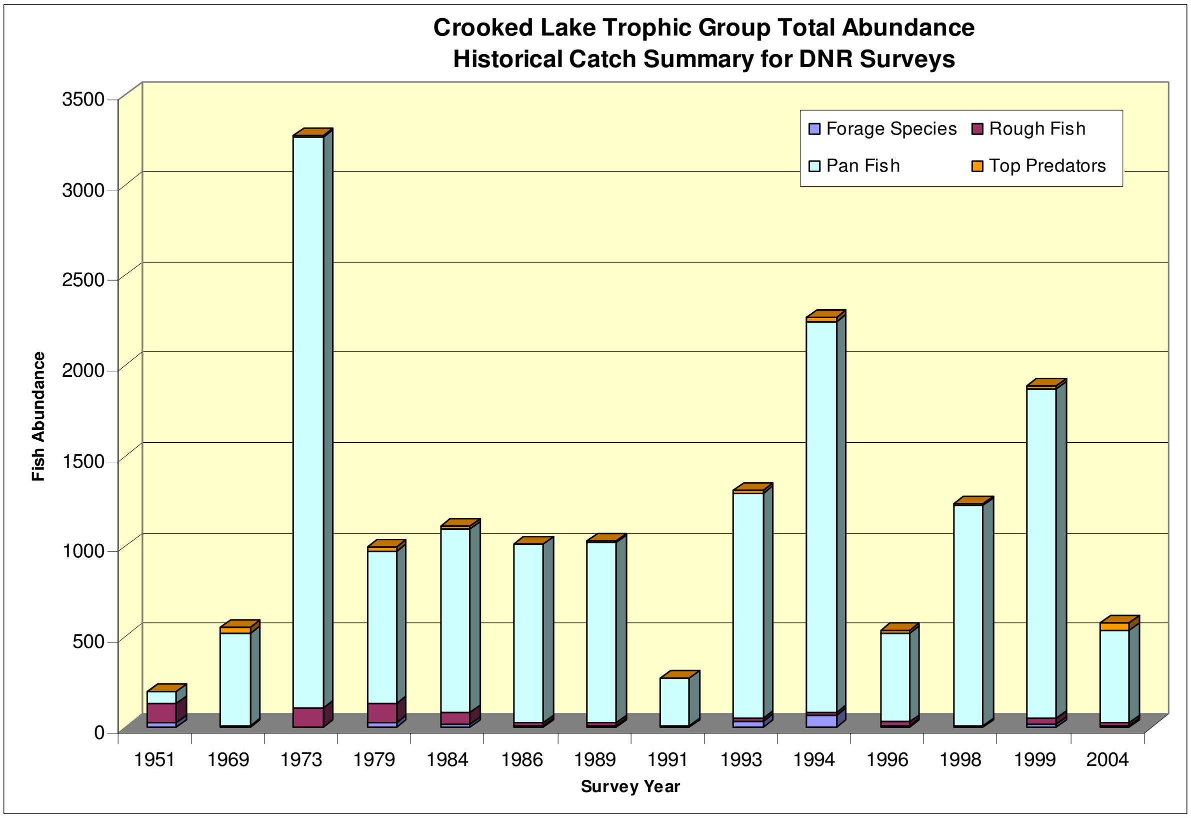


Figure 4.14.1: Fish trophic group abundance based on historical DNR surveys for Crooked Lake

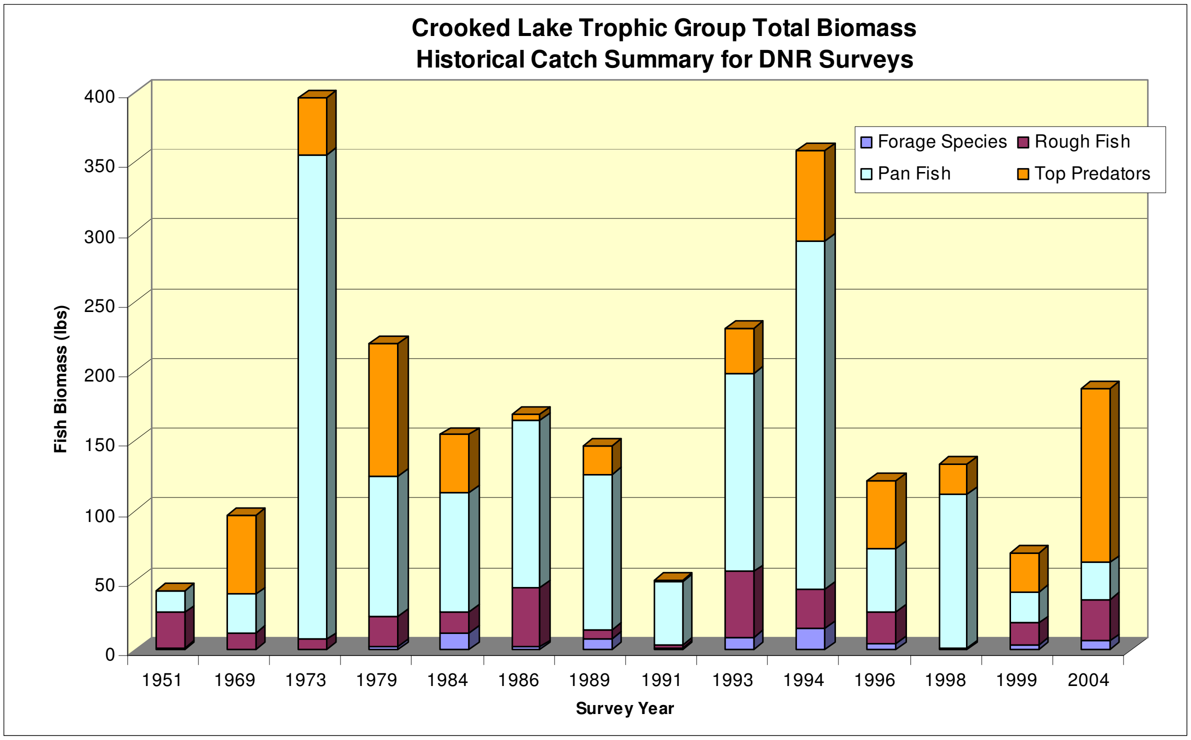


Figure 4.14.2: Fish trophic group biomass based on historical DNR surveys for Crooked Lake

Current Fish Management Emphasis

A variety of historical fish survey data are available. The lake management plan developed by the Fisheries Division of the DNR identifies:

Primary management species

- Walleye
- Channel catfish

Secondary management species

- Largemouth bass

The selection of walleye and channel catfish as primary management species is an interesting choice as neither species is naturally abundant in the lake and their populations are being maintained through supplemental stocking.

Problem Species

While rough fish are present in the lake, including black bullhead and common carp, they are not dominating the fish community and do not appear to be creating water quality nor fish community problems. Although carp are not abundant in the lake, the management of the carp population will be critical in maintaining healthy conditions in Crooked Lake. If the carp population were to get out of control, the lake could switch to a turbid water state. Limiting the size of the carp population will be important in protecting Crooked Lake.