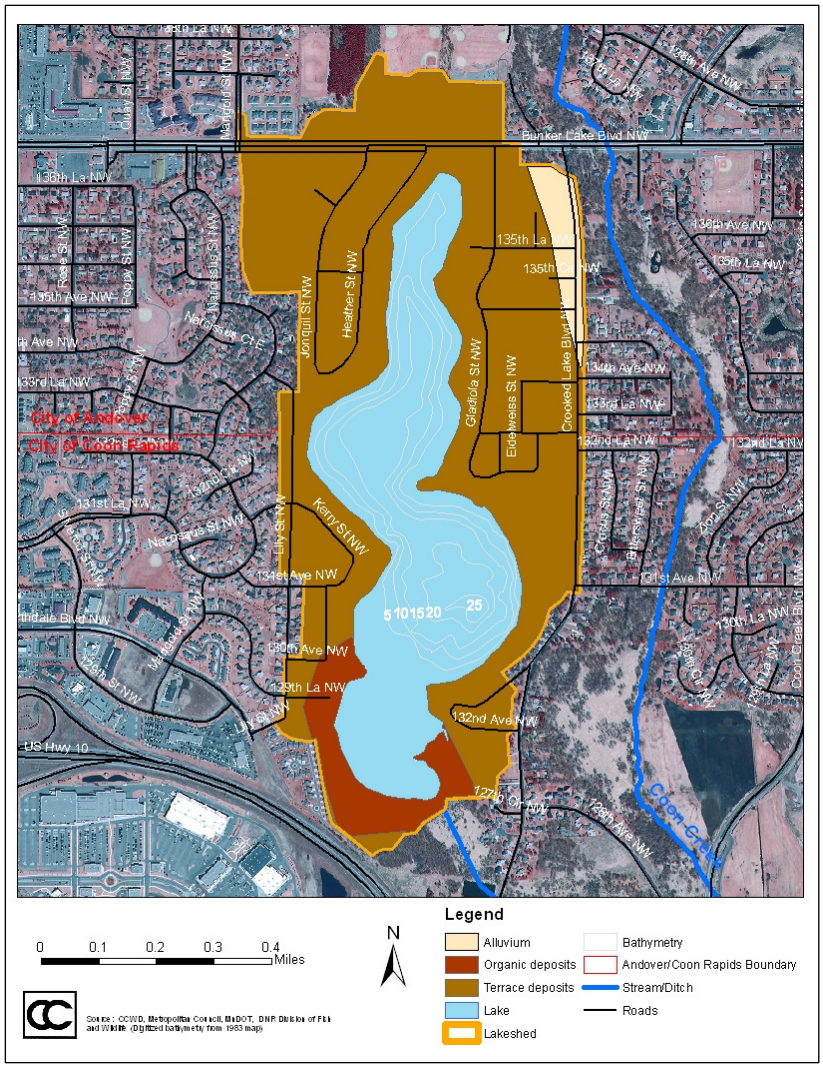
3.0 Watershed and Hydrologic Characteristics of Crooked Lake

3.1 Geologic Setting and Hydrogeology

Crooked Lake is located in the Mississippi Sand Plain portion of the Anoka Sandplain. This geologic feature is an undulating outwash plain characterized by flat topography, sandy soils, and a shallow water table.

Surficial geology in the area is composed of postglacial deposits formed from the retreat of the Superior Lobe of the Grantsburg sublobe of the Lake Wisconsin glaciers. The majority of the watershed is composed of terrace deposits with the exceptions of the area in the south of the lake which is composed of organic deposits and a small area in the northeast adjacent to Coon Creek which is composed of alluvial deposits.

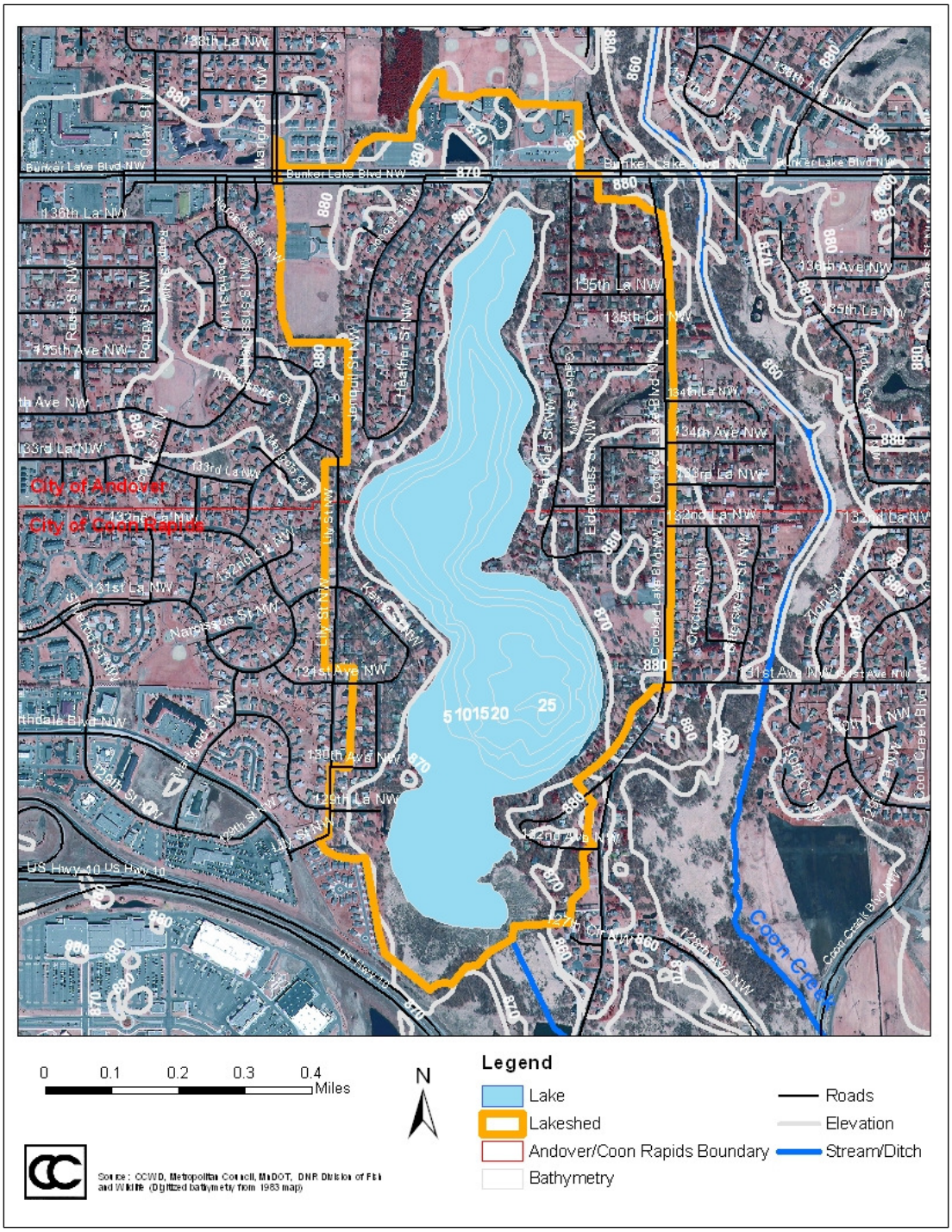
Figure 3.1 Crooked Lake Surficial Geology



3.2 Topography

The watershed of Crooked Lake is typified by gently rolling topography generally ranging between 860-880 feet in elevation above sea level. The lake bottom has a mean slope of 0.02%. Elevations are more varied to the east and north of the lake and flatten out to the west.

Figure 3.2 Crooked Lake Topography



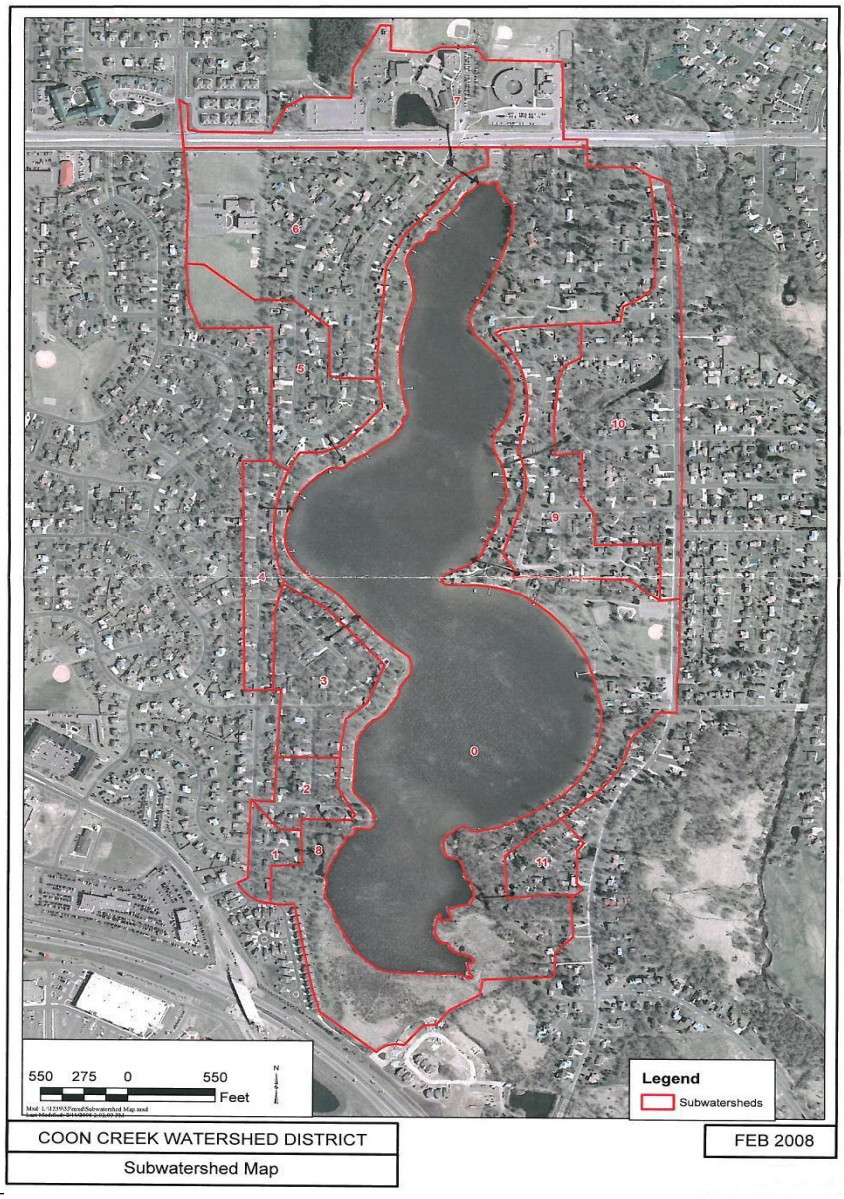
3.3 Subwatersheds & Watershed Ratio

The Crooked Lake watershed is approximately 236 acres in size. The ratio of the size of the drainage are to the size of the lake is approximately 2:1

The watershed is comprised of 11 Subwatersheds (Sub WS):

Sub WS	Area (ac)		Sub WS	Area (ac)
1	3.3		7	24.7
2	4.8		8	75.9
3	13.0		9	17.7
4	7.8		10	29.5
5	15.4		11	4.6
6	39.8		**Total Area**	**236**

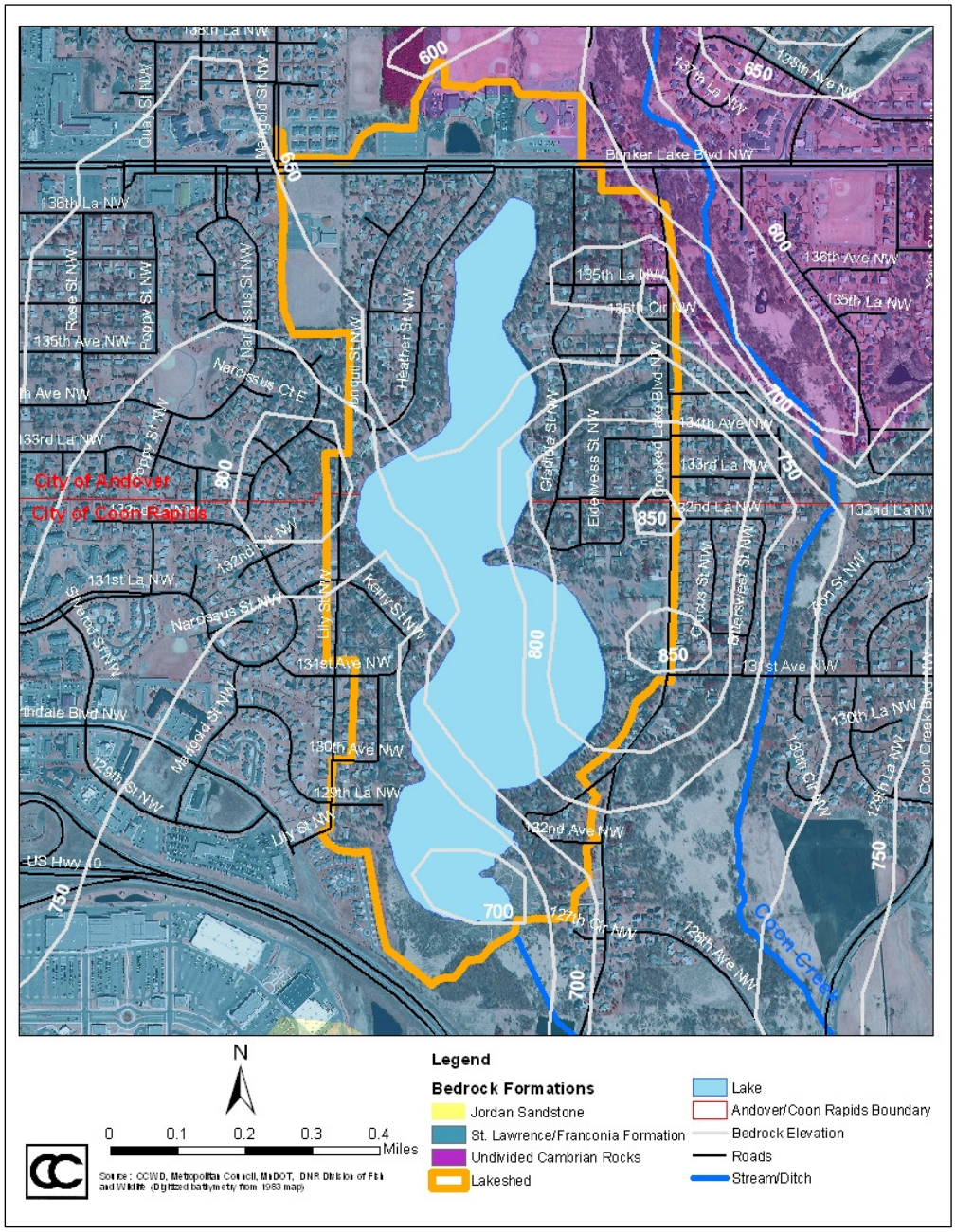
Figure 3.3 Subwatersheds of Crooked Lake



3.4 Bedrock Geology

Bedrock geology of Crooked Lake consists mainly of St. Lawrence and Franconia formations, with a small portion at the northern end of the watershed characterized as undivided Cambrian rock. Crooked Lake lies in an upthrust area between two faults to the northwest and southeast. Bedrock elevation ranges between 650-850 feet above sea level. It is shallowest beneath the surface in the eastern portion of the watershed and deepest in the northern portion of the watershed. (Bedrock Geologic Map and Bedrock Topographic Map of the Seven-County Twin Cities Metropolitan Area, Minnesota Geologic Survey, 1986).

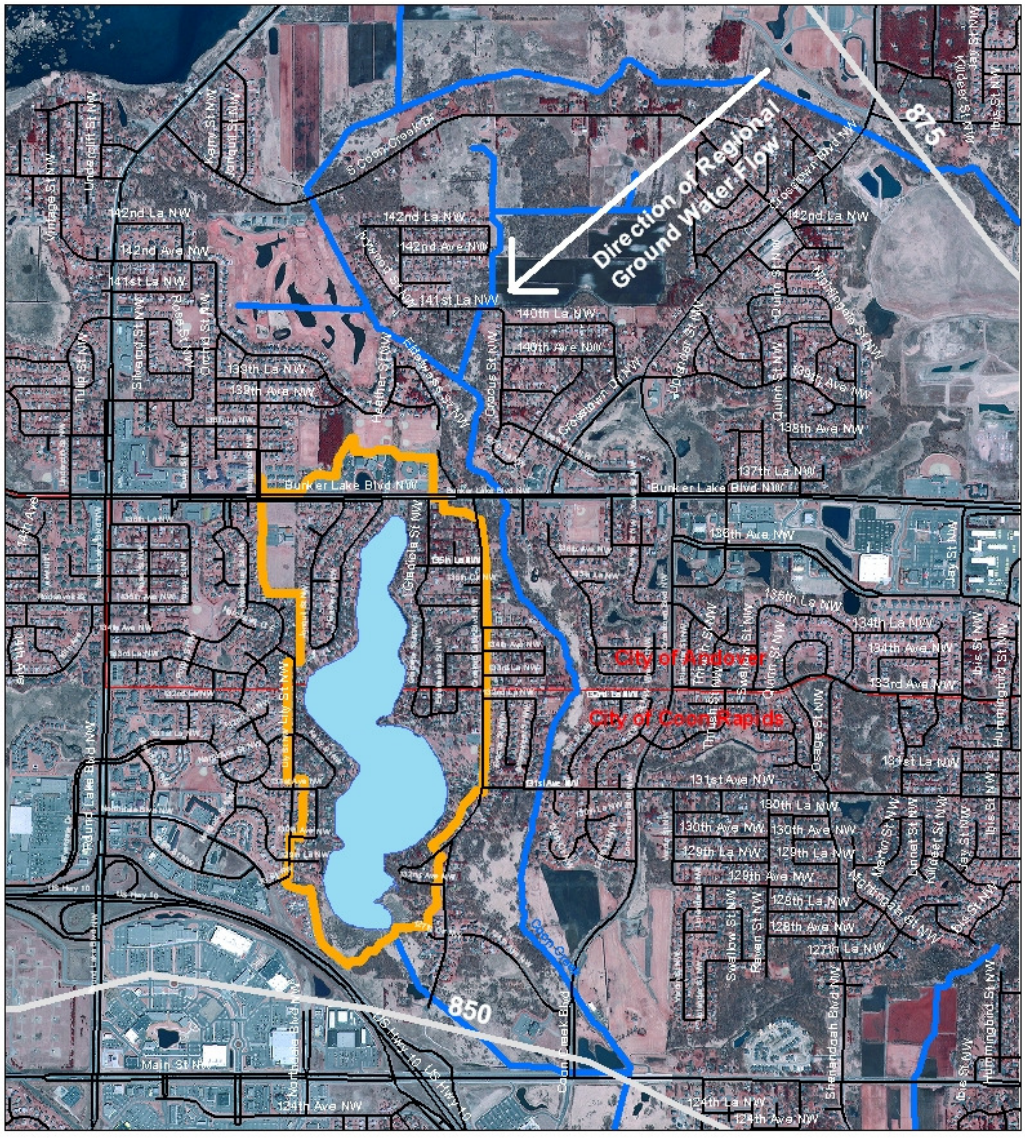
Figure 3.4 Bedrock Geology of Crooked Lake



3.5 Ground Water Levels

Ground water elevations in the Crooked Lake watershed range from approximately 850 to 860 feet above sea level going, respectively, from the extreme southern portion of the watershed in the northeastern portion of the watershed. Ground water generally flows from the northeast to the southwest towards the Mississippi River. Ground water susceptibility to pollution is ranked as very high, with water-borne contaminants at the land's surface taking hours to months to reach the uppermost aquifer. (Anoka Sandplain Regional Hydrogeologic Assessment, MN Department of Natural Resources, 1993).

Figure 3.5 Hydrogeology of the Crooked Lake Area



3.6. Land Use

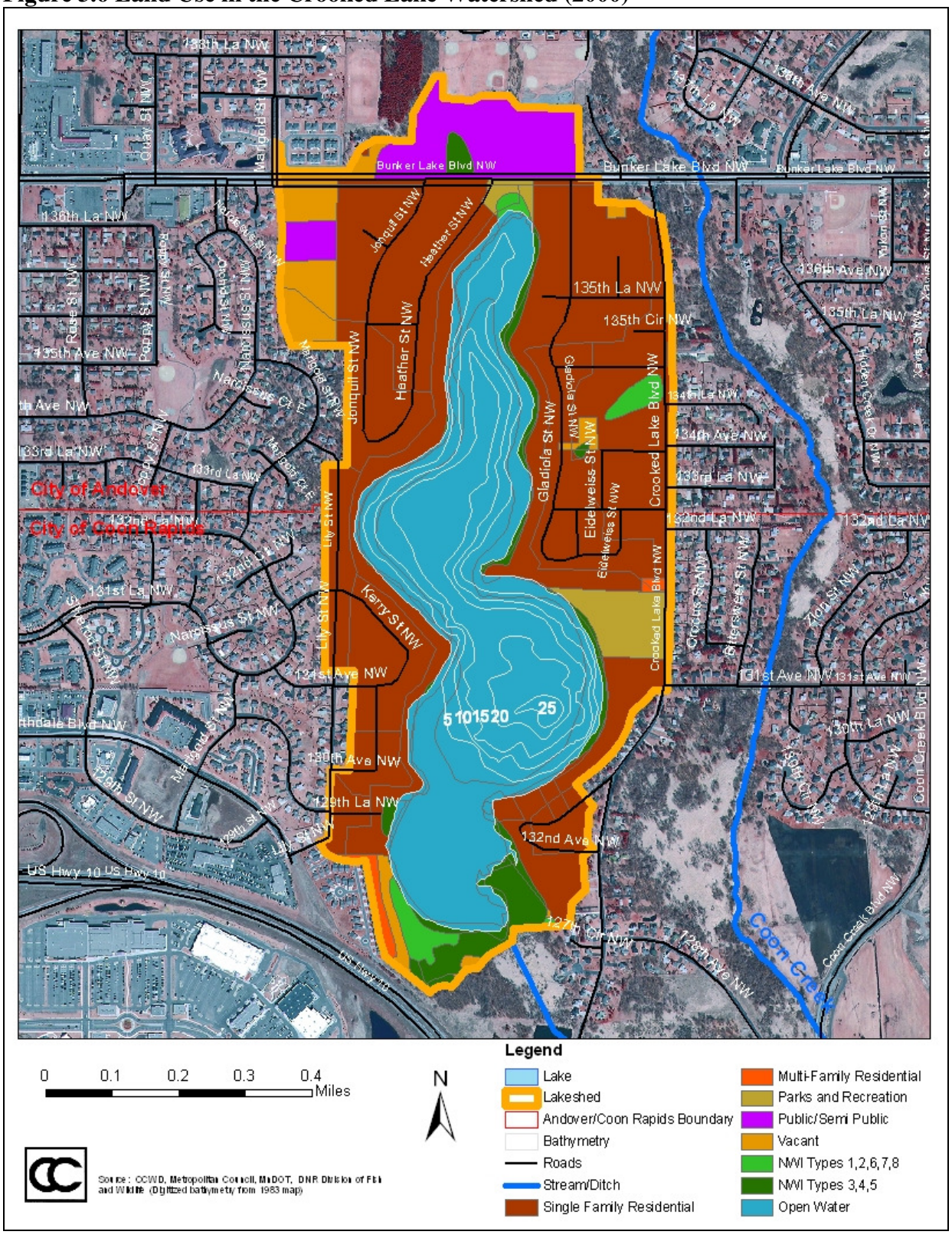
Land use in the Crooked Lake watershed falls into one of eight categories as outlined in Table 3.6 below. The majority of land use (78%) in the watershed is single family residential; mostly detached housing units with the exception of a townhome complex in the southwest part of the lake. Multi-family housing is located north of the Crooked Lake city park; it composes a very small percentage of land use in the watershed.

There are two park areas located in the watershed: the boat landing on the northern shore in Andover, and a city park on the east shore in Coon Rapids. Public/semi-public use include two churches, both in the north in Andover: Riverdale Assembly of God in the northwest area and Meadow Creek church/school complex north of Bunker Lake Boulevard. Parcels of vacant land exist adjacent to Riverdale church in the northwest, adjacent to the townhome development in the southwest, and in the northeast of the watershed near the southern end of the abandoned aqueduct. The remainder of the watershed is composed of wetlands and about one-third is open water (30.1%).

Table 3.6 Land Use in the Crooked Lake watershed (2005)

Land Use	Area (Acres)	Percentage of Total	Land Use Impervious Percentage %	Pervious Curve Number (CN)
Single Family	184.8	78.3%	25	74
Multi-family	2.6	1.1%	70	74
Parks and Recreation	9.6	4.0%	5	60
Public/Semi-public	22.4	9.5%	50	74
Vacant	16.6	7.0%	5	60
	236			

Figure 3.6 Land Use in the Crooked Lake Watershed (2000)



3.7 Hydrologic Characteristics of Crooked Lake

Crooked Lake is sustained by a combination of surface water runoff and ground water inputs. The term "hydrologic cycle" denotes the general circulation of water in various physical states (liquid, solid, gas) from surface water to the atmosphere, from the atmosphere over and through the ground, and back to surface water again. Quantification of the hydrologic cycle is accomplished by developing a drainage basin budget. The parameters of the hydrologic cycle (precipitation, evaporation, transpiration, infiltration, and runoff) are balanced until all of the water entering and leaving the watershed is accounted for.

The budget of any drainage basin may be represented by the equation:

$$P = ET + R + \Delta SMS + \Delta GMS + \Delta DS + GWF$$

$$\text{Lake Level} = R + GWF - P - ET - \Delta SMS - \Delta DS - \Delta GMS$$

where

P = Total precipitation input
ET = Total evapotranspiration loss
R = Total Runoff
ΔSMS = Change in soil moisture storage
ΔGMS = Change in ground water storage
ΔDS = Change in depression storage
GWF = Ground water flux (ground water flow into or out of the drainage basin).

Precipitation

Precipitation in its various forms is the source of all water coming into the watershed. Significant variation in precipitation amounts can occur within the watershed from individual storm events. Precipitation is also highly variable on an annual and monthly basis.

The average annual precipitation in the watershed is 30.6 inches with a normal variation of 28.3 to 34.1 inches. About 70 percent of the annual precipitation, approximately 22 inches, falls between April and September. About 6 inches of precipitation occur on average during the spring ground water recharge period of April and early May. Measurable precipitation of 0.01 inches occurs on about 110 days per year, 4 of which have 1 inch or more.

Annual amounts of precipitation have ranged from a low of 15.56 inches in 1976 to a high of 43.03 inches in 1991 (UM, 1999). The most precipitation occurring in any month was 9.35 inches in June 1975.

Table 3.7.1 Hydrologic condition as a function of annual precipitation

Year	Annual Precipitation	Acre Feet	Hydrologic Condition
2000	27.3	850.9	Dry
2002	36.1	1,125.1	Wet
2003	21.7	676.3	Dry
2005	31.5	981.8	Normal
2006	26.7	832.2	Dry

2007 was 2.53 inches below normal.

Evapotranspiration Loss

Evapotranspiration includes evaporation from all water, soil, ice, vegetative and other surfaces, and transpiration from plants. Evapotranspiration losses can be grouped into three categories:

1. Interception losses
2. Evaporation from undrained basins
3. Evapotranspiration from soil and ground water.

Since no method exists for directly measuring evapotranspiration, it is the most difficult component of the water budget to account for.

Potential Evapotranspiration (PET), the amount of water that would be lost to the atmosphere if water were not limiting, can be estimated using a number of methods. The Thornthwaite equation uses mean temperature and latitude to determine monthly potential evapotranspiration (Thornthwaite, 1955). The estimated annual PET for Crooked Lake is 24.9 inches per year.

Table 3.7.2 Effective Precipitation (Annual Precipitation minus PET)

Year	Precipitation	Effective Precipitation	Acre Feet
2000	27.3	2.4	74.8
2002	36.1	11.2	1,125.2
2003	21.7	-3.2	-99.7
2005	31.5	6.6	205.7
2006	26.7	1.8	56.1
2007	28.8	3.9	121.5

Surface Water Flows into Lake

The drainage area of Crooked Lake is 260 acres in 11 subwatersheds. 75.9 acres flow directly to the lake via overland flow. The remaining 184 acres drains through storm sewer pipes. The 75.9 acres (subwatershed number 8) includes all of the lakeshore property including Crooked Lake Beach Park and the north-northeast neighborhood in the vicinity of 135th Avenue NE. The table below shows the size, pervious curve number, percent impervious and discharge method for each subwatershed:

Table 3.7.3 Subwatershed (Sub WS) Runoff Character

Sub WS	Area (ac)	Pervious CN	Percent Impervious	Discharge type
1	3.3	74	0.26	Pipe
2	4.8	74	0.25	Pipe
3	13.0	74	0.25	Pipe
4	7.8	74	0.25	Pipe
5	15.4	71	0.21	Pipe
6	39.8	71	0.22	Pipe
7	24.7	72	0.26	Pipe
8	75.9	71	0.22	Direct Inflow
9	17.7	74	0.25	Pipe
10	29.5	72	0.23	Pipe
11	4.6	74	0.25	Pipe
Total Area	236			

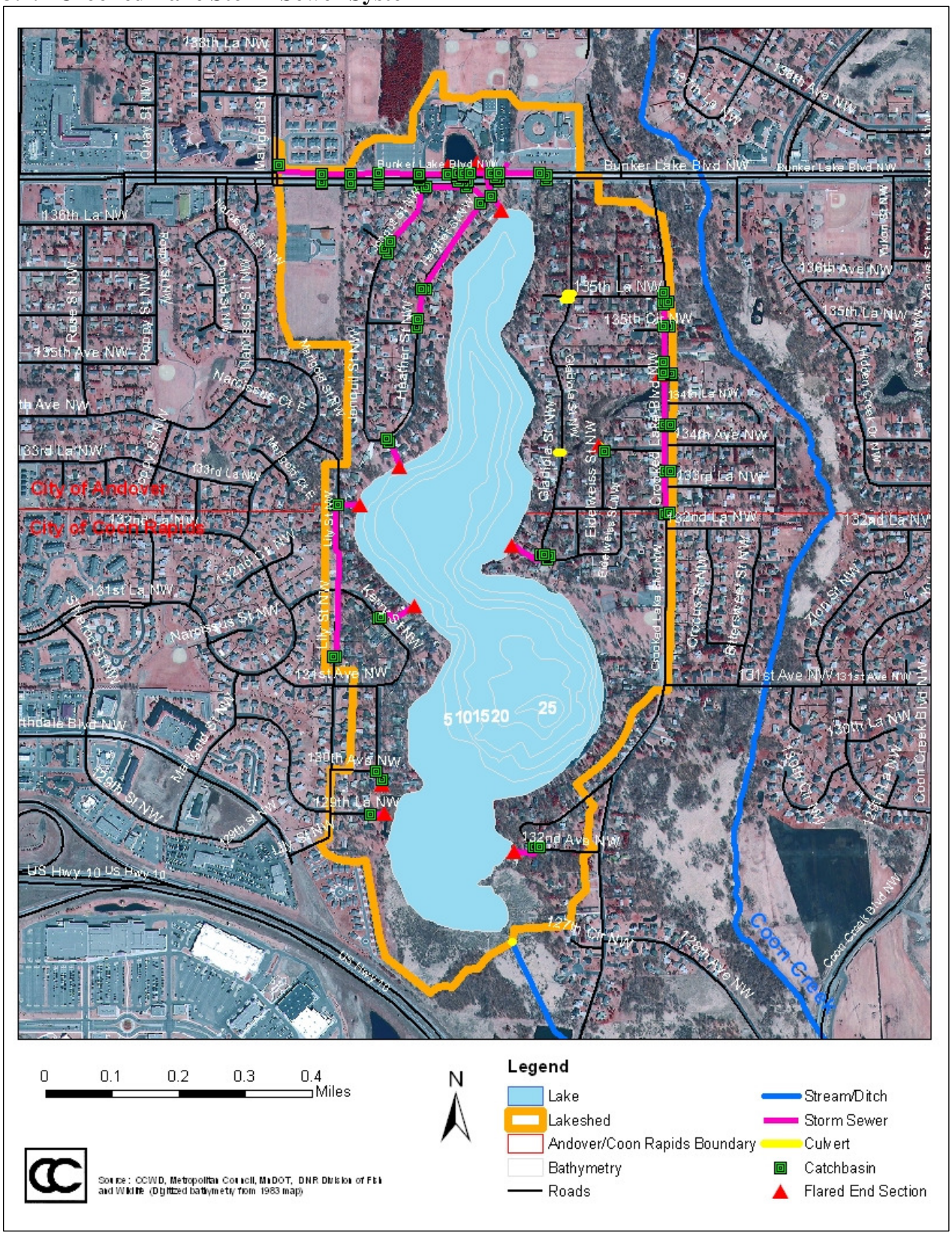
Tributaries and Pipes: Crooked Lake has no natural surface water tributaries. However, there are 2.06-miles of storm sewer from both the City of Andover and Coon Rapids that convey water into the lake.

Eighty-four catch basins (71 in Andover and 13 in Coon Rapids) direct street runoff into the storm sewer system. Eight stormwater outfalls are located at various locations around the lake (three in Andover and five in Coon Rapids). In addition, remnants of an historic aqueduct are still discernable in a neighborhood in the northeast portion of the watershed. The aqueduct was once used to direct water from Coon Creek to Crooked Lake for augmenting lake levels but was disconnected due to poor water quality in Coon Creek. Storm water still enters the lake in this area via overland flow through a culvert under Crooked Lake Boulevard. There is one surface water outlet to the lake via a culvert in an earthen dam in the southern end of the lake.

3.7.4 Annual Inflow to Crooked Lake

Year	Annual Inflow (ac-ft)		Year	Annual Inflow (ac-ft)
2000	131		2005	154
2002	202		2006	154
2003	102			

3.7.1 Crooked Lake Storm Sewer System



Soil Moisture Storage

Soils in the watershed of Crooked Lake are mainly of the Hubbard-Nymore association. These soils are formed in outwash sands and are characterized by nearly level to gently sloping, excessively drained soils that are sandy throughout. Organic content is typically low and water table at a depth of more than 6 feet. Due to this low water capacity, soils are prone to doughtiness and wind erosion. Soils in this association are within the C or D hydrologic group and are found mainly along the shores of Crooked Lake or adjacent to the marshy areas in the southern part of the watershed. Soils in the A and B hydrologic group are found higher up in the watershed.

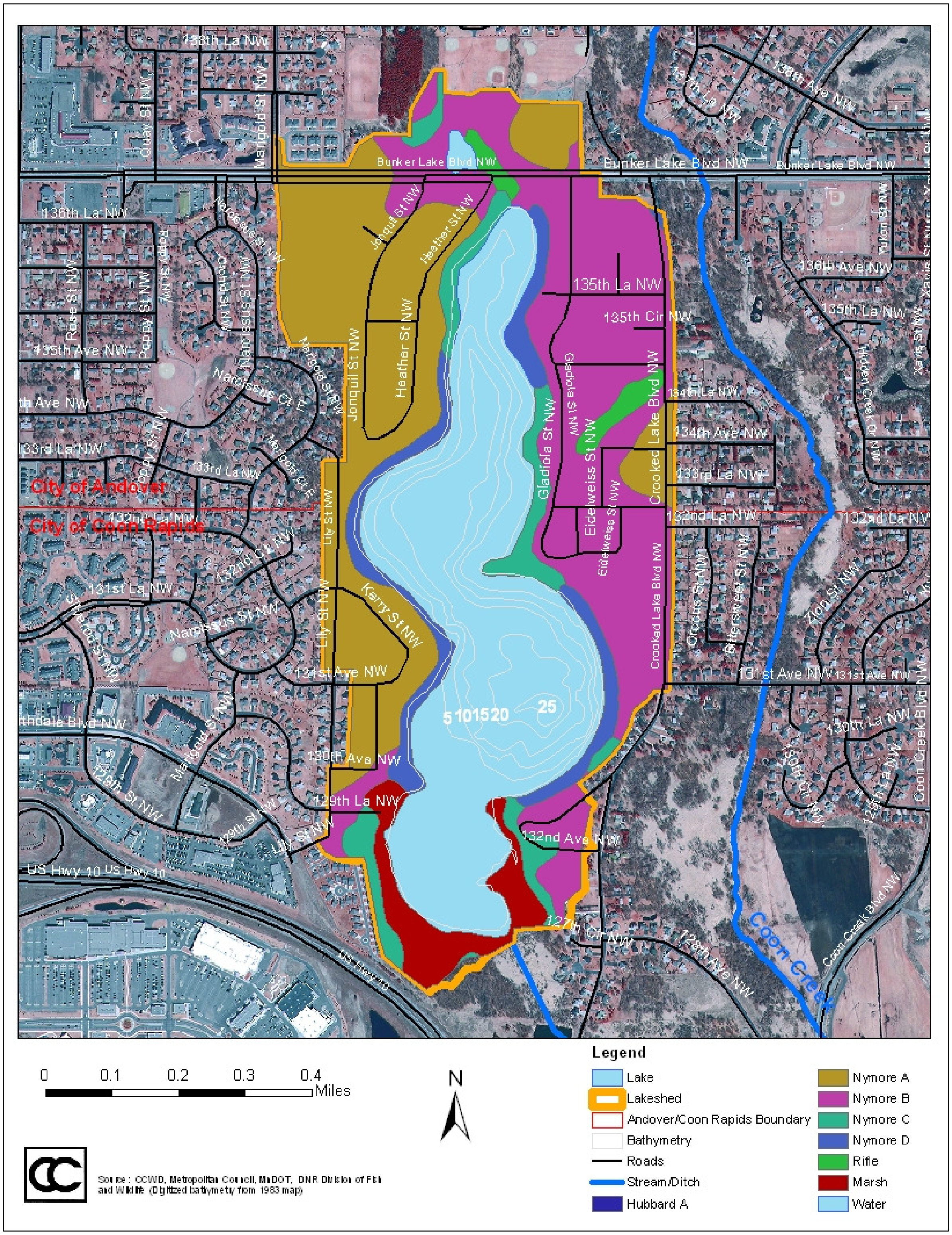
There are two areas of Rifle soils in the watershed, one is in the area of the abandoned aqueduct and the other straddles Bunker Lake Blvd. between the lake and a stormwater pond to the north. It is characterized by level, very poorly drained soils formed in organic material. It has a very high available water capacity and organic content, and the water table is very close to the surface.

Seventy-five percent (194 acres) of the soils surrounding Crooked Lake are excessively well drained (Hydrologic Groups A & B). However, because the area is fully developed and soils are fully compacted, runoff is much higher than on undeveloped A and B soils.

Table 3.7.5 Soils of Crooked Lake

Soil Name	Hydrologic Group	Soil Type	Slope	Size (Acres)
Hubbard	A	coarse sand	0-2%	<0.1
Nymore	A	loamy sand	0-2%	91.06
	B	loamy sand	2-6%	103.0
	C	loamy sand	6-12%	29.1
	D	loamy, coarse sand	12-25%	19.5
Rifle	D	mucky peat	0-1%	5.1
Marsh	unclassified	unclassified	0-1%	14.5
Open Water	unclassified	unclassified	unclassified	120.4

3.7.2 Crooked Lake Soils



Ponding and Depression Storage
Depression storage includes ponds and wetlands in addition to small depressions that fill with and hold water during and after rainstorms. The Crooked Lake watershed includes two ponds:

Church Pond is approximately 2.5 acres in size when full. This pond collects all runoff from Subwatershed 7 which is basically Bunker Lake Boulevard and the properties north. The pond contains 4.5 acre feet of live storage.

Aqueduct Wetland areas, adjacent to the aqueduct in the north east quadrant of the lake, provide some storage.

A 14.5-acre marsh is mapped at the southern end of the lake. Marshes are characterized as level shallow ponds or lakes where water is 1-3 feet deep for most of the year.

The remainder of the area is the open water of Crooked Lake itself. The soils are not characterized in this area.

Ground Water Storage
Best available information indicates that historical ground water levels in the immediate vicinity of Crooked Lake were probably at an elevation of approximately 859; they are now at approximately 850. This elevation is approximately 10 feet below much of the shoreline and 11 feet below the lake outlet. Ground water generally flows from the northeast to the southwest towards the Mississippi River (Anoka Sandplain Regional Hydrogeologic Assessment, Minnesota Department of Natural Resources, 1993).

It should be noted that ground water levels may fluctuate three to five feet per year and are the most significant determinant of the influence and effluence of ground water on surface water (Moering, 1993). These fluctuations are believed to be largely the result of plant, particularly tree, transpiration, but also have long-term climatic and anthropogenic dimensions as well.

Ground Water Flux
Observed values for the permeability of natural soils is approximately 230 feet /day for sands. Thus, the Anoka Sandplain Surficial aquifer possesses high flow-rates within the context of ground water. Flow rates will decrease when ground water encounters either surficial water bodies or other materials in the substrata. They will also decrease as ground water levels decrease because of the decrease in back pressure or head.

3.8 Lake Levels

The level of Crooked Lake is ultimately controlled by an earthen structure at the south end of the lake. The structure, built in the late 1930s, contains a 36-inch corrugated metal pipe set at an elevation of 860.3. The pipe has a board placed in front of it with a top elevation of 862.3. The top of the dam is at 863.4 (CCWD, 2008).

A 1972 study indicated that Crooked Lake is in fact an extension of the shallow ground water table (Hickok & Associates, 1972). This appears to be a reasonable conclusion given the lake substrata, and it explains, in part, the annual fluctuation in lake levels. Average lake levels appear to have fallen approximately one foot in the last five years. This appears to correspond with decreases in surficial aquifer levels throughout most of the Anoka Sand Plain.

Table 3.8 Annual Crooked Lake Levels

	Average	Min	Max	Range (Ft)
2003	860.98	860.17	861.57	1.40
2004	860.27	859.99	860.75	0.76
2005	860.23	859.68	860.51	0.83
2006	860.54	860.10	860.92	0.82
2007	860.35	859.68	860.86	1.18
2008	860.75	859.96	861.24	1.28

Highest recorded: 861.94 ft (05/16/1986)
Lowest recorded: 858.54 ft (08/29/1988)
Recorded range: 3.4 ft
Average water level: 860.76 ft
Last reading: 861.02 ft (4/29/2008)
Ordinary High Water (OHW) elevation: 862.1 ft

Figure 3.8 Crooked Lake Levels