Lake to Groundwater Interaction Study

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1.0 Background and Purpose of Study

The Chisago Lakes Lake Improvement District (CLLID) is situated in a hydrologically complex setting. There are approximately 22 lakes within the district boundaries (Figure 1). The largest lakes in the district border the western edge of the CLLID, along both sides of Highway 8. These western border lakes are connected through either open channels or pipes allowing water to flow between the lakes during high flow events. The lakes within the CLLID Boundaries are shown in Figure 1.

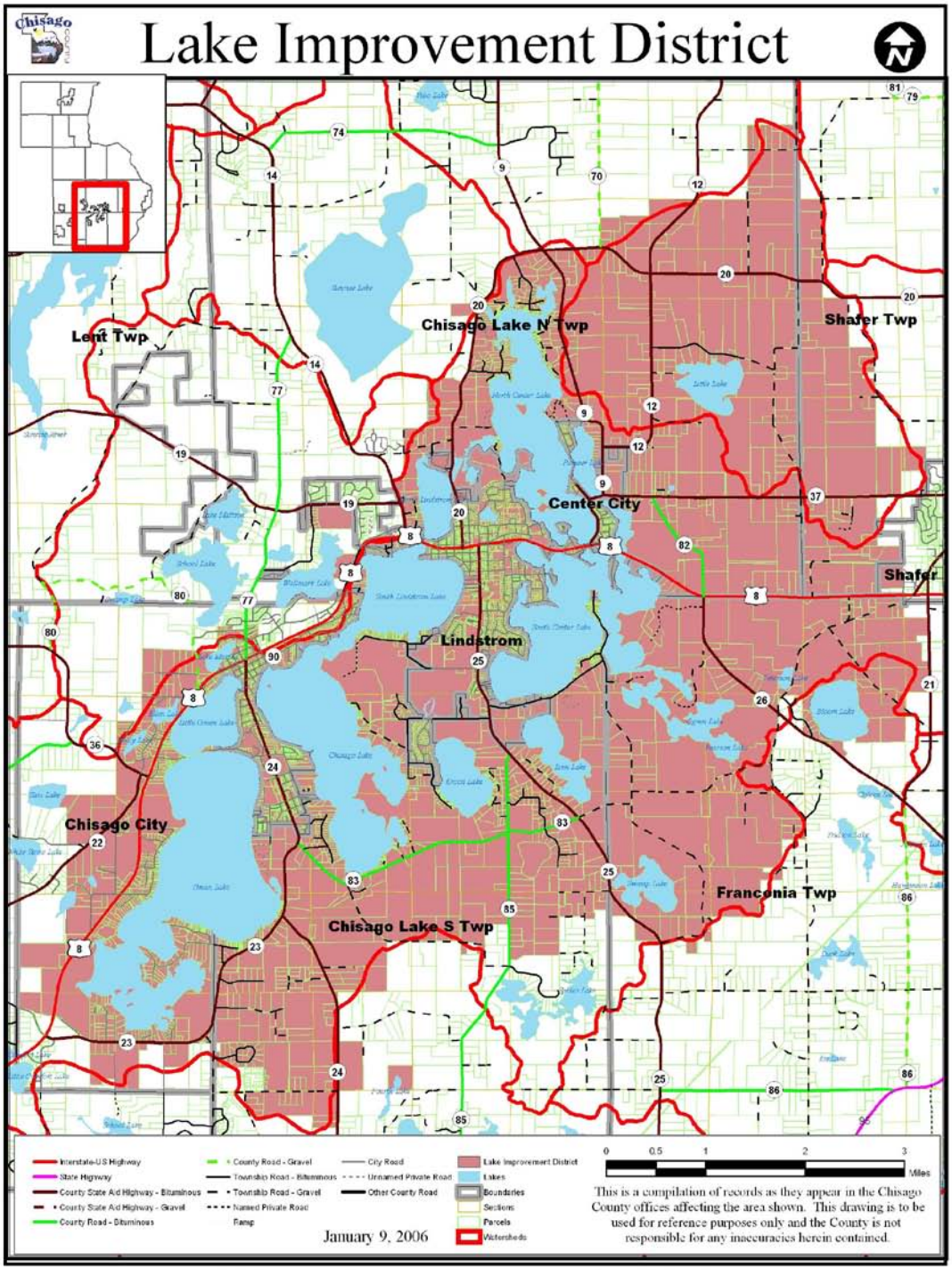
Surface water drainage within the CLLID is generally to the northwest. Water flows out of the district's lake system at the outlets of Lake Ellen and Wallmark Lake. From these locations, during high flow events, water flows from the lake system to Sunrise River through streams, other lakes, and wetlands.

Studies have been conducted in the past on the large western lakes within the Chisago Lakes system. In 1998 an XPSWMM model was created to analyze flows and storage within this lake system. This modeling was updated in 2004 for work associated with the Lofton Avenue weir. One finding from this modeling was that there were water losses occurring from the lake system that could not be explained through evaporation or surface flow. It was suspected that the water losses from the system were related to groundwater flows.

From 2004 to 2007, water quality sampling and testing was initiated and organized by the Chisago-Lindstrom Lake Association with assistance from the Center Lakes Association. After review of testing results, the Minnesota Pollution Control Agency (MPCA) declared North and South Center Lakes, Wallmark Lake, and Kroon Lake as "impaired" due to phosphorous content. In light of the impairment declaration, the CLLID has commissioned the development of a Soil and Water Analysis Tool (SWAT) model. This model will serve as a tool to identify phosphorous pollution hotspots (subwatershed sources) and to prioritize projects within the boundaries of the district.

In the upcoming SWAT modeling efforts, as for previous studies, subsurface flows will factor into the development of a water budget. While estimates can be made of the effects of groundwater losses on the water budget of the lakes system, this Groundwater Study was undertaken to confirm and quantify these losses. The results of this study document our better understanding of lake water-groundwater interactions in the CLLID, and will improve the quality of the results of the SWAT modeling.

Figure 1
District Boundaries



Chisago Lakes Groundwater Study
District Boundaries
Figure 1

2.0 Area Geology and Hydrogeology

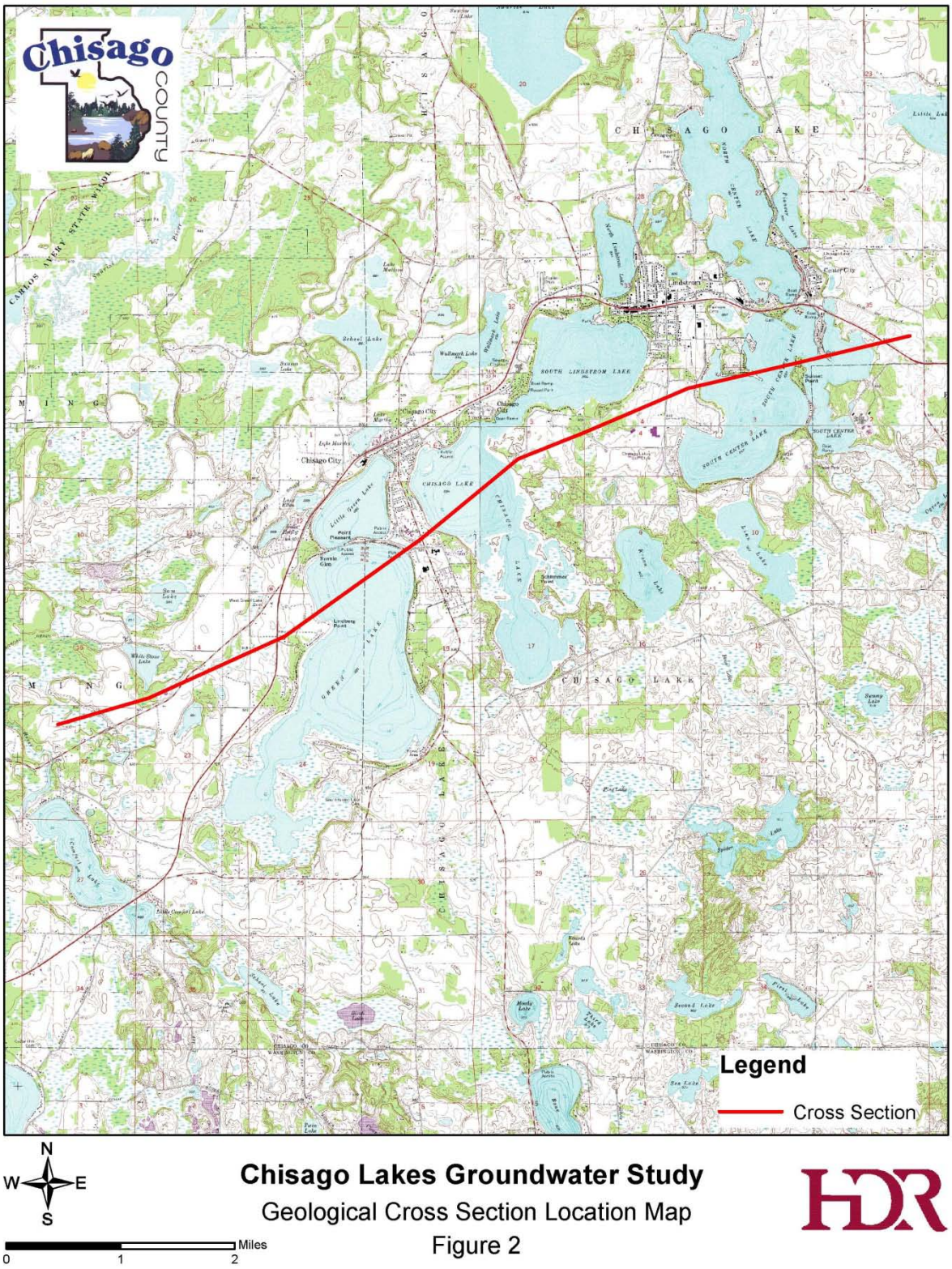
The soil in the Chisago Lakes area is comprised of glacial deposits of Late Wisconsinian age (10,000 to 35,000 years before present). The deposits are a complex mixture of glacial till, lacustrine sand, and coarse-grained fluvial outwash from multiple glacial advances and retreats across the area. The last glacial advance was the Grantsburg sublobe of the Des Moines lobe, which moved northeast across the area and incorporated material previously deposited by the Superior lobe (Meyer and others, 1990). Grantsburg sublobe sediment is described as unsorted, yellowish-brown to gray, loamy texture, with pebbles, cobbles and boulders (Meyer and Lusardi, 2001). Superior lobe sediment is described as unsorted, reddish-brown to reddish-gray, sandy texture, with pebbles, cobbles and boulders. The sediment from each glacial advance is intermixed with sand which was deposited in lakes formed when the Grantsburg sublobe stalled out.

Insight can be gained on the geology of an area by reviewing the logs created by well drillers. The logs contain information about the soil types (or rock) encountered at various depths. The Minnesota County Well Index contains the log data from over 340,000 wells that have been drilled in the State.

A review was conducted of the driller's logs in the vicinity of the Chisago Lakes area. These logs indicate that bedrock occurs generally 200-300 feet below ground surface (bgs). The uppermost bedrock encountered in the logs is sandstone and shale of the Franconia Formation. A variety of soil layers are present above the bedrock. In order to visualize the relationship of the various soil layers in relation to the position of the lakes, a geologic cross section was created. The location of the cross section is shown in Figure 2. The cross section is shown in Figure 3.

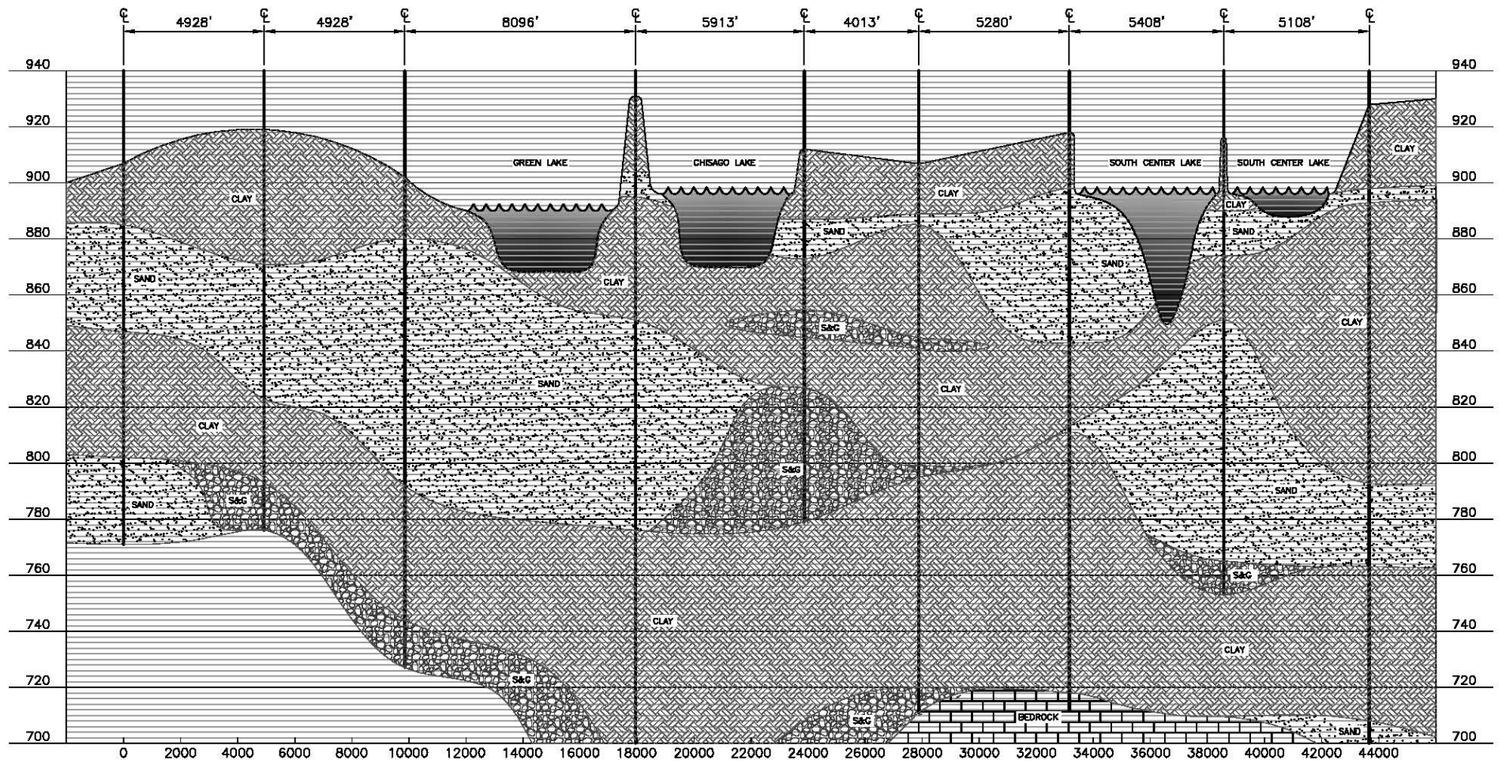
Based on well logs in the County Well Index, groundwater in area wells ranges from approximately 10 to 60 feet bgs, depending on which geologic layer the well screen or borehole intersects. Shallow groundwater flows mostly in a horizontal direction towards low points such as the Sunrise River, and roughly parallel to the ground surface. Static water levels in shallow wells (less than 50 feet bgs) are generally higher than the wells in deeper aquifers, however, meaning a portion of the shallow groundwater (including lake water) flows naturally downward into deeper geologic layers. This is called a downward vertical flow gradient; it implies that water is more likely to drain out the bottom of the lakes and shallow aquifers, and less likely to be recharged from deeper groundwater below.

Figure 2
Geological Cross Section Map



Chisago Lakes Groundwater Study
Geological Cross Section Location Map
Figure 2

Figure 3
Geologic Cross Section



SCALE: HORIZONTAL 1"=2000'
VERTICAL 1"=20' (VERTICAL EXAGGERATION X100)

NOTE:
1. SEE FIGURES 2 & 8 FOR LOCATION OF GEOLOGIC CROSS SECTION.

LEGEND

- SANDSTONE/ SHALE BEDROCK
- SAND & GRAVEL
- SAND
- CLAY OR TILL
- INFERRED BOUNDARY
- BORING LOCATION
- EXISTING SURFACE

HDR

GEOLOGIC CROSS SECTION

CHISAGO GROUNDWATER STUDY

DATE
April 2008

FIGURE
3

3.0 Survey Methodology

During the winter months, ice coverage on the lakes limits surface inflows and lake evaporation losses. Any changes to lake water surface elevations during this time would be predominantly the result of subsurface groundwater flows.

The following fourteen lakes were monitored as part of the study:

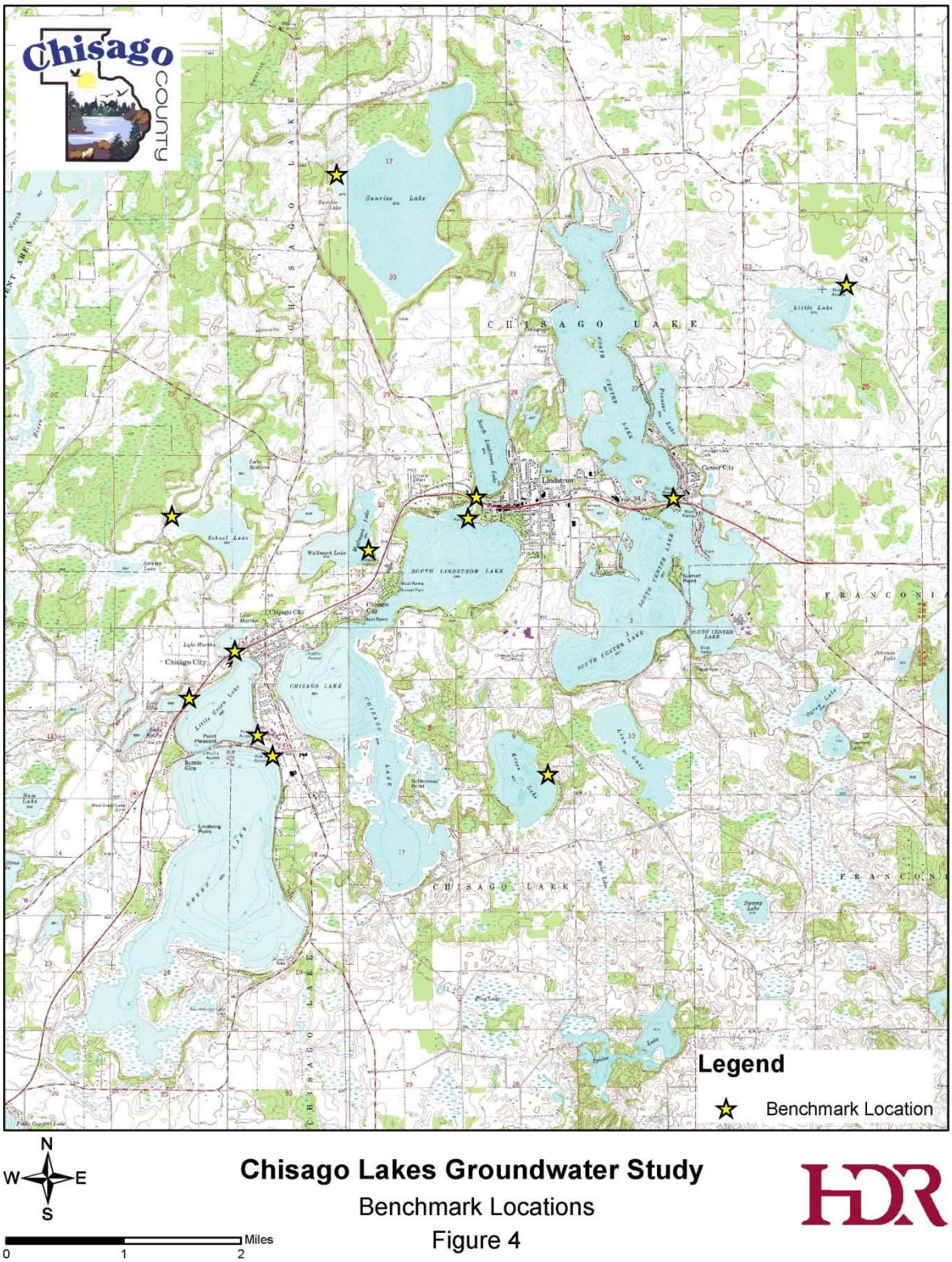
- North Center Lake
- South Center Lake
- Kroon Lake
- North Lindstrom Lake
- South Lindstrom Lake
- Chisago Lake
- Sunrise Lake
- School Lake
- Wallmark Lake
- Martha Lake
- Little Green Lake
- Green Lake
- Little Lake
- Lake Ellen

In order to determine water surface elevations, benchmarks with known elevations were needed in proximity to each lake survey location. A Registered Land Surveyor was used to set benchmarks at each site with GPS equipment. The benchmarks locations and descriptions used for this study are shown in Figure 4.

A standard surveying rod and a tri-pod mounted level were used for determining water surface elevations during site visits every 2-3 weeks. Surveys were performed during two discrete time periods: the winters of 2007-2008 and 2009-2010. For each site visit, all of the lake elevations were determined within a 5-6 hour time period. In order to perform survey measurements, the following steps were followed:

1. A hole was drilled through the lake ice with an ice auger approximately 100 feet from the benchmark on the shore.
2. A tri-pod and level were set up approximately half way between the benchmark and the cored hole.
3. The base of a survey rod was held on the surface of the water in the hole.
4. Using the level, survey readings were taken on the survey rod and the benchmark.
5. The survey readings were entered into a tracking spreadsheet to calculate the water surface elevation of the lake.

Figure 4
Benchmark Locations



4.0 Survey Results

2007-2008 Survey Results

A total of seven biweekly surveys were performed over a fourteen week period in the winter of 2007-2008. The detailed survey data is provided in Appendix A. Summarized results of the survey are provided in the following figures: Figure 5 shows the actual lake water surface elevations over the course of the study in 2007-2008; Figure 6 shows the change of water surface elevations for all lakes over the course of the study in 2007-2008 in relation to the water surface elevation on the date of the first survey;

From review of the tables and figures, the following conclusions can be drawn:

1. Of the 14 lakes surveyed, 5 lakes (Kroon, School, Wallmark, Little, and Ellen Lakes) maintained relatively steady water surface elevations. Water surface elevations within these lakes stayed within 0.12 feet (1.5”) of the elevation on the date of the first survey.

2. Two of the lakes surveyed (Martha and North Lindstrom) experienced significant fluctuations (positive and negative) in elevation. North Lindstrom ended the winter with a significant total net loss, while Martha and up having relatively little overall change from the elevation on the date of the first survey.

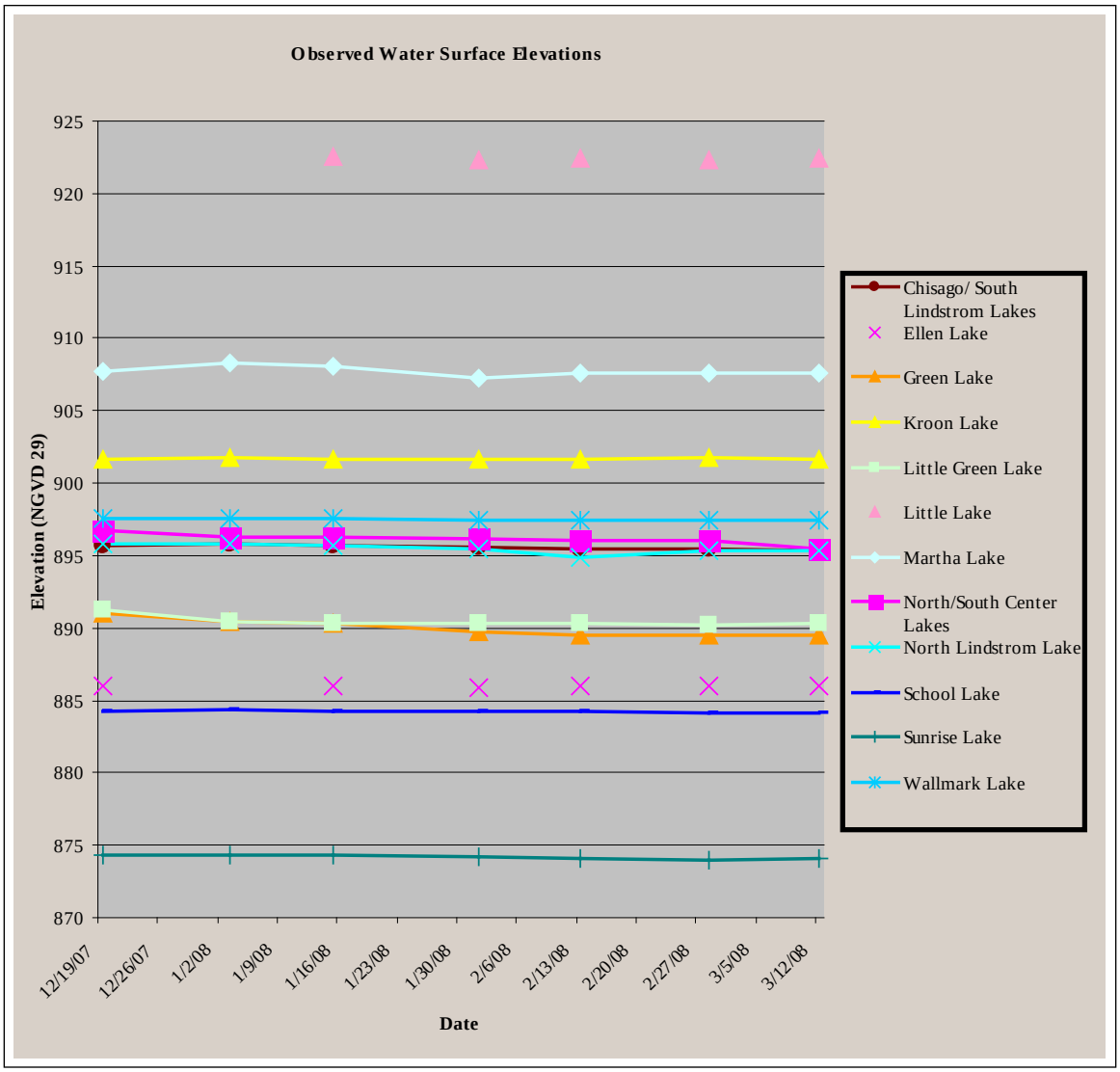
3. The remaining 7 lakes (North and South Center, South Lindstrom, Chisago, Sunrise, Little Green, and Green Lake) experienced significant and measurable losses throughout the duration of the study.

In total, there were 8 lakes with significant net water losses over the duration of the study in 2007-2008 (the 7 lakes listed in conclusion 3 and North Lindstrom from conclusion 2). These 8 lakes were studied further to determine how the elevation changes translated to lake volume losses. DNR contour data for the lakes was used to determine the surface area of the lakes. The lake surface areas were multiplied by the change in water surface elevation in order to estimate water volume losses from each of the lakes. Figure 7 shows the change in volume for the lakes that experienced significant total losses over the course of the study in 2007-2008. Table 1 shows the values of loss, over the course of the winter of 2007-2008, for each lake.

Table 1
2007-2008 Cumulative Lake Volume Loss

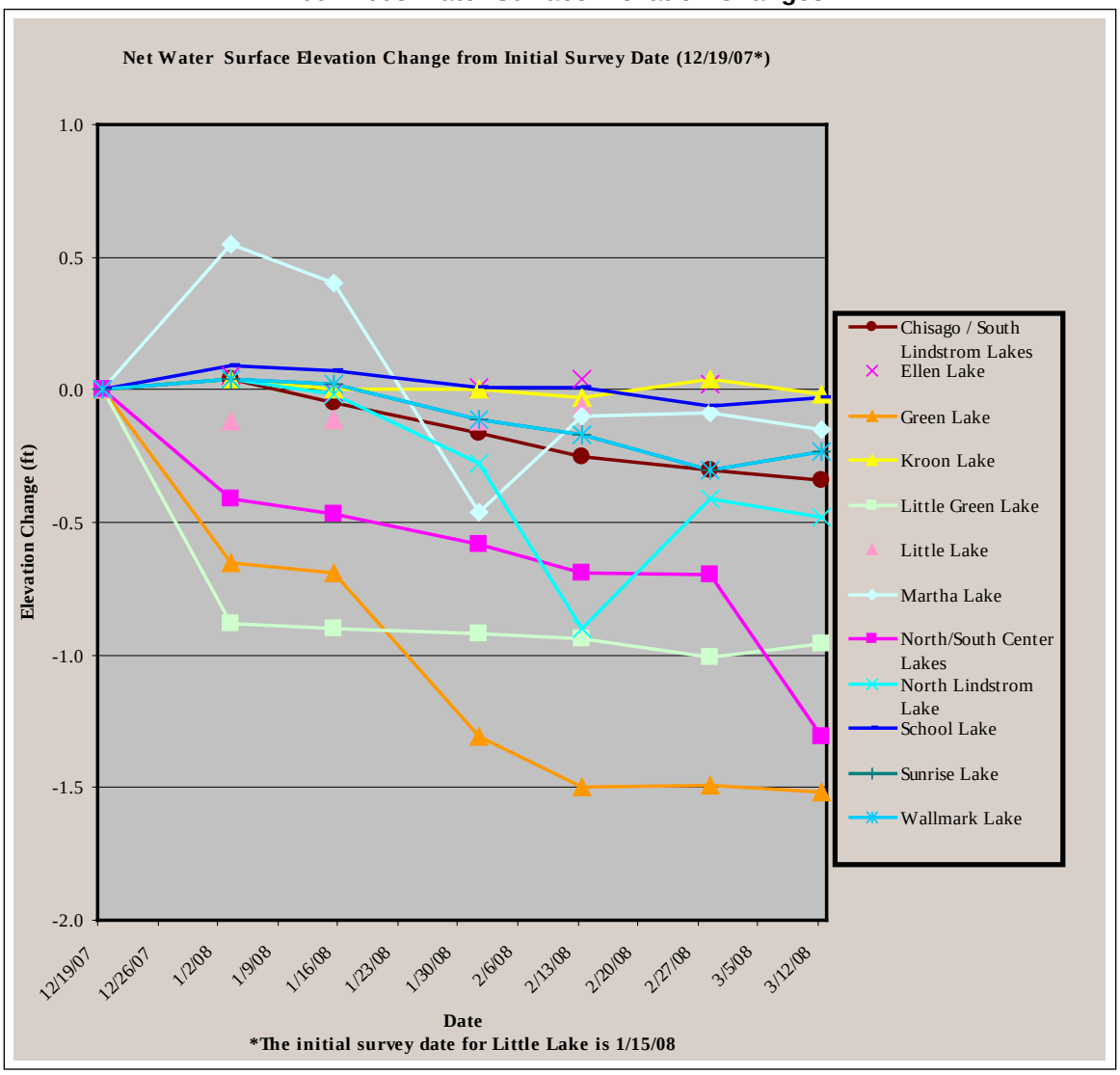
Lake	Total Water Loss (acre-feet)
Chisago Lake	306
Green Lake	2423
Little Green Lake	216
North Center Lake	1014
North Lindstrom Lake	68
South Center Lake	1171
South Lindstrom Lake	186
Sunrise Lake	184

Figure 5
2007-2008 Observed Water Surface Elevations



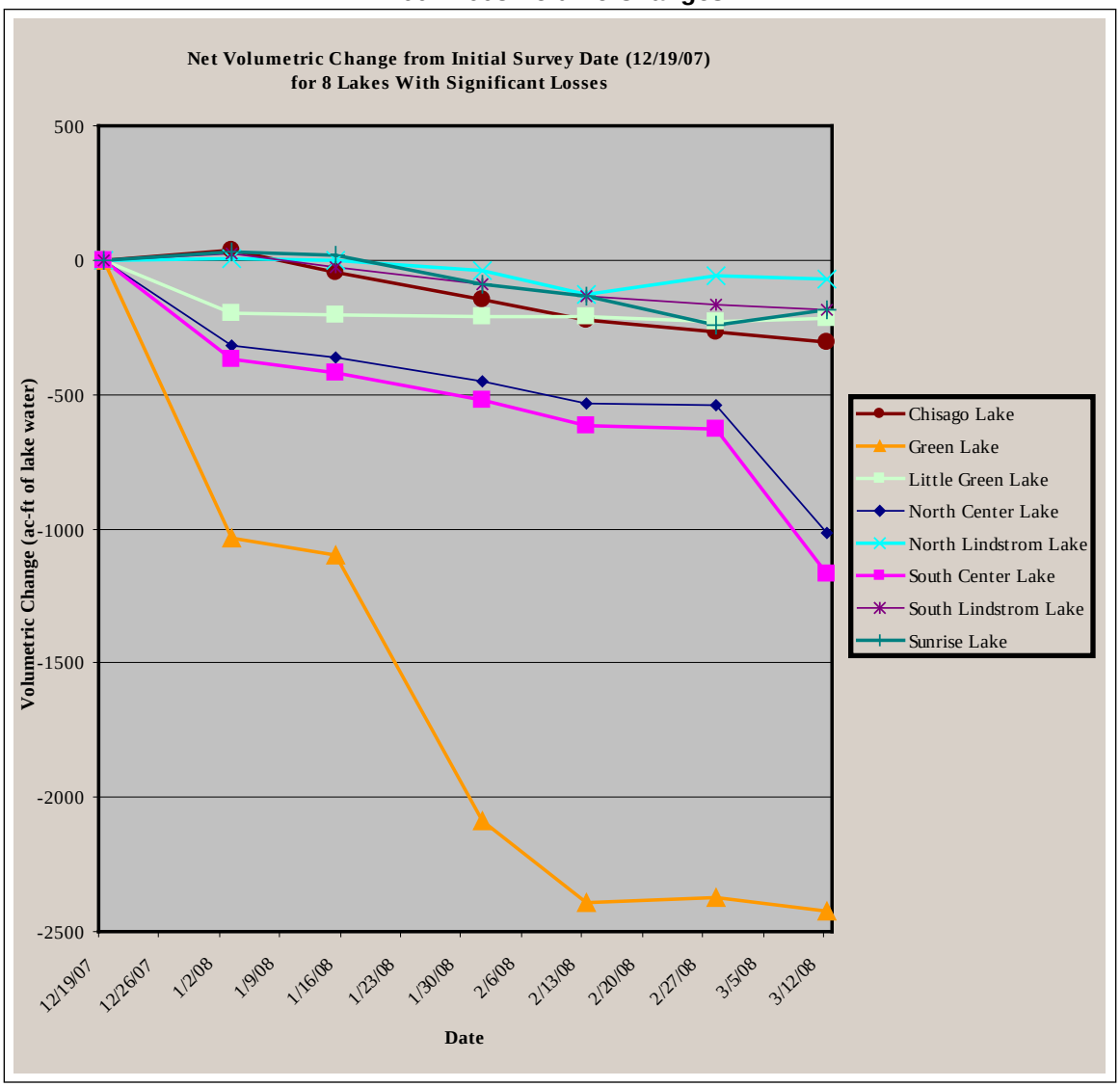
All elevation changes are relative to the lake elevations surveyed on 12/19/2007.

Figure 6
2007-2008 Water Surface Elevation Changes



Green Lake and Little Green Lake were connected during the duration of the study. The connection, however, was limited to a narrow shallow area. Due to the small size of the connection, it is thought that water was flowing from Little Green Lake to Green Lake, but the rate of flow was not sufficient to allow the water surface elevations of the two lakes to equalize.

Figure 7
2007-2008 Volume Changes



North and South Center Lakes were connected at the time of survey and as a result had the same water surface elevations. For this reason, these lakes are combined in Figures 5 and 6 (shown as a single line). Because of the different sizes of North and South Center Lakes, a similar drop in each lake results in different volume changes in each of the two lakes. For this reason Figure 7 shows the lakes separately.

2009-2010 Survey Results

A total of four surveys were performed over a nine week period in the winter of 2009-2010 every 2-3 weeks. The detailed survey data is provided in Appendix A. Summarized results of the survey are provided in the following figures: Figure 8 shows the actual lake water surface elevations over the course of the study in 2009-2010; Figure 9 shows the change of water surface elevations for all lakes over the course of the study in 2009-2010 in relation to the water surface elevation on the date of the first survey.

From review of the tables and figures, the following conclusions can be drawn:

1. Of the 14 lakes surveyed, eleven (North and South Center, Kroon, Sunrise, School, Wallmark, Martha, Little Green, Green, Little, and Ellen)maintained relatively steady water surface elevations. Water surface elevations within these lakes stayed within 0.12 feet (1.5”) of the elevation on the date of the first survey.

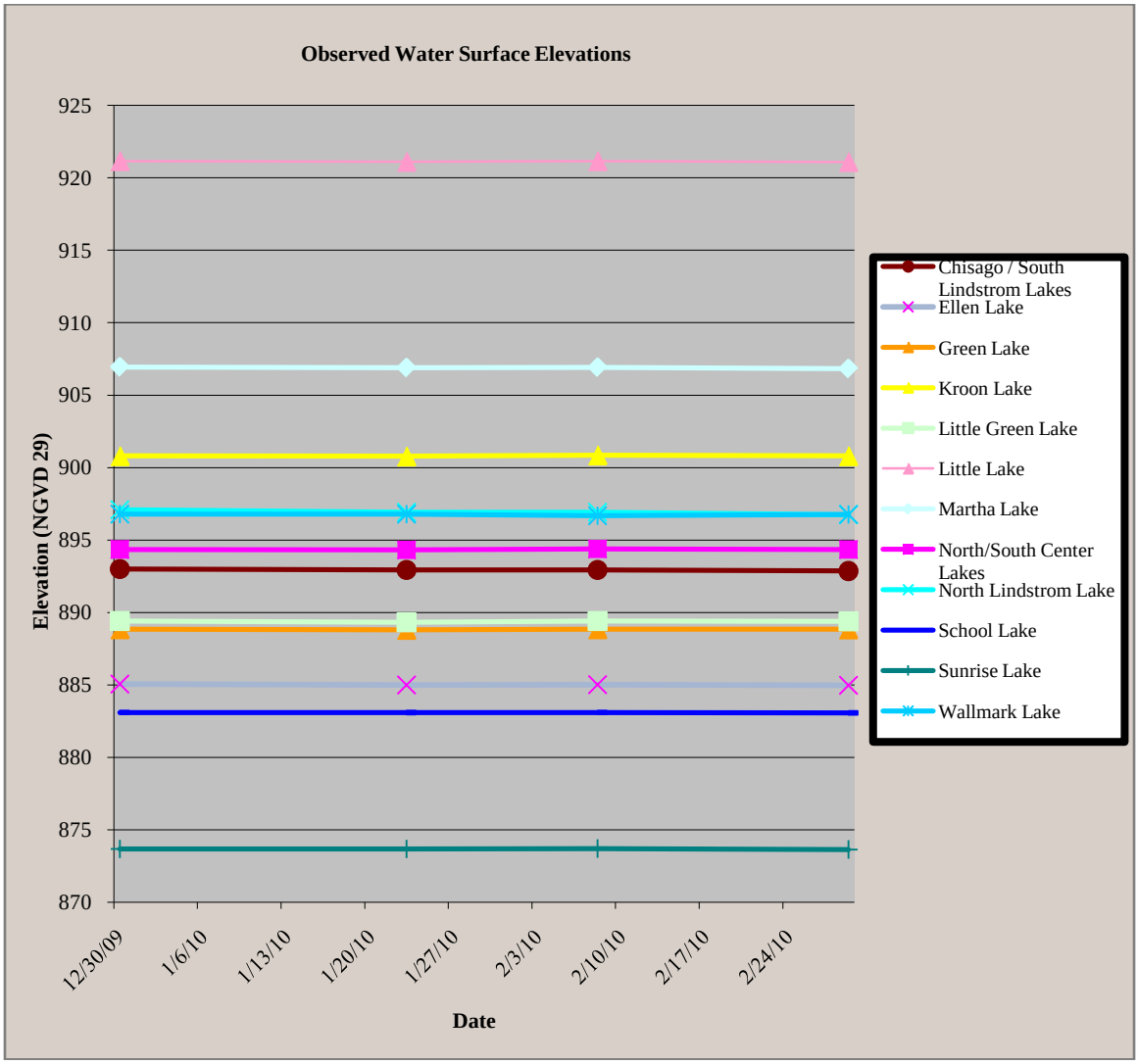
2. The remaining 3 lakes (Chisago, South Lindstrom and North Lindstrom Lakes) experienced measurable losses throughout the duration of the study.

In total, there were 3 lakes with measurable net water losses over the duration of the study in 2009-2010 (the lakes listed in conclusion2.. These 3 lakes were evaluated further to determine how the elevation changes translated to lake volume losses. DNR contour data for the lakes was used to determine the surface area of the lakes. . The lake surface areas were multiplied by the change in water surface elevation in order to estimate water volume losses from each of the lakes. Figure 10 shows the change in volume for the lakes that experienced measurable net losses over the course of the study in 2009-2010. Table 2 shows the values of loss, over the course of the winter of 2009-2010 for each lake.

Table 2
2009-2010 Cumulative Lake Volume Loss

Lake	Total Water Loss (acre-feet)
Chisago Lake	130
North Lindstrom Lake	48
South Lindstrom Lake	80

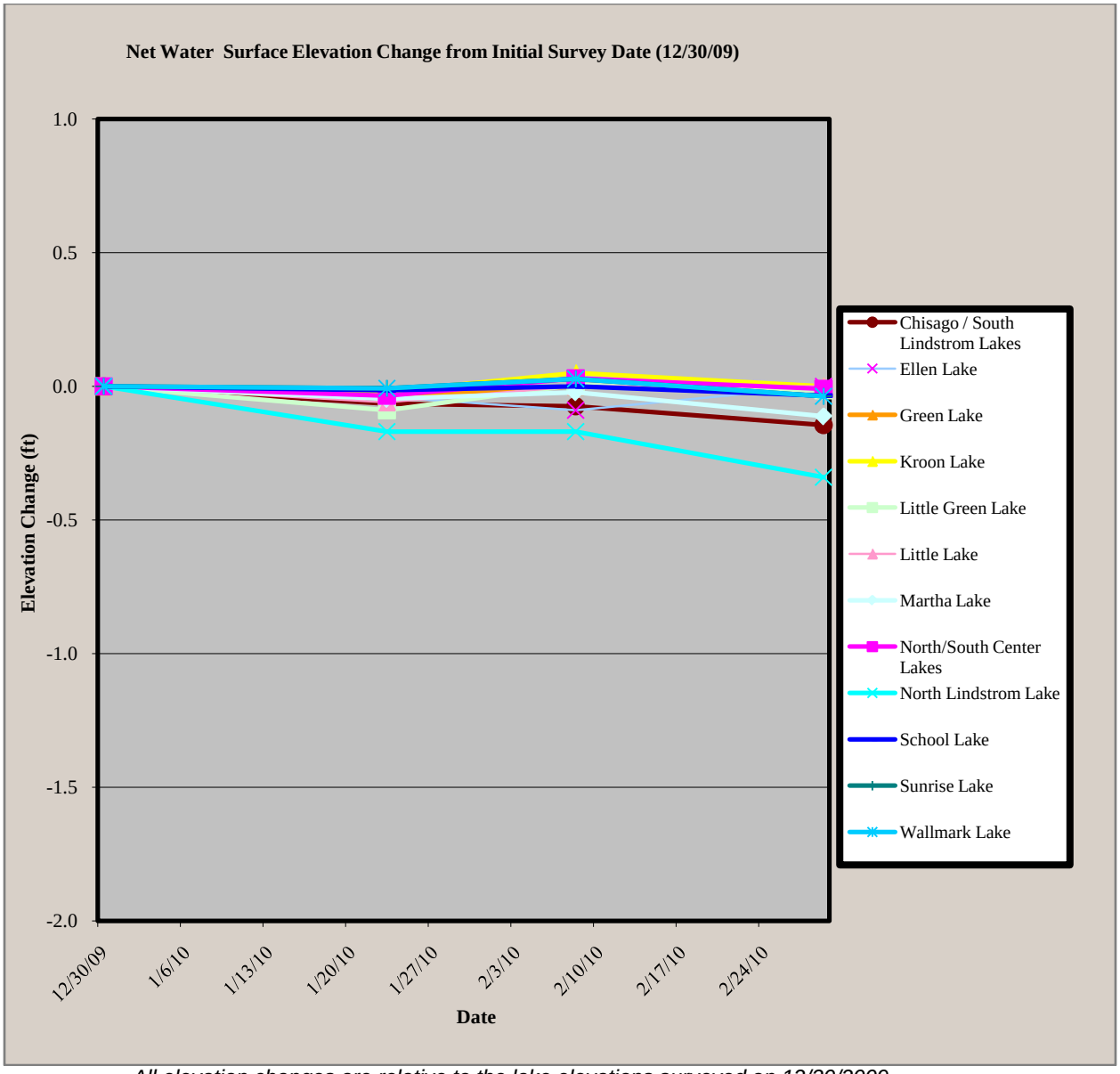
Figure 8
2009-2010 Observed Water Surface Elevations



In 2009, a channel was dredged between Green Lake and Little Green Lake. This dredged channel likely increased connectivity between the lakes during the 2009-2010 survey period.

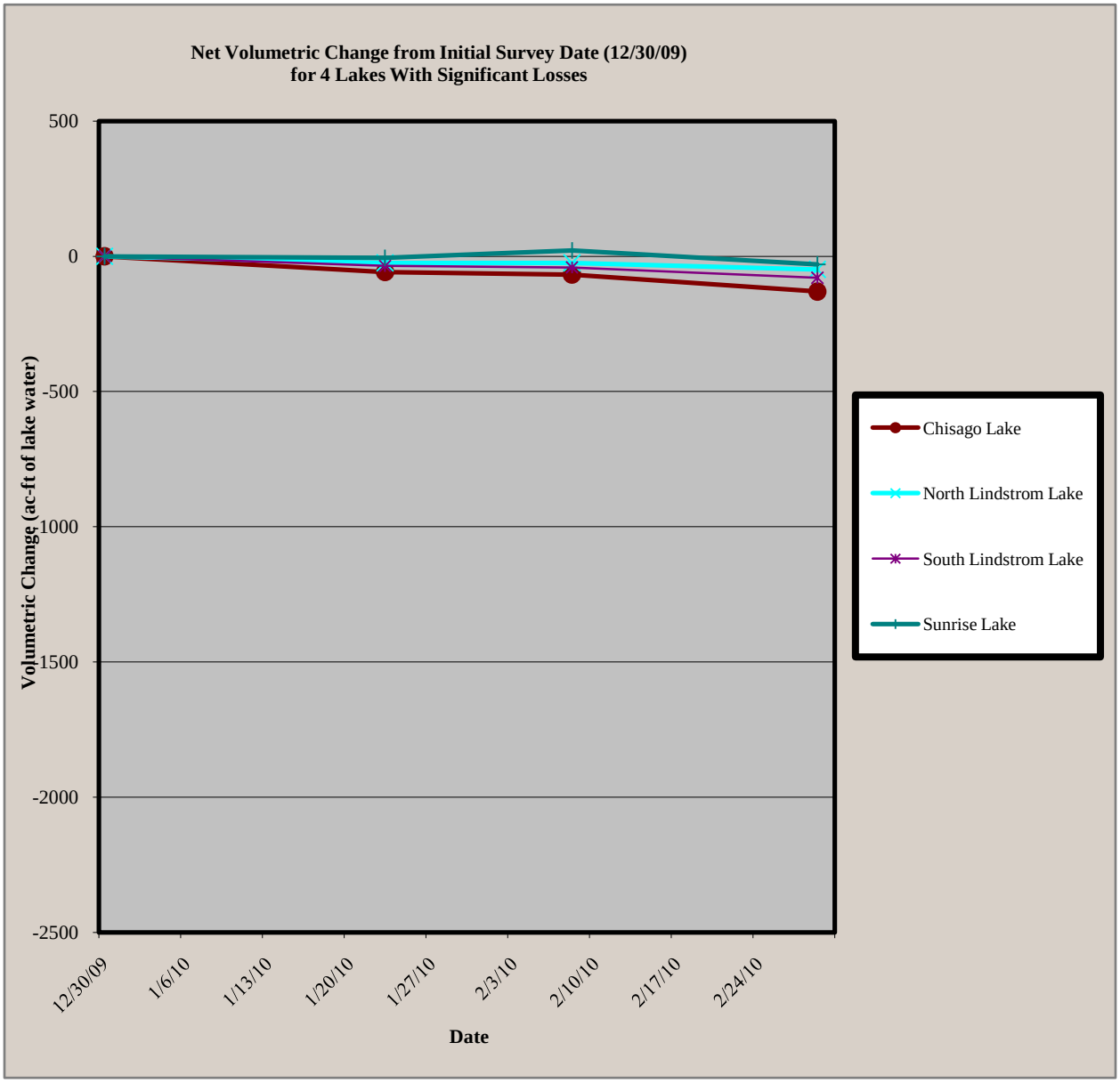
North and South Center Lakes were connected at the time of survey and as a result had the same water surface elevations. For this reason, these lakes are combined in Figures 8 and 9 (shown as a single line).

Figure 9
2009-2010 Water Surface Elevation Changes



All elevation changes are relative to the lake elevations surveyed on 12/30/2009.

Figure 10
2009-2010 Volume Changes



2007-2008/2009-2010 Survey Results Comparison

The 2009-2010 surveys were conducted to evaluate how low lake levels would influence net lake to groundwater losses. Survey elevations taken during 2009-2010 confirm that water levels were significantly lower than during the 2007-2008 period. Mean water surface elevations surveyed in the winter of 2009-2010 were more than 0.5 feet (6.0”) lower than the mean water surface elevations surveyed in the winter of 2007-2008 for the majority of lakes.

The following conclusions regarding volumetric losses between each survey period can be drawn:

- In general, total net volumetric losses over the course of each survey period were much greater in 2007-2008 than in 2009-2010. Eight lakes exhibited significant net volumetric losses in 2007-2008 (Table 1) while only three lakes did in 2009-2010 (Table 2).

- The three lakes surveyed in 2007-2008 with the largest net volumetric losses (Green, South Center, and North Center) exhibited insignificant losses over the survey period in 2009-2010.

- All three of the lakes with measurable volumetric losses observed in 2009-2010 had measurable volumetric losses in 2007-2008.

- The three lakes with the greatest net volumetric losses in 2009-2010 in order of loss from highest to lowest were: Chisago, South Lindstrom and North Lindstrom. The same order was exhibited among the three lakes during the winter of 2007-2008.

5.0 Groundwater Flow Directions

Although the main goal of the study was to confirm the existence of water losses and to quantify these losses where they occur, the data collected during the course of the study was examined (and compared with other publicly available data) to provide insight as to the general behavior of groundwater in the Chisago Lakes area.

In 1990-1993, Palen conducted a study of the shallow groundwater flows within Chisago County. This study involved reviewing water levels in wells, and determining the general direction of groundwater flows. Figure 11 shows the contours developed from the study which represent groundwater elevations. Based on these well levels and contours, Palen was able to draw arrows indicating general groundwater flow directions.

The Palen study determined that the dominant shallow groundwater flow direction in the Chisago Lakes area is north-northwest toward the Sunrise River, with localized deflections towards lakes and other topographic depressions. Potentiometric surface contours from the Palen study indicate a groundwater "divide" that occurs approximately 1 to 2 miles southeast of the Chisago Lakes. The location of this divide is shown in Figure 8. Groundwater on the northwest side of the divide flows generally northwest, through the CLLID to the Sunrise River. Groundwater to the southeast side of the divide flows away from the CLLID and is eventually discharged to the St. Croix River. This groundwater divide has the same location as the divide for surface runoff flows.

The lake water surface elevations recorded through the duration of the study are presented in Appendix A. The 2007-2008 elevations of these lakes with respect to each other were examined for consistency with the findings of Palen. Overall, the lake elevations surveyed generally fit within the expected north-northwest groundwater flow pattern (i.e., higher lake elevations to the southeast and lower lake elevations to the northwest). There were, however, three exceptions: Lake Martha and Wallmark Lake in 2007-2008 and 2009-2010 and North Lindstrom Lake in 2009-2010.

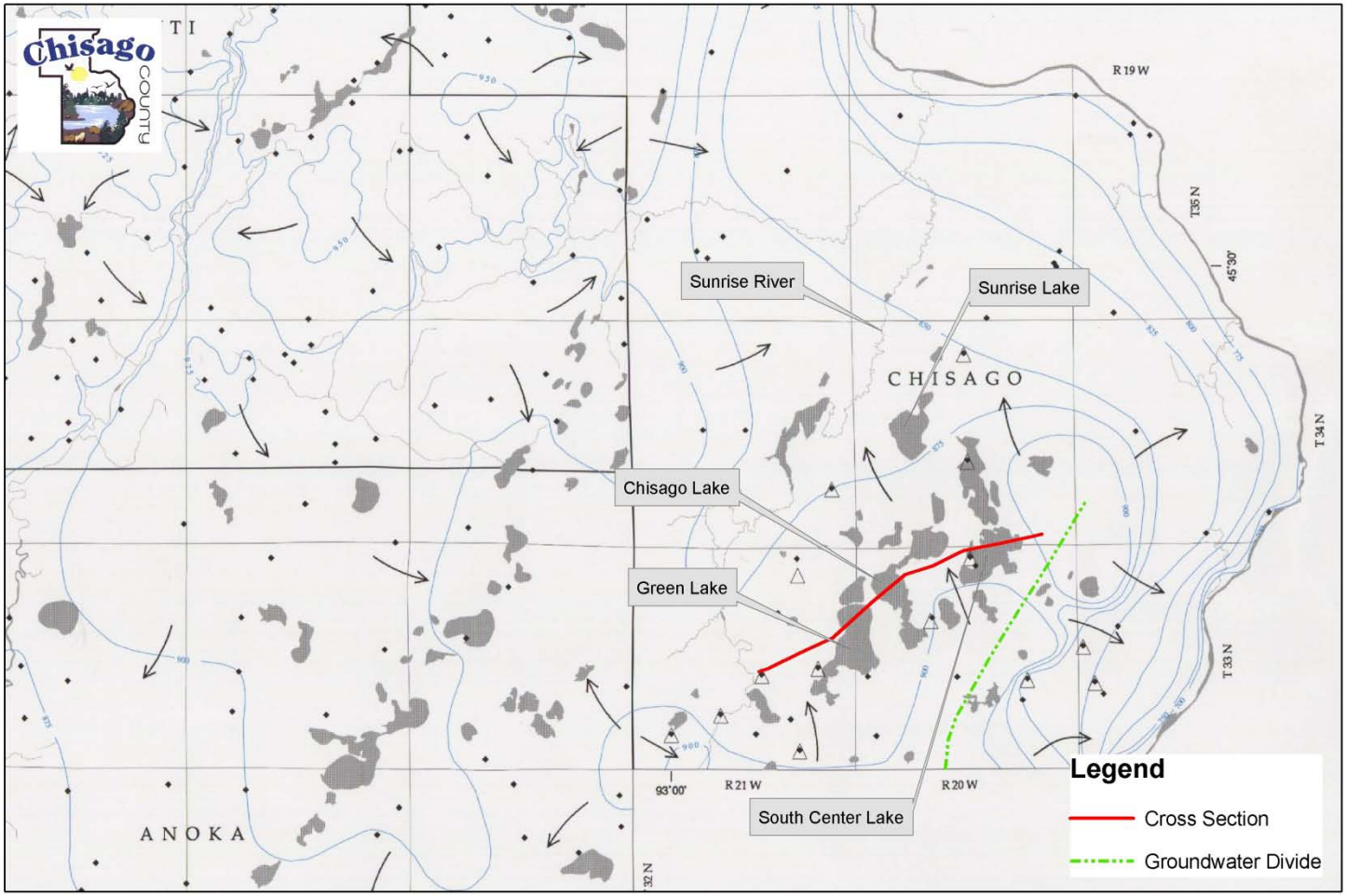
Lake Martha's water surface elevation was significantly higher than the water surface elevation of adjacent lakes during the winters of 2007-2008 and 2009-2010. For example, on 3/1/2010, Lake Martha had a water surface elevation of 907 feet above mean sea level. This elevation was 14 feet higher than Chisago Lake's elevation to the southeast and 18 feet higher than Little Green Lake's elevation to the south. This may give the impression that water flows outward from Lake Martha in a radial pattern, however Lake Martha's water surface elevations fluctuated during the study. This fluctuation indicates that the lake does not constantly lose water to groundwater recharge. Lake Martha is relatively shallow with a depth of approximately 6 feet. A review of logs for wells nearest Lake Martha indicates the lake may have a clay bottom, which could serve to isolate it somewhat from the surrounding lakes.

Wallmark Lake was also an exception to the general flow directions shown in the Palen study during the winters of 2007-2008 and 2009-2010. On 3/1/2010, Wallmark had an elevation of 897 feet above mean sea level. This water level was three to four feet higher than lakes to its south and southeast. Since Wallmark Lake was shown to fluctuate during the study it is possible that some water flowed out of the lake to the southeast while groundwater entered the lake from other directions.

North Lindstrom Lake was an exception to the general flow directions shown in the Palen study during the winter of 2009-2010. On 3/1/2010, North Lindstrom had an elevation of 897 feet above mean sea level. This water level was three to four feet higher than lakes to its south and southeast. The North Lindstrom Lake elevation was shown to drop during the winter of 2009-2010 and water surface elevations were generally lower than in 2007-2008. Therefore, it is possible that North Lindstrom Lake's water surface elevation was relatively less influenced by its surface water connection to South Lindstrom Lake and more influenced by local variations in groundwater flow.

It appears that the exceptions of Lake Marth, Wallmark Lake and North Lindstrom Lake are most likely due to localized variations in groundwater flows. Overall, the groundwater flow directions presented in Figure 11 appear to be generally correct and reasonable.

Figure 11
Groundwater Contour Map



N
W E
S

Chisago Lakes Groundwater Study
Groundwater Contour Map

6.0 Lake Classification and Water Level Fluctuations

Lakes can be classified into three categories, depending on how they interact with groundwater: losing (lake recharges groundwater), gaining (groundwater discharges to lakes), or flow-through (lake loses and gains water in different areas). This classification can change depending on the surrounding aquifer conditions, seasonal changes, or periods of abundant or sparse precipitation.

The lake classification system is discussed in a study entitled "Integrating Groundwater and Surface Water Management Washington County. This study area includes the Forest Lake Watershed, which is adjacent to the CLLID. The study noted the existence of 'losing' and 'flow-through' lakes. The geology of the Forest Lake Watershed area is somewhat similar to the Chisago Lake area so it is reasonable to have similar types of lakes in the CLLID area.

Based on the behavior of the lakes during the time they were monitored, the Chisago Lakes can be classified as follows:

2007-2008

- Losing Lakes: North and South Center, South Lindstrom, Chisago, Sunrise, Little Green, and Green Lake
- Flow-through Lakes: Kroon, School, Wallmark, Little, Ellen, Martha, and North Lindstrom Lake
- Gaining Lakes: None*

2009-2010

- Losing Lakes: Chisago, North Lindstrom, and South Lindstrom
- Flow-through Lakes: North and South Center, Sunrise, Little Green, Green, Kroon, School, Wallmark, Little, Ellen and Martha
- Gaining Lakes: None

The DNR published a document entitled "Natural Ordinary High Water Determination for the Chisago Chain of Lakes". This document states that elevations of the Chisago Lakes have fluctuated as much as 22 feet from 1848 to 1981. The early 1930's represented a particularly dry period. The DNR indicates that Chisago Lake had an elevation of 882.0 in 1935. This is approximately 13.7 feet below the elevation recorded for Chisago on this study's initial survey date (12/19/2007) and approximately 10.9 feet below on this study's final survey date (3/1/2010).

A review by HDR of historic lake elevations revealed that although there are regular short term lake level variations, long term lake elevations have remained relatively stable over the last four decades, and in some cases have risen. This indicates that over the last four decades, the lakes in this study which lose water to groundwater in the winter months are similarly recharged from precipitation, overland flow, or groundwater discharge during other months. Lake water surface elevations will likely continue to have short term and long term fluctuations in the future.

* Only Ellen Lake had a net gain in 2007-2008, acquiring 0.02 feet, which is within the margin of error of survey. For this reason the gain is considered negligible.

7.0 Limitations of Study

The water surface elevations were monitored during a fourteen week period during the winter of 2007-2008 and a nine week period during the winter of 2009-2010. The loss volumes calculated as part of this study are representative of the lake and groundwater conditions at the time of the study. Actual losses in the future could change based on lake elevations at the time of future surveys, and droughts or extended wet periods. One factor that could be somewhat unique to the duration of the 2007-2008 survey period is the fact that there were above average rains during August, September, and October. For this reason, there may have been an increase in subsurface flows late in 2007 that normally doesn't occur (or doesn't occur to such a high degree). Precipitation during the 2009-2010 period was above average in August and October, but well below average during the month of September. For 2009, total precipitation was well below average which may have led to relatively lower subsurface flows during the 2009-2010 survey period. Table 3 shows the monthly average rainfall totals for the Chisago Lakes area.

Table 3
Monthly Rainfall Averages

	PRECIPITATION TOTALS (in)												
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**YR**
Historical Data *	0.98	0.80	1.60	2.40	3.46	4.61	4.55	4.58	3.31	2.51	1.99	0.97	31.76
2007 **	0.79	1.07	2.65	3.15	3.25	1.77	2.16	5.15	4.49	6.38	0.03	1.95	32.84
2009 **	0.48	0.74	1.10	1.37	0.86	3.19	1.97	5.91	0.57	6.06	0.41	2.18	24.84
2007 County Average ***	0.62	1.03	2.76	2.25	2.76	2.17	2.23	4.08	5.00	5.73	0.06	1.80	30.92
2009 County Average ***	0.43	0.70	1.35	1.16	0.74	2.38	2.12	5.46	0.71	5.84	0.54	1.78	22.43

Source: National Oceanic and Atmospheric Administration, Midwestern Regional Climate Center
* Monthly Precipitation from 1971-2000 at NWS Station: 212881 Forest Lake 5 NE, MN
** 2007/2009 Monthly Precipitation Totals at NWS Station: 212881 Forest Lake 5 NE, MN
*** 2007/2009 Chisago County Monthly Precipitation Totals

Higher or lower water levels in lakes could expose different layers of soil to water. Lower water elevations would lower the water pressure on the layers of soil at the bottom of the lake resulting in potentially lower subsurface flow rates. Extended dry or wet periods could change the degree of difference in water table elevations from the Chisago Lakes area to the Sunrise River bottom resulting in a changed subsurface flow rate. The 2009-2010 survey period confirmed that the lakes behaved differently during lower lake level conditions. Although the 2009-2010 survey provided additional insight into net water losses and groundwater flows in the Chisago Lakes system, additional surveys would be valuable for adding to the understanding of this dynamic system. In particular, a study during high water conditions would be valuable. Although losses derived from a two winters will be very useful for calibration of water budget analyses, additional monitoring periods will increase the reliability of the results and improve our understanding of the relationship between the Chisago Lakes and groundwater.

When measuring water surface elevations, a survey rod was held approximately on the surface of the water. The difficulty in holding a survey rod steady, on a yielding surface (water), inevitably adds a certain amount of error to the water surface elevation measurements. Based on the average distance between the survey rod and the level

used to take readings, the degree of error was estimated to be approximately +/- 0.04 ft (1/2”). The elevations of the benchmarks that were set using GIS surveying equipment are considered accurate to within +/- 0.05 ft.

Volume losses or gains within lakes were determined by multiplying the change in water surface elevation by the surface area of the lake. DNR GIS data or USGS quad map delineation was used for determining lake surface area. Chisago County LiDAR data could be used to determine lake surface areas with more accuracy.

8.0 Future Investigations

The main purpose of this study, to provide data sufficient for calibration of future SWAT modeling, was accomplished. Additional surveys (in future winters) could provide information on how the lakes interact with groundwater under varying conditions.

As discussed under the Study Limitations section, the County's LIDAR data was not used to calculate volume losses. While the volume losses presented in this report are adequate for SWAT calibration, LIDAR contours could be used to increase the accuracy of the volume loss calculations.

Furthermore, it is important to note that the DNR and the Minnesota Geological Survey (MGS) are working to develop a hydrogeologic atlas for Chisago County. The data from this CLLID study will be shared with the DNR and the MGS for use with their study or other purposes. No preliminary data or mapping from the DNR or MGS was available for use in this study. Once the DNR and MGS study is completed, the geologic cross sections and other data in their report should be reviewed in conjunction with the findings of this report to see if additional insight can be gained on the observed water volume changes.

Lastly, if it is determined that the CLLID needs additional information (or a better understanding) of the lake-groundwater interaction of the area, additional studies could be performed to augment the results of the recently completed work. Although we see no need for performing these additional studies at this time based on current CLLID needs, follow-up studies could include the following:

- A study could be performed combining monitoring of well water elevations, lake elevations and geochemistry in order to evaluate location-specific interactions between the lakes and groundwater. Static water level measurements would be collected from water table wells or piezometers in the area, and lake elevations surveyed up to four times per year to observe seasonal fluctuations. Groundwater and lake water samples would be collected and analyzed for basic cation/anion geochemistry and stable isotopes of hydrogen and oxygen to determine the relative age and source of the water. A similar study was performed in 1990-1991 by the Minnesota Department of Natural Resources (DNR) during a regional hydrogeologic assessment which included Anoka, Chisago, Isanti, and Sherburne counties (Palen and others, 1993). The proposed water chemistry study would examine the Chisago Lakes area, specifically. Such a study would be coordinated with the DNR and Minnesota Geological Survey (MGS), who are currently working to develop a hydrogeologic atlas for Chisago County.

- Piezometric wells could be installed for purposes of collecting site-specific water table and geochemistry information. New wells would only be completed in critical areas that are found to be spatially lacking groundwater level and chemistry collection points. Data loggers that automatically collect groundwater level information at specified intervals (e.g., hourly, daily) could be installed in piezometers and lakes. This task would also be coordinated with the DNR and MGS.

- A groundwater computer model could be created that would tell us where groundwater flows into lakes and where surface water flows out of the lakes. Available information such as well logs and lake elevations would be used in the model. Additional lake and groundwater level information (from wells or new piezometers) would be required. Lakebed drilling to evaluate the geology under the lakes would also be necessary.

9.0 Conclusion

The 2007-2008 and 2009-2010 surveys were successful at confirming and quantifying groundwater losses from fourteen lakes in the area of the CLLID. The results between the survey periods varied, as is to be expected from a dynamic system with many variables. Net lake water losses from this groundwater study can be incorporated into SWAT or other computer modeling efforts that involve the use of water budgets. Surveys can be conducted in future years in order to gain a better understanding of how the lake system behaves under varying conditions. This report, the associated spreadsheets used to calculate water losses, and the benchmarks set up for this study, can be used by County personnel or others for subsequent lake level measurements.

10.0 References

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Palen, B.M., Kanivetsky, R., and Christopher, R.A., 1993, Water-table hydrogeology, plate 2, *in* Anoka Sand Plain Regional Hydrogeologic Assessment: Minnesota Department of Natural Resources Regional Assessment Series RHA-1, scale 1:200,000.

Appendix A
Survey Data

Date: 12/19/2007

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	7.94	0.50	7.44	896.72	0.7
South Center Lake	904.16	7.94	0.50	7.44	896.72	0.7
Kroon Lake	907.15	5.62	0.17	5.45	901.70	0.8
North Lindstrom Lake	899.63	5.74	1.87	3.87	895.76	0.9
South Lindstrom Lake	901.35	10.81	5.19	5.62	895.73	0.9
Chisago Lake	901.35	10.81	5.19	5.62	895.73	0.9
Sunrise Lake	876.35	5.70	3.66	2.04	874.31	0.9
School Lake	887.28	5.92	2.86	3.06	884.22	0.9
Wallmark Lake	900.39	5.47	2.60	2.87	897.52	0.9
Martha Lake	916.33	9.66	1.04	8.62	907.71	0.9
Little Green Lake	897.70	8.81	2.37	6.44	891.26	1.2
Green Lake	896.37	11.17	5.83	5.34	891.03	1.1
Little Lake	927.04					
Ellen Lake	890.38	6.40	1.96	4.44	885.94	0.7

Date: 1/3/2008

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	8.34	0.49	7.85	896.31	1.0
South Center Lake	904.16	8.34	0.49	7.85	896.31	1.0
Kroon Lake	907.15	6.15	0.74	5.41	901.74	1.0
North Lindstrom Lake	899.63	5.64	1.81	3.83	895.80	1.3
South Lindstrom Lake	901.35	6.66	1.08	5.58	895.77	1.2
Chisago Lake	901.35	6.66	1.08	5.58	895.77	1.2
Sunrise Lake	876.35	5.68	3.68	2.00	874.35	1.1
School Lake	887.28	5.48	2.51	2.97	884.31	1.1
Wallmark Lake	900.39	5.65	2.82	2.83	897.56	1.2
Martha Lake	916.33	8.74	0.67	8.07	908.26	1.1
Little Green Lake	897.70	7.54	0.22	7.32	890.38	1.2
Green Lake	896.37	8.51	2.52	5.99	890.38	1.2
Little Lake	927.04					
Ellen Lake	890.38					

Date: 1/15/2008

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	8.87	0.96	7.91	896.25	1.5
South Center Lake	904.16	8.87	0.96	7.91	896.25	1.5
Kroon Lake	907.15	5.68	0.23	5.45	901.70	1.3
North Lindstrom Lake	899.63	5.68	1.79	3.89	895.74	1.5
South Lindstrom Lake	901.35	7.02	1.35	5.67	895.68	1.4
Chisago Lake	901.35	7.02	1.35	5.67	895.68	1.4
Sunrise Lake	876.35	5.41	3.39	2.02	874.33	1.3
School Lake	887.28	5.93	2.94	2.99	884.29	1.5
Wallmark Lake	900.39	5.51	2.67	2.84	897.55	1.0
Martha Lake	916.33	8.41	0.19	8.22	908.11	1.3
Little Green Lake	897.70	8.20	0.86	7.34	890.36	1.2
Green Lake	896.37	6.38	0.35	6.03	890.34	1.2
Little Lake	927.04	5.62	1.07	4.55	922.49	1.5
Ellen Lake	890.38	5.57	1.18	4.39	885.99	1.2

Date: 2/01/2008

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	8.88	0.86	8.02	896.14	2.0
South Center Lake	904.16	8.88	0.86	8.02	896.14	2.0
Kroon Lake	907.15	5.63	0.18	5.45	901.70	2.0
North Lindstrom Lake	899.63	5.64	1.49	4.15	895.48	1.8
South Lindstrom Lake	901.35	7.58	1.80	5.78	895.57	2.1
Chisago Lake	901.35	7.58	1.80	5.78	895.57	2.1
Sunrise Lake	876.35	5.62	3.47	2.15	874.20	1.9
School Lake	887.28	5.86	2.81	3.05	884.23	1.7
Wallmark Lake	900.39	5.41	2.50	2.91	897.48	1.7
Martha Lake	916.33	9.24	0.16	9.08	907.25	1.9
Little Green Lake	897.70	8.93	1.57	7.36	890.34	1.9
Green Lake	896.37	8.49	1.84	6.65	889.72	2.0
Little Lake	927.04	5.76	1.09	4.67	922.37	1.8
Ellen Lake	890.38	5.77	1.32	4.45	885.93	1.9

Date: 2/13/2008

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	9.88	1.75	8.13	896.03	2.0
South Center Lake	904.16	9.88	1.75	8.13	896.03	2.0
Kroon Lake	907.15	5.69	0.21	5.48	901.67	2.1
North Lindstrom Lake	899.63	5.71	0.94	4.77	894.86	2.4
South Lindstrom Lake	901.35	10.51	4.64	5.87	895.48	2.2
Chisago Lake	901.35	10.51	4.64	5.87	895.48	2.2
Sunrise Lake	876.35	5.84	3.63	2.21	874.14	2.0
School Lake	887.28	5.81	2.76	3.05	884.23	1.9
Wallmark Lake	900.39	5.54	2.61	2.93	897.46	1.9
Martha Lake	916.33	10.21	1.49	8.72	907.61	2.1
Little Green Lake	897.70	8.87	1.49	7.38	890.32	2.1
Green Lake	896.37	8.83	1.99	6.84	889.53	2.1
Little Lake	927.04	5.81	1.15	4.66	922.38	2.0
Ellen Lake	890.38	5.73	1.30	4.43	885.95	2.0

Date: 2/28/2008

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	9.83	1.69	8.14	896.02	2.2
South Center Lake	904.16	9.83	1.69	8.14	896.02	2.2
Kroon Lake	907.15	6.14	0.73	5.41	901.74	2.5
North Lindstrom Lake	899.63	5.81	1.53	4.28	895.35	2.3
South Lindstrom Lake	901.35	10.63	4.71	5.92	895.43	2.4
Chisago Lake	901.35	10.63	4.71	5.92	895.43	2.4
Sunrise Lake	876.35	6.18	3.84	2.34	874.01	2.2
School Lake	887.28	5.83	2.71	3.12	884.16	2.0
Wallmark Lake	900.39	5.66	2.74	2.92	897.47	2.1
Martha Lake	916.33	10.74	2.03	8.71	907.62	2.1
Little Green Lake	897.70	8.97	1.52	7.45	890.25	2.3
Green Lake	896.37	8.75	1.92	6.83	889.54	2.4
Little Lake	927.04	7.28	2.61	4.67	922.37	2.3
Ellen Lake	890.38	5.91	1.51	4.40	885.98	2.0

3/12/2008

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	11.14	2.39	8.75	895.41	2.1
South Center Lake	904.16	11.14	2.39	8.75	895.41	2.1
Kroon Lake	907.15	7.86	2.39	5.47	901.68	2.5
North Lindstrom Lake	899.63	6.06	1.71	4.35	895.28	2.4
South Lindstrom Lake	901.35	10.53	4.57	5.96	895.39	2.7
Chisago Lake	901.35	10.53	4.57	5.96	895.39	2.7
Sunrise Lake	876.35	5.96	3.69	2.27	874.08	2.4
School Lake	887.28	5.79	2.70	3.09	884.19	2.2
Wallmark Lake	900.39	5.67	2.72	2.95	897.44	2.1
Martha Lake	916.33	10.66	1.89	8.77	907.56	2.3
Little Green Lake	897.70	8.84	1.44	7.40	890.30	2.4
Green Lake	896.37	9.07	2.21	6.86	889.51	2.5
Little Lake	927.04	8.49	3.88	4.61	922.43	2.4
Ellen Lake	890.38	5.89	1.47	4.42	885.96	2.2

Date: 12/30/2009

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	11.45	1.64	9.81	894.35	0.80
South Center Lake	904.16	11.45	1.64	9.81	894.35	0.80
Kroon Lake	907.15	7.45	1.10	6.35	900.81	0.89
North Lindstrom Lake	899.63	5.36	2.82	2.54	897.09	0.95
South Lindstrom Lake	901.35	10.63	2.29	8.35	893.01	0.80
Chisago Lake	901.35	10.63	2.29	8.35	893.01	0.80
Sunrise Lake	876.35	6.38	3.71	2.67	873.69	0.85
School Lake	887.28	4.99	0.81	4.18	883.10	0.80
Wallmark Lake	900.39	4.95	1.35	3.60	896.79	1.07
Martha Lake	916.33	10.28	0.90	9.38	906.95	1.08
Little Green Lake	897.70	9.06	0.77	8.29	889.41	1.06
Green Lake	896.37	9.28	1.76	7.52	888.86	0.84
Little Lake	927.04	9.23	3.35	5.88	921.17	0.84
Lake Ellen	890.38	5.36	0.05	5.32	885.07	0.80

Date: 1/21/2010

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	11.85	2.01	9.84	894.32	1.51
South Center Lake	904.16	11.85	2.01	9.84	894.32	1.51
Kroon Lake	907.15	8.53	2.16	6.37	900.79	1.43
North Lindstrom Lake	899.63	4.77	2.06	2.71	896.92	1.57
South Lindstrom Lake	901.35	10.76	2.35	8.41	892.94	1.63
Chisago Lake	901.35	10.76	2.35	8.41	892.94	1.63
Sunrise Lake	876.35	6.21	3.53	2.68	873.68	1.20
School Lake	887.28	5.47	1.28	4.19	883.09	1.17
Wallmark Lake	900.39	5.12	1.51	3.61	896.79	1.16
Martha Lake	916.33	10.15	0.73	9.43	906.90	1.37
Little Green Lake	897.70	8.62	0.24	8.38	889.32	1.78
Green Lake	896.37	8.87	1.32	7.56	888.82	1.39
Little Lake	927.04	9.44	3.52	5.93	921.12	1.46
Lake Ellen	890.38	6.08	0.70	5.38	885.00	1.19

Date: 2/8/2010

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
North Center Lake	904.16	12.04	2.26	9.78	894.38	1.70
South Center Lake	904.16	12.04	2.26	9.78	894.38	1.70
Kroon Lake	907.15	7.95	1.65	6.30	900.86	1.93
North Lindstrom Lake	899.63	5.20	2.49	2.71	896.92	1.69
South Lindstrom Lake	901.35	11.62	3.20	8.42	892.93	1.90
Chisago Lake	901.35	11.62	3.20	8.42	892.93	1.90
Sunrise Lake	876.35	5.75	3.11	2.64	873.71	1.39
School Lake	887.28	5.09	0.92	4.18	883.10	1.58
Wallmark Lake	900.39	5.37	1.66	3.71	896.68	1.44
Martha Lake	916.33	10.08	0.68	9.40	906.93	1.76
Little Green Lake	897.70	8.95	0.66	8.29	889.42	1.97
Green Lake	896.37	10.13	2.61	7.52	888.86	1.73
Little Lake	927.04	10.13	4.25	5.88	921.16	1.75
Lake Ellen	890.38	7.20	1.84	5.36	885.03	1.54

Date: 3/1/2010

Lake:	Benchmark Elevation	Shot on Water (ft)	Shot on Benchmark (ft)	Shot Differential (ft)	Elevation of Water	Depth of Ice (ft)
		AVG	AVG	AVG	AVG	
North Center Lake	904.16	12.16	2.34	9.82	894.34	2.06
South Center Lake	904.16	12.16	2.34	9.82	894.34	2.06
Kroon Lake	907.15	10.33	3.98	6.35	900.81	1.92
North Lindstrom Lake	899.63	5.55	2.67	2.88	896.75	2.03
South Lindstrom Lake	901.35	11.76	3.27	8.49	892.86	2.22
Chisago Lake	901.35	11.76	3.27	8.49	892.86	2.22
Sunrise Lake	876.35	6.78	4.07	2.71	873.65	1.65
School Lake	887.28	4.99	0.78	4.21	883.07	1.61
Wallmark Lake	900.39	5.19	1.56	3.63	896.76	1.65
Martha Lake	916.33	11.04	1.55	9.49	906.84	2.13
Little Green Lake	897.70	9.69	1.38	8.31	889.40	2.11
Green Lake	896.37	9.59	2.06	7.53	888.85	1.71
Little Lake	927.04	10.23	4.29	5.94	921.10	2.01
Lake Ellen	890.38	8.51	3.11	5.41	884.98	1.78

Chisago Lakes Groundwater Study: 2007-2008 Lake Volume Tracking

	Lake Surface Area Info		Volume Change from First Survey (ac-ft)							Volume Change from Previous Survey (ac-ft)						
	Lake Surface Area*		Survey Dates							Survey Dates						
Lakes	**(ac)**		**12/19/07**	**1/3/08**	**1/15/08**	**2/1/08**	**2/13/08**	**2/28/08**	**3/12/08****	**12/19/07**	**1/3/08**	**1/15/08**	**2/1/08**	**2/13/08**	**2/28/08**	**3/12/08**
North Center Lake	774.1		0	-317	-364	-449	-534	-542	-1014	0	-317	-46	-85	-85	-8	-472
South Center Lake	894		0	-367	-420	-519	-617	-626	-1171	0	-367	-54	-98	-98	-9	-545
Kroon Lake	181.4		0	7	0	0	-5	7	-4	0	7	-7	0	-5	13	-11
North Lindstrom Lake	142.2		0	6	-3	-40	-128	-58	-68	0	6	-9	-37	-88	70	-10
South Lindstrom Lake	548.3		0	22	-27	-88	-137	-164	-186	0	22	-49	-60	-49	-27	-22
Chisago Lake	898.8		0	36	-45	-144	-225	-270	-306	0	36	-81	-99	-81	-45	-36
Sunrise Lake	799.1		0	32	16	-88	-136	-240	-184	0	32	-16	-104	-48	-104	56
School Lake	194	a	0	17	14	2	2	-12	-6	0	17	-4	-12	0	-14	6
Wallmark Lake	162.4	a	0	6	5	-6	-10	-8	-13	0	6	-2	-11	-3	2	-5
Martha Lake	27	a	0	15	11	-12	-3	-2	-4	0	15	-4	-23	10	0	-2
Little Green Lake	225.5		0	-198	-203	-207	-212	-228	-216	0	-198	-5	-5	-5	-16	11
Green Lake	1594.1		0	-1036	-1100	-2088	-2391	-2375	-2423	0	-1036	-64	-988	-303	16	-48
Little Lake	149.7		0	0	0	-18	-16	-18	-9	0	0	0	-18	1	-1	9
Ellen Lake	23.4	a	0	0	1	0	0	1	0	0	0	1	-1	0	1	0

* Source: DNR Lake Bathymetric GIS Data; Zero elevation contour (http://deli.dnr.state.mn.us/) unless otherwise noted

a Delineated from 1991 USGS DOQ

** Total Volume Change over Duration of Study. A net loss is indicated by negative number, while a net gain is indicated by a positive number.

Chisago Lakes Groundwater Study: 2009-2010 Lake Volume Tracking

	Lake Surface Area Info		Volume Change from First Survey (ac-ft)				Volume Change from Previous Survey (ac-ft)			
	Lake Surface Area*		Survey Dates				Survey Dates			
Lakes	**(ac)**		**12/30/09**	**1/21/10**	**2/8/10**	**3/1/10**	**12/30/09**	**1/21/10**	**2/8/10**	**3/1/10**
North Center Lake	774.1		0	-27	23	-8	0	-27	50	-31
South Center Lake	894		0	-31	27	-9	0	-31	58	-36
Kroon Lake	181.4		0	-4	9	0	0	-4	13	-9
North Lindstrom Lake	142.2		0	-24	-24	-48	0	-24	0	-24
South Lindstrom Lake	548.3		0	-36	-41	-80	0	-36	-5	-38
Chisago Lake	898.8		0	-58	-67	-130	0	-58	-9	-63
Sunrise Lake	799.1		0	-6	22	-30	0	-6	28	-52
School Lake	194	a	0	-3	0	-7	0	-3	3	-7
Wallmark Lake	162.4	a	0	-1	-18	-5	0	-1	-17	13
Martha Lake	27	a	0	-1	-1	-3	0	-1	1	-2
Little Green Lake	225.5		0	-20	1	-3	0	-20	21	-5
Green Lake	1594.1		0	-64	0	-16	0	-64	64	-16
Little Lake	149.7		0	-7	0	-9	0	-7	0	-9
Ellen Lake	23.4	a	0	-2	-1	-2	0	-2	-1	-1

* Source: DNR Lake Bathymetric GIS Data; Zero elevation contour (http://deli.dnr.state.mn.us/) unless otherwise noted

a Delineated from 1991 USGS DOQ

Total Volume Change over Duration of Study. A net loss is indicated by negative number, while a net gain is indicated by a positive number.

Appendix B
Benchmark Locations

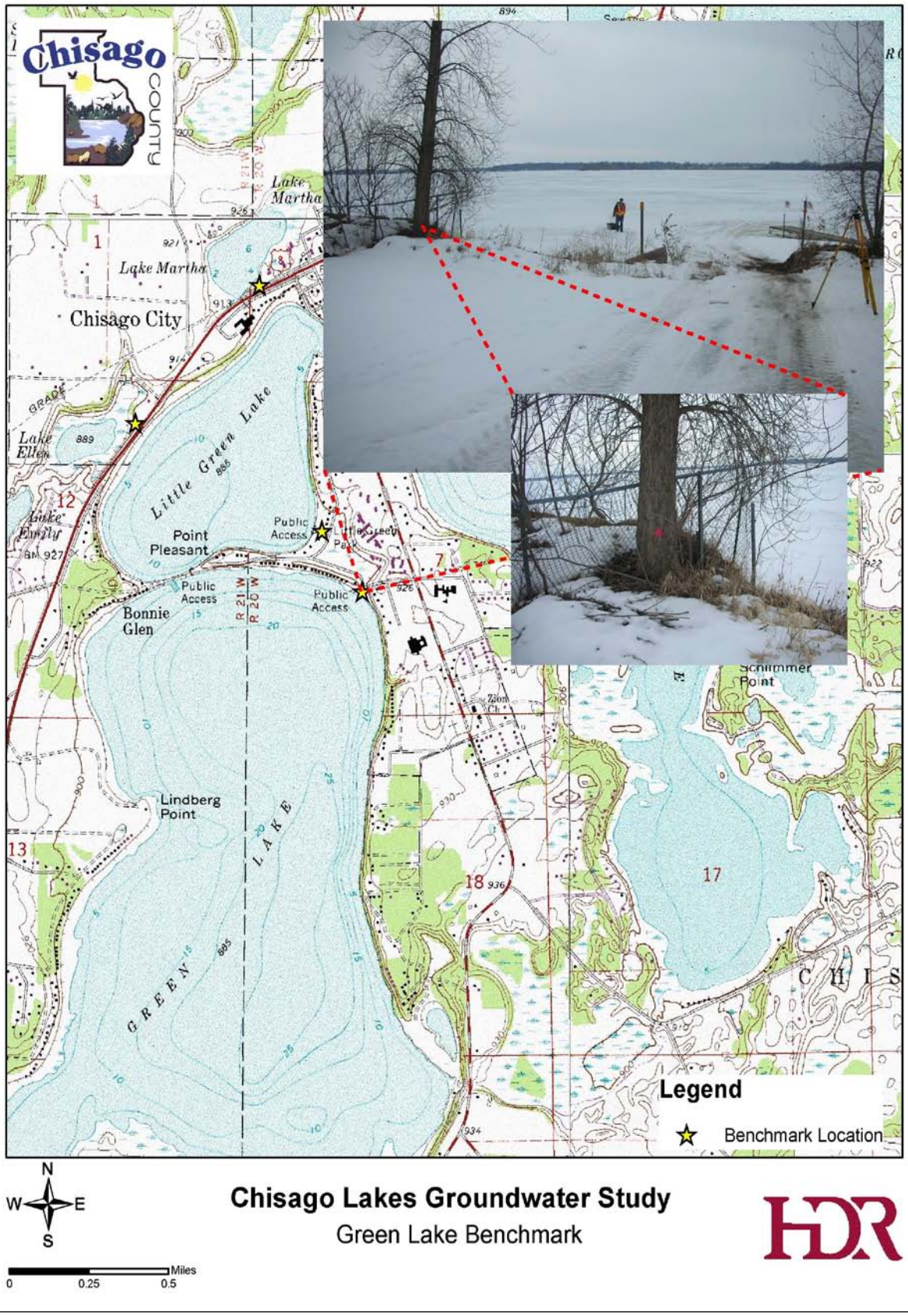
N
W E
S

0 0.25 0.5 Miles

Chisago Lakes Groundwater Study

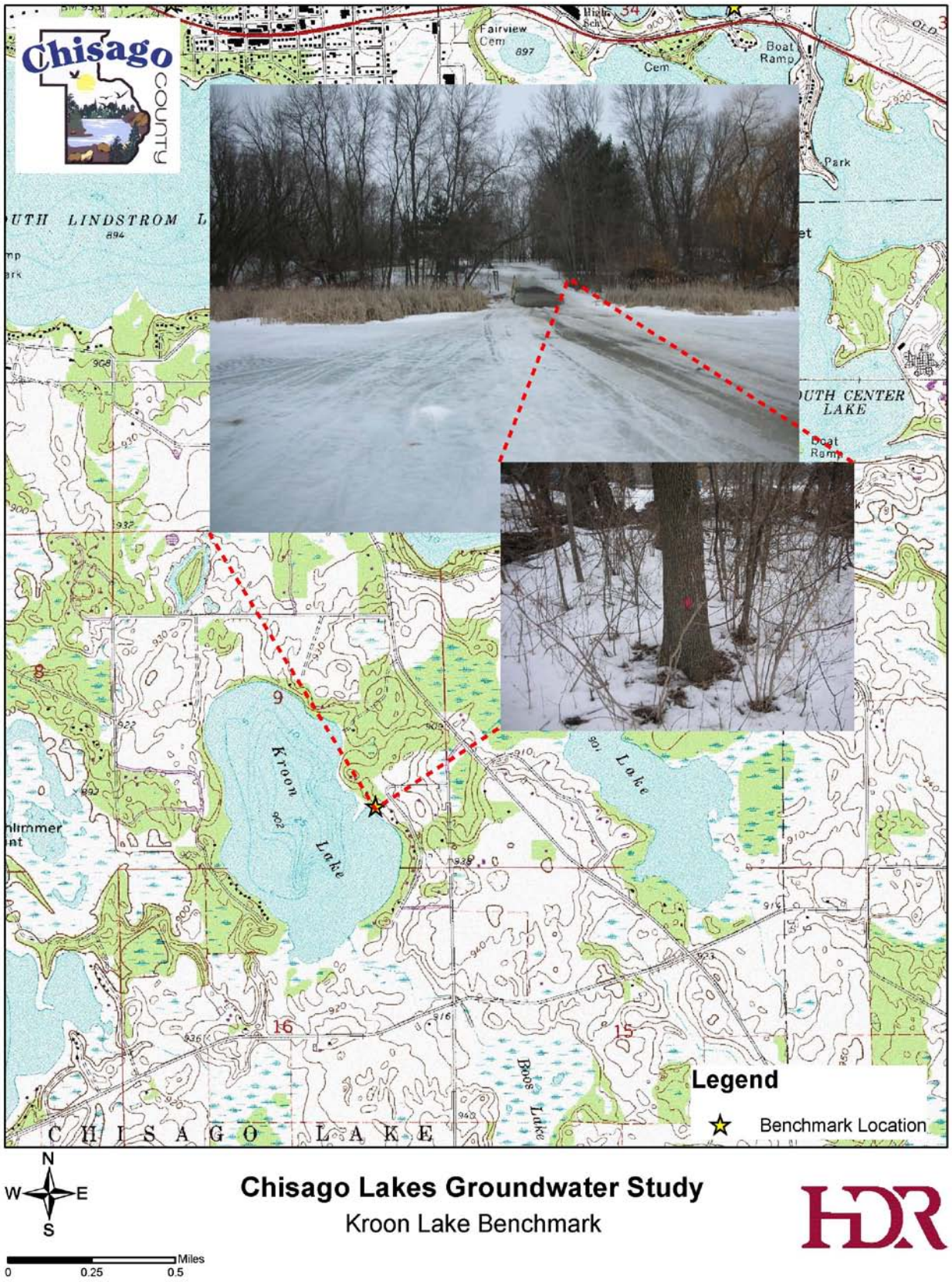
Ellen Lake Benchmark

HDR



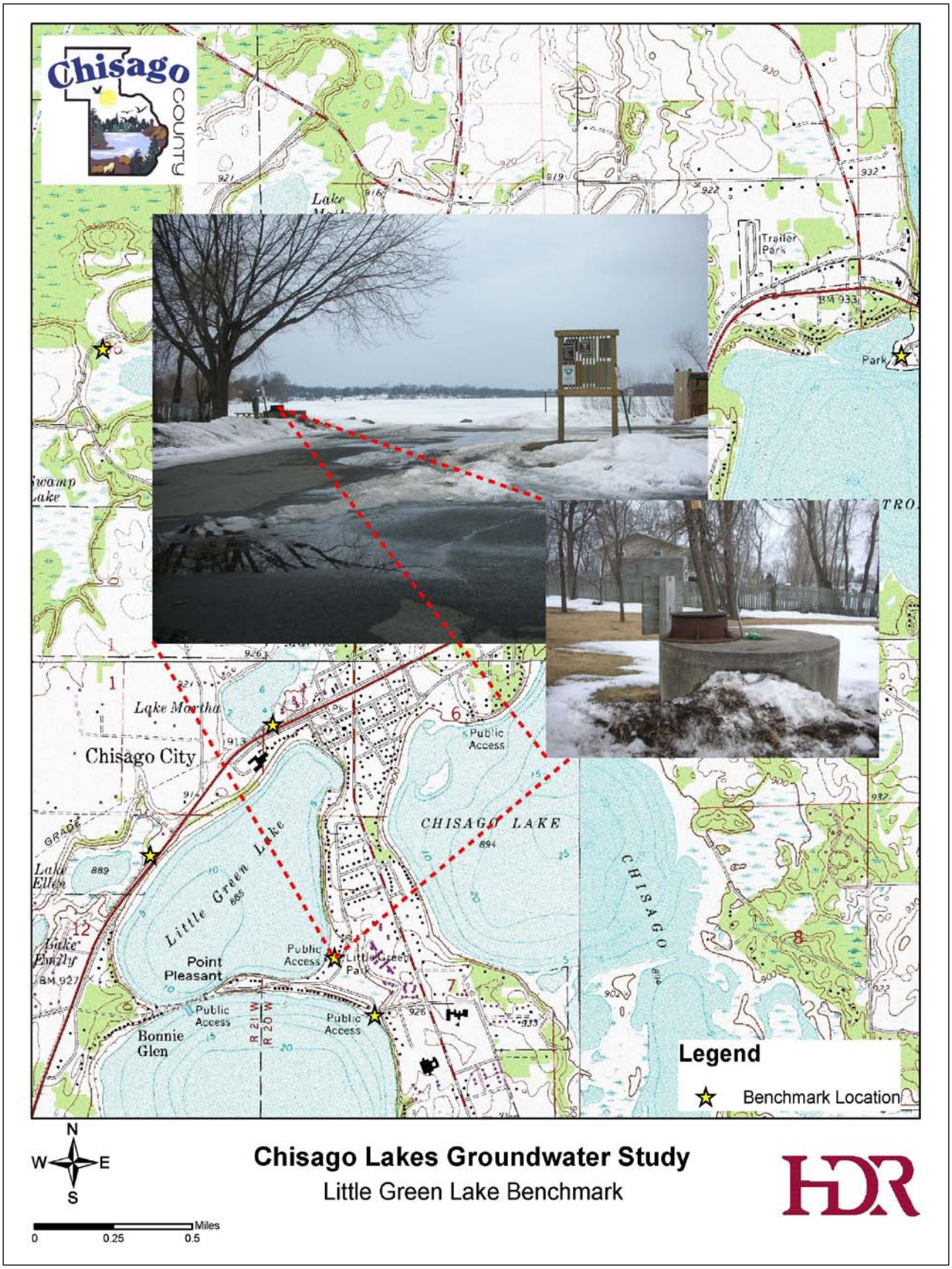
Chisago Lakes Groundwater Study

Green Lake Benchmark



Chisago Lakes Groundwater Study

Kroon Lake Benchmark


Chisago County
Lake Martha
Chisago City
Little Green Lake
CHISAGO LAKE
Point Pleasant
Bonnie Glen
Public Access
Little Green Park
Trailer Park
Park
Legend
Benchmark Location
N
W
E
S
Miles
0
0.25
0.5
Chisago Lakes Groundwater Study
Little Green Lake Benchmark
HDR

N
W E
S

0 0.25 0.5 Miles

Chisago Lakes Groundwater Study

Martha Lake Benchmark

HDR

Chisago Lakes Groundwater Study

Little Lake Benchmark

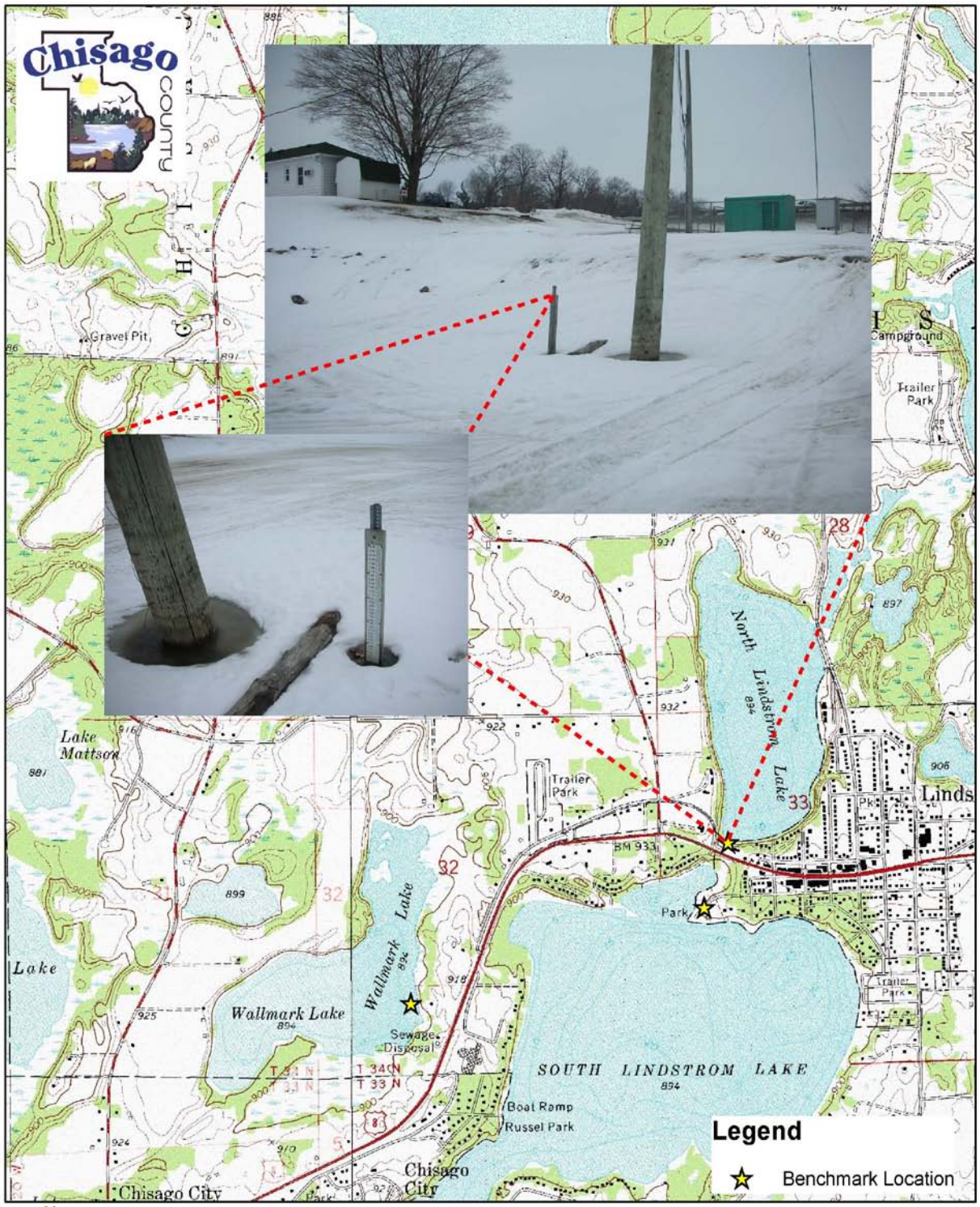
N
W E
S

Miles
0 0.25 0.5

Chisago Lakes Groundwater Study

North/South Center Lake Benchmark

HDR



N
W E
S

0 0.25 0.5 Miles

Chisago Lakes Groundwater Study

North Lindstrom Lake Benchmark

HDR

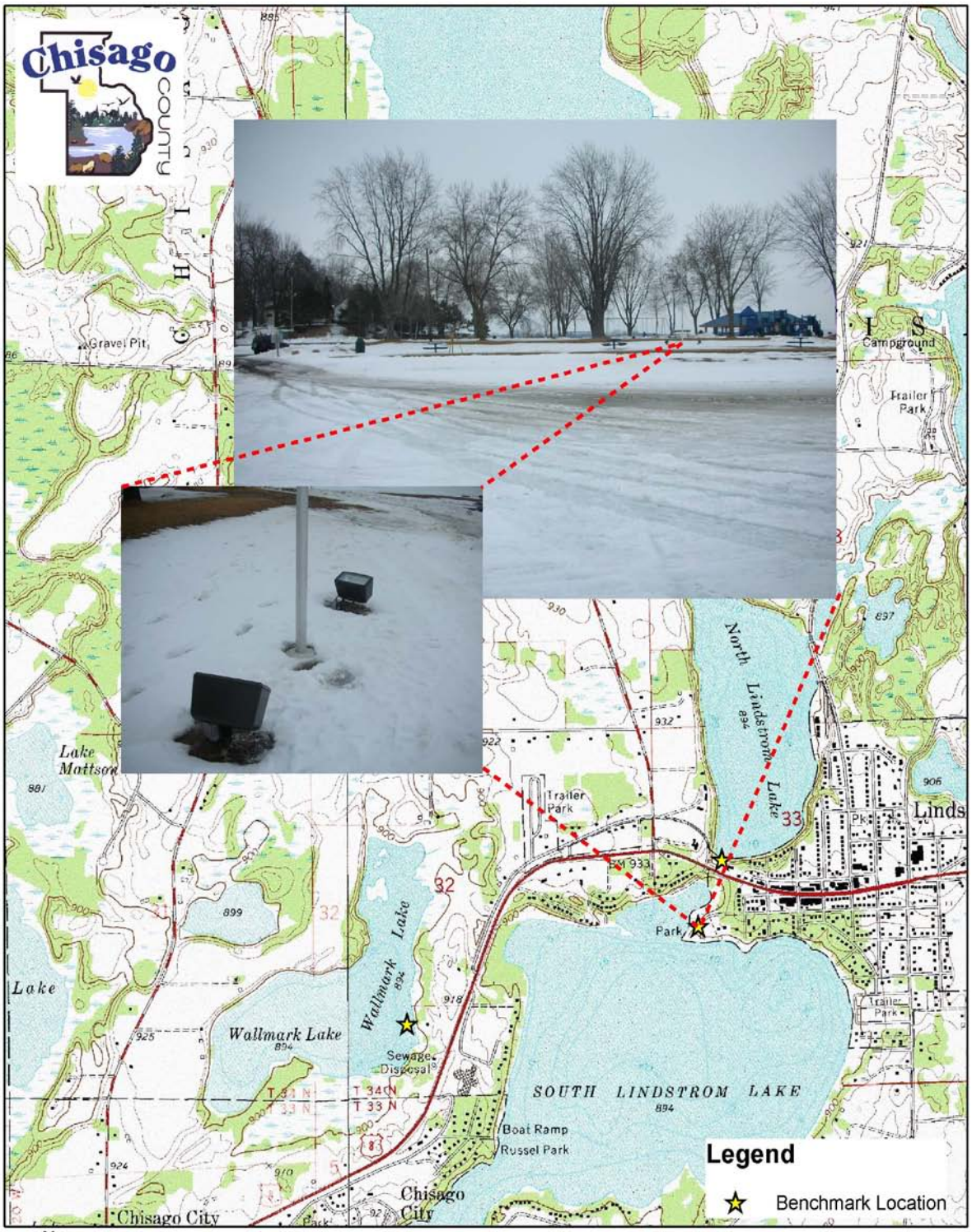
N
W E
S

0 0.25 0.5 Miles

Chisago Lakes Groundwater Study

School Lake Benchmark

HDR



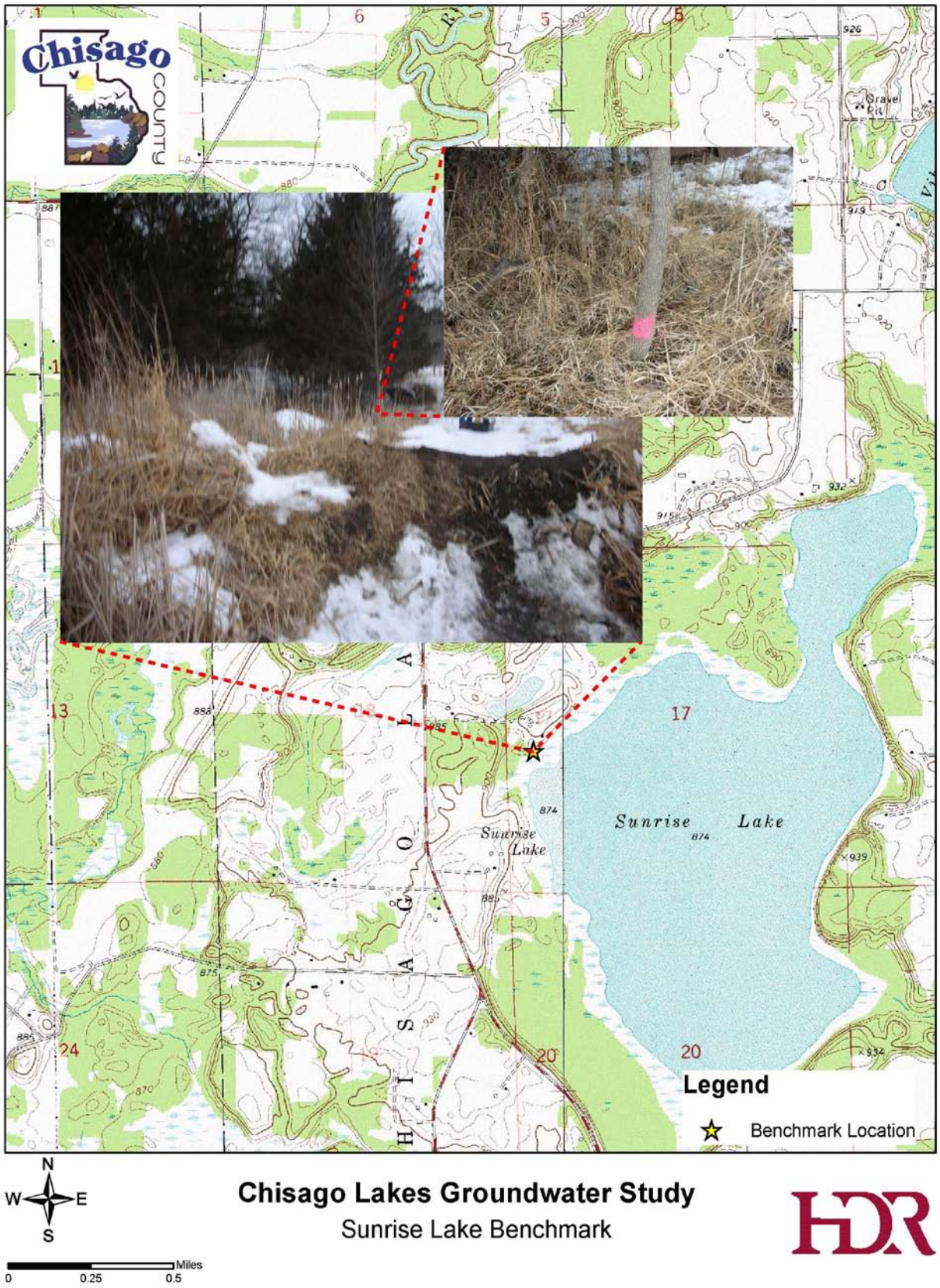
N
W E
S

0 0.25 0.5 Miles

Chisago Lakes Groundwater Study

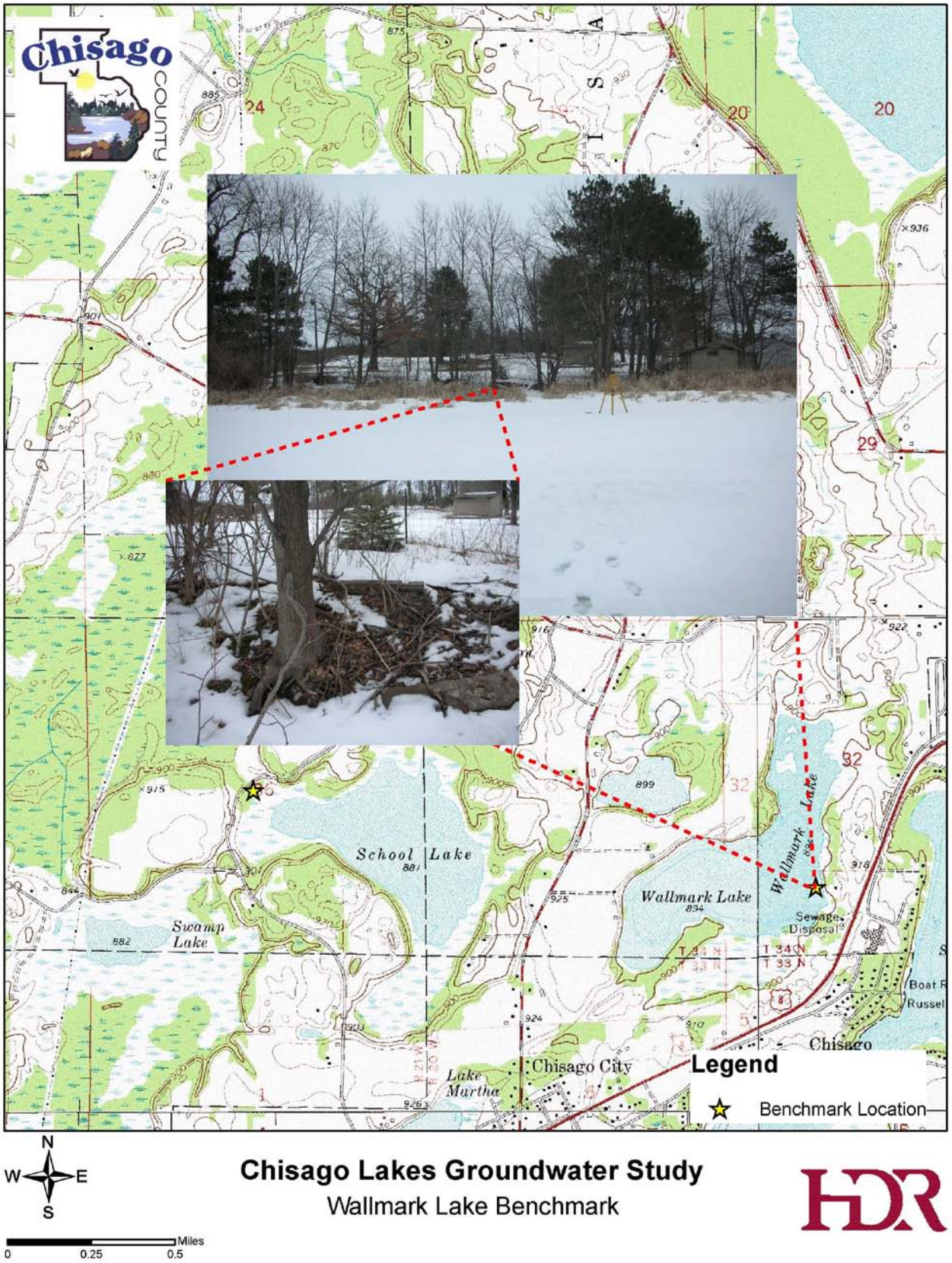
Chisago/South Lindstrom Lake Benchmark

HDR



Chisago Lakes Groundwater Study

Sunrise Lake Benchmark



Chisago Lakes Groundwater Study

Wallmark Lake Benchmark

Chisago Lakes Groundwater Study: Benchmark Locations

Lake	Benchmark Reference	Northing	Easting	Elevation (NGVD 29)
North/South Center Lake	Nail in Telephone Pole	134586.871sft	568143.786 sft	904.158
Kroon Lake	Nail in Tree Across from Public Access Sign by Water's Edge			907.15
North Lindstrom Lake	Top of 2x6 on Lake Level Gauge	134643.265 sft	559255.694 sft	899.634
Chisago/South Lindstrom Lake	Flagpole Base West of Park	133673.088 sft	558893.378 sft	901.353
Sunrise Lake	Nail in Tree on South Side of Access	149184.968 sft	552968.939 sft	876.353
School Lake	Nail in Tree on West Side at Bottom of Coulee	133778.350 sft	545529.009 sft	887.276
Wallmark Lake	Nail in Tree 30' North of Shed at Waters Edge Near Small Pine Tree			900.393
Martha Lake	Shot taken on Hydrant Top of Nut West of Trappers	127683.415 sft	548376.481 sft	916.326
Little Green Lake	Top of Metal Manhole Cover on the Large Concrete Structure at Public Lake Access Site			897.70
Green Lake	Nail in Tree Fence Left of Dock Facing Water			896.37
Ellen Lake	Nail in Telephone Pole near Gravel road South of Svens			890.38
Little Lake	Spike in Tree on East Edge of Parking Lot			927.04