

**PART I WELLHEAD PROTECTION AND  
VULNERABILITY ASSESSMENT REPORT**

**CITY OF CROOKSTON,  
POLK COUNTY, MINNESOTA**

Prepared For



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## PUBLIC WATER SUPPLY PROFILE

### PUBLIC WATER SUPPLY

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Crookston, MN 56716  
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### GENERAL INFORMATION

UNIQUE WELL NUMBER(S) \_\_\_\_\_ 147243, 191552, 191553, 191554, 685465, 685456  
SIZE OF POPULATION SERVED \_\_\_\_\_ Approximately 8,200  
COUNTY \_\_\_\_\_ Polk County

# **WELLHEAD PROTECTION AND VULNERABILITY ASSESSMENT REPORT**

## **CITY OF CROOKSTON, POLK COUNTY, MINNESOTA**

### **EXECUTIVE SUMMARY**

This report documents the delineation of Wellhead Protection Areas (WHPA) for the drinking water supply wells (City Wells No. 1 through 6) operated by the City of Crookston, Minnesota (City). Wellhead protection helps to prevent man-made contaminants from entering drinking water supply wells. Areas have been delineated in accordance with Minnesota Rules, Parts 4720.5100 to 4720.5590, which are under the jurisdiction of the Minnesota Department of Health (MDH). Leggette, Brashears & Graham, Inc. (LBG) was contracted by the City to complete the ground-water flow model, WHPA delineation, and vulnerability assessment for this report. The WHPAs were delineated using MODFLOW (a numerical groundwater flow model) and the particle-tracking module, MODPATH. Findings in this report are the result of collaboration between the City, LBG, the United States Geological Survey (USGS), and the MDH.

The City is located on the Red Lake River (River) in the central portion of Polk County, Minnesota. The City's wellfields are located approximately 12 and 19 miles east of the City. The geologic units of interest in the vicinity of the City wells consist of glacial deposits that are underlain by Precambrian bedrock. The City's wells are completed in an unconfined/semiconfined aquifer and a shallow, confined, sand aquifer contained within a glacial till. Tests for tritium, which is an indicator as to the age of groundwater, determined that the source aquifers are being recharged by relatively young water. Well logs for the City wells are presented in Appendix I.

In Central Polk County, ground water is encountered in the quaternary aquifers, with the flow direction being generally from southeast to northwest toward the River, which serves as the local and regional hydrologic discharge point for the flow system. The ground-water flow model was created based on the conceptual hydrogeologic model of the major sand units within the study area. The particle-tracking package, MODPATH, was used in conjunction with the calibrated flow model to determine the 1-, 5-, and 10-year time-of-travel pathlines necessary for delineating the WHPA for Wells No. 1 through 6. A combined pumping rate from all wells of 325.2 million gallons per year was applied based on past use, following the Minnesota Department of Health (MDH) guidelines.

The Drinking Water Supply Management Area (DWSMA) for each well field area were delineated using section and quarter section boundaries, and the 10-year WHPAs generated by the model. The DWSMA delineation encompasses each well field's WHPA(s) separately, as they are distinct. The subsequent vulnerability ratings of the surficial unconfined/semiconfined aquifer (Wells No. 2 and 3) and shallow confined aquifer (Wells No. 1, 4, 5, and 6) in the vicinity of the City wells were determined to be high to moderate and moderate, respectively.

# **PART I WELLHEAD PROTECTION AND VULNERABILITY ASSESSMENT REPORT**

## **CITY OF CROOKSTON, POLK COUNTY, MINNESOTA**

### **1.0 INTRODUCTION**

#### **1.1 Objective and Scope of Work**

The purpose of this report is to present the Part I wellhead protection area (WHPA) and vulnerability assessment results for the city of Crookston, Minnesota (City). The City contracted Leggette, Brashears & Graham, Inc. (LBG) to complete the WHPA work necessary to meet the requirements of Minnesota Rules (MR) 4720.5205 and 4720.5510.

The scope of work completed by LBG was as follows:

- Obtained and evaluated available hydrogeological information, required data elements, and developed a conceptual hydrogeologic model;
- Obtained historical water usage data from the City and determined the pumping rates for delineating the WHPAs;
- Participated in several meetings with the Minnesota Department of Health (MDH) and the United States Geological Survey (USGS) to discuss the conceptual hydrogeologic model and numerical model setup;
- Setup the numerical ground-water flow model based on the conceptual hydrogeologic model. LBG applied the numerical ground-water flow model MODFLOW;
- Calibrated the flow model to the ambient ground-water flow field using static water levels from surrounding water supply wells, and to transient flow conditions using aquifer pumping test data in the vicinity of Wells No. 5 and 6;
- Simulated the 1-, 5-, and 10-year time of travel for Wells No. 1 through 6;
- Conducted a sensitivity analysis that consisted of increasing and reducing the conductivities for each of the major units, and varying recharge;
- Delineated the WHPA based on the 10-year time of travel, and delineated the associated DWSMA based on cultural features as defined in MR 4720.5100; and,
- Assessed the vulnerability of Wells No. 1 through 6 and the DWSMA using available geologic information to meet the MDH criteria.

## **2.0 DATA ELEMENTS AND ASSESSMENT (MR 4720.5200)**

### **2.1 Required Data Elements**

The MDH requires specific data elements to be identified and assessed by the public water supplier as part of the WHP plan. These include physical environment, land use, water quantity and water quality.

#### **2.1.1 Physical Environment Data Elements**

Physical data includes natural and man-made features that may have an influence on areas surrounding the wellhead, and ultimately the well itself. Elements considered included precipitation, geology, surficial soils, and other water resources.

Precipitation - Recharge was considered in limited areas of the model. More discussion on this will be included in the modeling section of this report.

Geology - Data gathered from existing well logs, discussion with USGS and MDH staff, and use of published and unpublished studies, including the Liesch Associates (1991) electrical resistivity survey, were used to construct a conceptual geologic model, define aquifer extent, and construct hydrogeologic cross sections (Figures 2 and 7). Descriptions of the geology including aquifers, confining layers, recharge areas, discharge areas, and any sensitive areas are included in Section 3.0 of this report.

Soils - Soil characteristics that could influence the subsequent delineation of the WHPAs were considered. Variable recharge rates were partially defined based on the sand content of the surficial soil and glacial drift, and extent of the unconfined/semiconfined aquifer.

Water Resources - Surficial water features and watersheds were assessed based on existing maps and publications, and discussions with MDH and USGS staff. Isotopic water data from the City wells plots on or near the meteoric water line and is isotopically different from water collected from Judicial Ditch #66 (Figure 8). Data for the City wells is from April 11, 2005 and the ditch sample is from Station #5078770 collected on July 14, 2004 (data provided by MDH and USGS staff). If these data represent the general conditions of the site, then it seems unlikely that water from this ditch, or other surface water bodies, influences groundwater recharge. Therefore, surface waters were not

considered a significant source of recharge to the subject aquifers within the WHPAs and a conjunctive delineation was not considered.

### **2.1.2 Land Use Data Elements**

Regardless of whether an aquifer is unconfined or not, land use always factors in determining and managing the DWSMA around the WHPA. Unconfined aquifers, however, are particularly vulnerable to land use factors since they may be in direct contact with surface water and directly recharged by precipitation. Land and ground water uses within the DWSMA may have effects on the aquifer used by some of the City wells as portions of the aquifer exhibit unconfined and semiconfined conditions.

Land Use - Political boundaries, public land survey boundaries, and cultural features were used to establish the DWSMA for the City.

Public Utility Services – Construction, maintenance, well logs, and pumping records of public water supply wells were used for delineating the WHPAs, to establish the DWSMA, and to conduct the subsequent City well and DWSMA vulnerability assessments.

### **2.1.3 Water Quantity Data Elements**

Surface water features can impact an aquifer that is unconfined if there is hydraulic connection. High-capacity wells in the immediate vicinity of each other can also influence one another.

Surface Water Quantity - Surface water bodies were included in the model as boundary conditions to define the ground-water flow field (Figure 2). However, these features are located at a distance where they do not influence the subsequent delineation of the WHPAs. The flow boundaries are discussed in more detail in Section 3.0.

Ground Water Quantity - Six active water supply wells (Wells No. 1 through 6) are located east of the City and distributed between two wellfields as shown on Figures 1 and 4. These wells provide all the water for the City's distribution system. Well construction details, past and projected pumping rates are presented in Table 1. Review of the Minnesota Department of Natural Resources (DNR), Water Appropriations Permit Program database identified five other high-capacity wells/discharge points within the model domain. These discharge points are illustrated on Figure 4 and listed in Table 2.

Three of these locations are for surface dewatering of gravel mining operations. These discharge points were modeled as shallow wells.

#### **2.1.4 Water Quality Data Elements.**

Water quality is an indication of aquifer vulnerability. Unconfined aquifers make surface water quality a necessary element. The vulnerability of a confined system can be assessed with chemical data, including organic and inorganic chemicals, tracer results, isotopic and dissolved oxygen data.

Surface Water Quality – Stable isotope and chemical monitoring data was obtained from the MDH and USGS, and reviewed as part of this study. Water quality is described briefly in the Vulnerability Assessment section of this report (Section 4.0).

Ground Water Quality - Stable isotope and chemical monitoring data, including volatile organic compound analysis results, was obtained from the MDH and USGS, and reviewed as part of this study. Water quality is described briefly in the Vulnerability Assessment section of this report (Section 4.0).

### **3.0 WHPA AND DWSMA DELINEATION (MR 4720.5205)**

#### **3.1 Boundaries, Wellhead Protection Area Map**

A map illustrating the locations of the WHPAs for each well are shown on Figure 15.

#### **3.2 Documentation**

##### **3.2.1 Physiographic and Hydrogeologic Setting**

The City is located in Polk County along the Red Lake River (Figures 1 and 2). The old well field (Wells No. 1 through 4) is located approximately 12 miles east of the City, at the southwest corner of Red Lake County. The new well field (Wells No. 5 and 6) is located approximately 19 miles east-southeast of the City. The surface elevation of the City wellfields and surrounding area of interest ranges from approximately 260 to 350 meters (m) above mean sea level (m-amsl) (850 to 1150 feet above mean sea level [ft-amsl]). The USGS 7.5 minute topographic maps indicate there are several rivers, lakes, wetlands, and streams in the vicinity of the City. Surface water flow is generally to the west-northwest toward the River.

The geology in the vicinity of the City consists of surficial beach deposits that are made up primarily of wave-washed till and sandy beach ridges. These are underlain by glacial drift that consists of layers of sand and gravel, and till. Precambrian-aged bedrock ranges from 37 to 120 meters below ground surface (bgs) (120 to 392 feet bgs).

Sustainable ground-water yields are obtained from the sand and gravel layers, which are referred to as the surficial unconfined/semiconfined aquifer and the shallow confined aquifer (Cowdery and Walsh, pers. comm., 2006; Lindgren, 1996). These supply water to the City wells. A deep confined aquifer is also present, but is beyond the scope of this study. Hydrogeologic cross sections through the study area show these units (Figures 2 and 7). For the purpose of this model, the surficial unconfined/semiconfined aquifer and the shallow confined aquifer were labeled as S1 and S2, respectively. Ground-water flows in the glacial drift in a general southeast to northwest direction toward the River (Figure 3), which serves as the local and regional hydrologic discharge point for the flow system. The generalized potentiometric surface map shown on Figure 3 is consistent with observations made by the USGS (Cowdery, pers. comm., and unpublished map, 2006).

##### **3.2.2 Delineation Criteria**

The following discussion represents a summary of the five criteria for delineating the WHPA, which are specified in MR 4720.

Time of Travel- Travel times of 1-, 5-, and 10-years were used when simulating ground-water movement with pathlines. The 10-year time of travel was used to delineate the WHPA.

Daily Volume of Water Pumped - The City currently has six active water supply wells (Wells No. 1 through 6), located east and east-southeast of the City (Figures 1 and 2). Wells No. 2 and 3 are completed in the surficial unconfined/semiconfined aquifer, and Wells No. 1, 4, 5, and 6 are completed in the shallow confined aquifer. Well construction details are presented in Table 1 and well logs are in Appendix I.

The daily volume selected for each well used in the WHPA was based on MN 4720.5510, subpart 4 and MDH guidelines, which state that volumes used in the WHPA delineation must be based on the greatest annual volume of water used during the previous 5 years or the greatest annual volume projected over the next 5 years, whichever is greater. The City and MDH determined historical usage from the preceding 5 year period (2000 to 2004) would be used to determine the pumping rates for each well to delineate the WHPA, because the City does not anticipate significant water usage increases over the next 5 years. The City's historical pumping records from 2000 to 2004 indicate the maximum annual usage of the total system was 325.2 million gallons per year (mgy) (approximately 1.2 million cubic meters per year [m<sup>3</sup>/yr]) based on the maximum rates for each well over the 5-year period, or approximately 0.89 million gallons per day (mgd) (approximately 3,370 cubic meters per day [m<sup>3</sup>/day]). This rate was divided so fifty percent of the flow was assigned to Wells No. 1 through 4 (normalized between these wells based on historical usage), and the remaining assigned to Wells No. 5 and 6. As a result of this reallocation the pumping rates applied to the existing wells is less than the historical rates. Therefore, the City will ask for a variance to the rule when requesting the approval of Part I of the WHP Plan from the MDH. Pumping values applied to each well in the model are in Table 1.

Flow Boundaries - Hydrologic boundaries that can affect delineation are surface water features, geological boundaries, high capacity wells, and overland drainage.

Surface water features include the River, which is the local and regional discharge point of the flow system of interest. Therefore, the River affects the direction of ground-water flow and was included in the flow model as a constant-head boundary. The area

near Maple Lake is also included in the model as a constant head boundary forming the upgradient head for the aquifers.

Geological boundaries were necessary to create the conceptual geologic model and identify key hydrostratigraphic units used in the flow model. Geologic information was obtained from the Minnesota County Well Index (CWI), and information from the *Availability and Quality of Water from Drift Aquifers in Marshall, Pennington, Polk, and Red Lake Counties, Northwestern Minnesota* (USGS, 1996).

The five high-capacity wells/discharge points identified in the model domain that could influence ground-water flow, and/or create negative boundary conditions that could affect the delineation of the WHPA, were included in the model (Table 2). Historical maximum discharge rates for these from the previous 5 years (2000 to 2004), as obtained from the DNR Water Appropriations Permit Program were applied.

Surface runoff is directed toward local streams and ditches and eventually the River, which is the only surface water feature of interest since it is the primary discharge point for the regional aquifers.

Ground-water Flow Field - The ground-water flow field was simulated using MODFLOW. Simulated heads were calibrated to static water levels obtained from 133 wells in the CWI and screened in the various geologic units. The generalized potentiometric surface map shown on Figure 3 is consistent with observations made by the USGS (Cowdery, pers. comm., and unpublished map, 2006).

Aquifer Transmissivity - The transmissivity (T) of an aquifer is defined as the rate at which water is transmitted through a unit width of aquifer under a hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness. Several aquifer analyses have been performed in the area of the City wellfields dating back to the 1970's. The most recent tests performed in the area of Wells 5 and 6 found an average T value of approximately 30,000 gallons per day per foot (gpd/ft) for the shallow confined aquifer. This translates into a hydraulic conductivity for the aquifer of approximately 67 feet per day (ft/day) or 20 meters per day (m/d) with an estimated aquifer thickness of 60 feet. Earlier studies by the City and other consultants (Liesh, 1991) concluded that the surficial unconfined/semiconfined aquifer has a higher conductivity than the shallow confined aquifer and that the transmissivity in the shallow confined aquifer is lower in the vicinity of Wells No. 1 and 4 than in the area of Wells No. 5 and 6.

### **3.2.3 Delineation Method.**

The ground-water flow model was setup using the data elements and conceptual hydrogeologic model that was developed to identify the hydrogeologic units, hydrologic processes, and boundaries that control the flow conditions observed in the vicinity of the City well fields. These conditions were evaluated to determine the dimensions of the numerical model and design of the finite-difference grid (Figures 5 and 6). Data sources utilized to develop the conceptual hydrogeologic model included USGS and MDH maps, and CWI data. These sources were obtained as hard copy maps and ArcView layers (shapefile and image formats).

As discussed in Section 3.2.1, ground water is encountered in sand and gravel layers associated with glacial deposits. The model was developed to represent the surficial unconfined/semiconfined aquifer and the shallow confined aquifer. The domain was divided into a three-dimensional, non-uniform grid as shown on Figure 5. The model has 332 rows, 338 columns, and 6 active layers. Finer grid spacing, shown on Figure 6, was applied in the vicinity of the well fields. This grid spacing provides better definition in the area of the flow field where simulating the influence of pumping.

Several steps were required to incorporate the hydrostratigraphic units from the conceptual model into the flow model. First, the surface elevation was imported to define the surface of the top layer of the model. The sand units were defined from elevations estimated from the geologic cross sections created from CWI data (Figure 7).

The size of the domain and the general flow-field characteristics of the model were based on boundary conditions. Measured heads obtained from CWI logs with screened intervals completed in the glacial aquifers near these features suggest that they reflect the water table surface; however, the River is the only significant natural feature within the model domain that controls flow and impacts the WHPA with respect to boundary interference. It is unclear exactly how well the River is connected hydraulically to the underlying aquifer systems. As a result, a constant-head condition was assigned at the northern, northwestern, and western edges of the model domain to represent the River. The southwestern and eastern boundaries were defined as no-flow boundaries because they are generally parallel to the direction of flow. The southeastern boundary is defined as a constant head boundary in an area of lakes and wetlands assumed to be the primary recharge point for the shallow confined aquifer.

### **3.2.4 Other Model Input Parameters .**

Discretization of aquifer properties involves assigning initial values to each cell in the model domain. Hydraulic properties input for this model included horizontal components for

hydraulic conductivity ( $k_x$  and  $k_y$ ), vertical hydraulic conductivity ( $k_z$ ), specific yield (Sy), specific storage (Ss), and effective porosity ( $n_e$ ) (required for MODPATH to calculate linear flow velocity).

Hydraulic properties were assigned to the model domain grid using the data elements and delineation criteria described in Sections 2.0 and 3.0, and based on geologic information from well logs and cross sections (Figure 7). Initial hydraulic conductivities for the model were obtained from USGS estimates and published values typical for the aquifer materials as well as transmissivity results from pumping tests (section 3.2.2). The initial conductivity for the shallow confined aquifer was taken from the WSN pumping test found in Appendix II. The value for the surficial aquifer in the area of the old well field (approximately 250 ft/day) was estimated from the range established by several previous pumping tests and information contained in the Lindgren report. The till conductivity (~1.0 ft/day) was based on the value from the Lindgren model (Lindgren, 1996). The value for effective porosity for the sand is 0.25. All model input values are summarized in Table 3. Final conductivity values, determined during calibration, are within the ranges of the aquifer test results and are consistent with the aquifer materials.

### **3.2.5 Delineation Results**

Calibration - The goal of numerical model calibration is to obtain a reasonable correlation between the simulated model results and observed field data. The calibration process is completed by running several steady-state simulations and comparing calculated heads to the measured head data at known calibration points within the model domain. For this calibration, 133 CWI well locations were used for comparison. These wells are private or municipal and are completed in the glacial sediments.

Figure 9 presents the calibration wells and simulated potentiometric contour map for steady-state conditions. Flow is toward the River, which flows west along the northern side of the domain. Using the head values from the 133 measured wells, an error analysis on the steady-state model was performed. Figure 10 presents a plot of the results of this analysis indicating that the overall normalized root mean squared (NRMS) error for the ground-water flow model is approximately 4.6 percent. In general, a NRMS of approximately 10 percent or less is acceptable (National Ground Water Association, 1998). Table 4 summarizes the measured, simulated, and residual head values from all 133 wells.

A transient calibration was also completed in the vicinity of Wells No. 5 and 6 to further refine the conductivity value for the shallow confined aquifer. Results of this

calibration can be seen on Figure 10 and the original pumping test data can be found in Appendix II. In completing this calibration, the hydraulic conductivity of the shallow confined aquifer as well as its specific storage value were reduced in order to obtain a reasonable comparison to observed data. The calibrated value for the conductivity of the shallow confined aquifer is 51 ft/day as compared to the original 67 ft/day. The calibrated value for the till remained at approximately 1.0 ft/day and the value for the surficial, unconfined aquifer changed from over 200 ft/day to 83 ft/day. The final values are summarized in Table 3.

Another test of the calibration process is the frequency distribution of the error. A “good” calibration will have error values that follow a normal distribution (bell-shaped) curve. Figure 11 illustrates that the error values for all wells in this model closely approximate a normal distribution.

Uncertainty - The calibration data shows a reasonably close correlation between measured and calculated head values. However, the model is based on a large amount of data and the head measurements used in the calibration are single measurements that are listed on each well record that were collected during different seasons, over many years and in different aquifers. Because the area of the model is so large, there is uncertainty in the result when focused on any particular area. Also, the simple fact that glacial deposits are highly inhomogeneous, as evidenced by the variation in pumping test results, forces the generalization of the area of interest, adding to the uncertainty. Fortunately, good pumping test data provide greater accuracy in the area of Wells No. 5 and 6.

In order to address some of the uncertainty, sensitivity analyses were performed that consisted of increasing and reducing the conductivities for each of the major units and the recharge value by 50%. The ten-year pathlines were plotted for each of the resulting model runs and then compiled into a single, composite capture zone (Figure 15). This composite zone, therefore, accounts for some of the variability in the input parameters. For example, the conductivity values for the shallow confined aquifer, as determined from pumping tests, ranged from less than 30 ft/day to over 70 ft/day. The final calibrated value for this aquifer is 51 ft/day. This value was then varied from 26 ft/day to 76 ft/day to include most of the range. However, it is not uncommon for parameters to vary by an order of magnitude or more over short distances in glacial deposits. Therefore, even under ideal circumstances, there would still be a significant amount of uncertainty. This model is intended to represent average conditions.

More extensive observation data collected within the same general time period, and more accurate, site-specific T values from additional aquifer tests throughout the model domain, particularly upgradient of both wellfields could improve calibration and model confidence. Additionally, a more detailed and reduced scale modeling effort based on these results could increase accuracy and confidence within each individual wellfield.

WHPA Delineation - With the flow fields calibrated, a ground-water pathline analysis was performed using MODPATH to delineate the capture zones for 1-, 5-, and 10-year times of travel and ultimately the WHPA for the 10-year time interval. The flow rates applied to each well used in the delineation are listed in Table 1. The capture zones used to delineate the WHPAs were established for each of the six City wells by placing 20 ground-water particles around the wells in each of the model layers in which the wells are completed. The particles were then tracked backward from the wellhead through the flow field for the specified travel time. The pathlines projected to the surface from all model layers are shown on Figures 12, 13, and 14 for the 1-, 5-, and 10-year time of travel, respectively. The final WHPAs presented in Figure 15 encompass all 10-year time-of-travel capture, including the sensitivity analyses scenarios. It can be seen that the higher conductivity and influx from recharge in the unconfined/semiconfined surficial aquifer causes the shape of the capture zones to be narrower and extend further upgradient when compared to the capture zones in the shallow confined aquifer. The City well capture zones were not adversely affected by groundwater withdrawal from nearby water supply wells or gravel pits. As mentioned in Section 2.1.1, it was determined that surface waters were not a significant factor on the subject aquifers and subsequent delineation of the WHPAs. Therefore, a conjunctive delineation was not considered.

### **3.3 DWSMA Boundaries**

The Drinking Water Supply Management Area (DWSMA) for each well field area were delineated using section and quarter section boundaries, and the composite 10-year WHPAs generated by the model. The DWSMA delineation encompasses each well field's WHPA(s) separately, as they are two distinct well fields. Figure 16 shows the final DWSMA boundaries for the City wells.

## 4.0 VULNERABILITY ASSESSMENT

### 4.1 Well Vulnerability

The well vulnerability assessment was conducted in accordance with the MDH guidance document, *Assessing Well Vulnerability for Wellhead Protection* (MDH, 1997) and in accordance with MR 4720.5550. A well's vulnerability is scored on a Vulnerability Assessment Worksheet based on the following six categories: DNR geologic sensitivity rating, casing integrity, casing depth, pumping rate, isolation distance from contaminant sources, and chemical and isotopic information. A numeric score is given to each well based on this data. A score of 45 or above causes a well to be considered vulnerable.

A Level 2 assessment was completed for the surficial unconfined/semiconfined aquifer, in which City Wells No. 2 and 3 are completed. The Level 2 assessment considers depth to the water table and the characteristics of the vadose material to determine an estimate of the vertical downward travel time of contaminants from the surface to the water table (DNR, 1991). For the purpose of the Level 2 assessment, it was assumed that the depth to water across the surficial aquifer extent (Figures 2 and 7) was less than 20 feet with isolated overlying low permeable units greater than 10 feet thick. Some clay is present near grade at select locations throughout the extent of the surficial aquifer, and may provide a barrier to the vertical migration of contaminants (Figure 7).

A Level 3 assessment was conducted for the shallow confined aquifer because it is overlain by varying thicknesses of till. The Level 3 assessment evaluates the sensitivity of aquifers below the water table aquifer and considers the cumulative thickness of low permeability, or confining, geologic units (DNR, 1991). The DNR geologic sensitivity rating is an empirical value determined by dividing the cumulative thickness of low permeability units (e.g. clay) above the aquifer by 10. The resulting score is termed the "L-score". A higher L-score indicates more low-permeability material above the aquifer, and therefore a lower vulnerability. A low L-score represents higher vulnerability. For example, a rating of L-1 has a higher vulnerability than L-9, because there is less low-permeability material present above the aquifer.

A well is automatically considered vulnerable, independent of its score, if tests indicate nitrate-nitrogen levels are greater than 10 mg/L, there are detections of pathogens or human-made chemical compounds above background levels, or if tritium is detected at 1 tritium unit (TU) or more. MDH considers a well that meets or exceeds any one of these criteria to be vulnerable.

Vulnerability assessment worksheets and the total score of the six vulnerability categories for Wells No. 1 through 6 are presented in Appendix III. Per MDH guidance, any well that receives an assessment rating of 45 points or greater is considered a vulnerable well. In addition, if tritium is detected a well is considered vulnerable because this isotope is indicative of post-1953 recharge. Wells No. 1, 2,

3, and 4 are vulnerable because they contain tritium greater than 1 TU, even though they have vulnerability scores less than 45 points. Although Well No. 5 does not have data to support a tritium detection (no sample was collected from this well for tritium analysis), it is still considered vulnerable due to its vulnerability score of 45 and its proximity to Well No. 6, which is completed in the same aquifer and has a tritium detection. Although Well No. 6 has a tritium detection less than 1 TU, it is still considered vulnerable due to its vulnerability score of 45.

Nitrate-nitrogen detections also indicate that at least one of the City wells may be impacted by low levels of nitrate contamination; however, the analytical result is from treatment plant effluent and cannot be associated with a particular well. In addition, the USGS provided data from the Glacial Ridge Project indicating there were several sample locations within the domain from the shallow unconfined/semiconfined aquifer that had nitrate-nitrogen detections in ground water that exceeded the criteria of 10 mg/L. There were detections of lead and copper in several domestic wells in the vicinity of the City; however, it is presumed that these detections are the result of individual domestic well service lines and not representative of impacts in the aquifer. There were no significant detections of volatile organic compounds.

#### **4.2 DWSMA Vulnerability**

As described above, the lithology in the proposed DWSMAs consists of varying combinations of sand, gravel, clay, and silt. In general, the sand aquifers are divided into a surficial unconfined/semiconfined aquifer and a shallow confined aquifer as illustrated on Figure 7. The two aquifers are separated by a laterally extensive till that exists across the entire model domain, except for the area east of Maple Lake. Vertical leakage between the two aquifers likely exists and was determined by the tritium data from both well fields (MDH) and temperature data for the new well field (USGS).

The Level 2 assessment, as discussed in Section 4.1, was completed for the surficial unconfined/semiconfined aquifer, in which City Wells No. 2 and 3 are completed. For the purpose of the Level 2 assessment, it was assumed that the depth to water across the surficial aquifer extent (Figures 2 and 7) was less than 20 feet with isolated overlying low permeable units greater than 10 feet thick. Some clay is present near grade at select locations throughout the extent of the surficial aquifer, and may provide a barrier to the vertical migration of contaminants (Figure 7). The geologic sensitivity for the surficial system in the proposed DWSMA is high to moderate.

Figure 17 illustrates the geologic sensitivity ratings (L-scores), also discussed in Section 4.1, throughout the DWSMAs and surrounding area for the shallow confined system. The L-score ratings ranged from L-0 (no confining units) to L-28 across the model domain and were based strictly on the lithologic description in the CWI. The L-score ratings ranged from L-2 to L-15 within the DWSMAs.

The geologic sensitivity for the shallow confined system in the proposed DWSMAs is rated as low to very low, as determined by the thickness and lateral extent of the till that significantly reduces the vulnerability of this aquifer to impacts from contaminants at grade.

Figures 18 and 19 illustrate the vulnerability assessments of the DWSMAs for both the surficial unconfined/semiconfined and shallow confined aquifers, respectively. The calculated vulnerability values were based on MDH guidelines; *Assessing Well and Aquifer Vulnerability for Wellhead Protection*, (MDH, 1997). Pursuant to MDH guidance (MDH, 1997), the presence of tritium in City Wells No. 1, 2, 3, 4, and 6 would result in the geologic sensitivity ratings automatically increasing by one classification. Discussions with the MDH indicated if the area already possesses a high vulnerability classification, the rating does not need to be increased. Therefore, the vulnerability rating of the surficial unconfined/semiconfined aquifer (Wells No. 2 and 3) is high with isolated areas of moderate, and the rating of the shallow confined aquifer (Wells No. 1, 4, 5, and 6) is moderate. Figure 20 illustrates the cumulative DWSMA vulnerability assessment, which concatenates the results presented on Figures 18 and 19.

#### **4.3 Recommendations for Future Improvements**

Although not required, the following items would improve the understanding of the aquifer systems, the groundwater flow model discretization, and the resulting WHPAs and DWSMAs.

- Conduct additional aquifer pumping tests to spatially refine transmissivity values across the model domain.
- Collect or incorporate groundwater level measurements from many wells across the domain from a similar time. Groundwater levels used in the model were from the CWI and range over many years.
- Collect annual groundwater samples from Wells No. 5 and 6 for tritium analysis to evaluate whether pumping from these wells is drawing near surface water through the confining unit. The time it takes for “young” water to travel to the confined aquifer may be used to refine hydraulic conductivity estimates of the confining till for future delineations.
- Collect groundwater samples for nitrate analysis to determine the potential impacts to the aquifer systems.

- Collect quarterly water samples for one year from the City wells and Judicial Ditch #66 for isotopic analysis to identify seasonal variations.
- Use of real-time USGS pressure-temperature data being gathered near the new well field could be useful in estimating recharge from the beach ridge aquifer to the confined aquifer.

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DSH:mcp  
August 8, 2006  
S:\Tech\Crookston WHP\Documents\Crookston-Final\_8-06.doc

## 5.0 REFERENCES

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# **TABLES**

**Table 1**

**Summary of the Municipal Wells used in the WHPA Delineation  
City of Crookston, Minnesota**

Well No.	Unique No.	Aquifer	Year Constructed	Casing Depth (ft)	Well Depth (ft)	Past Use (MGY)					Projected Value Used in the WHPA Delineation 2006-2010 (MGY)	Vulnerability Status
						2000	2001	2002	2003	2004		
1	147243	QBAA	1978	138	164	130.0	132.0	114.9	127.2	126.8	66.6	Vulnerable
2	191552	QBAA/QWTA	1982	41	56	47.5	48.2	42.0	50.2	50.0	24.4	Vulnerable
3	191553	QBAA/QWTA	1982	50	70	82.4	83.7	72.9	59.3	59.1	42.3	Vulnerable
4	191554	QBAA	1982	127	156	57.1	58.0	50.5	59.2	59.0	29.3	Vulnerable
5	685466	QBAA	2003	93	123	N/A	N/A	N/A	N/A	N/A	81.3	Vulnerable
6	685465	QBAA	2003	88	118	N/A	N/A	N/A	N/A	N/A	81.3	Vulnerable
<b>Total</b>											<b>325.2</b>	

**Notes:**

- Projected use is the combined maximum annual pumping volume for each individual well between 2000 and 2004, distributed between the old and new wells.
- QBAA: Quaternary Buried Artesian Aquifer
- QWTA: Quaternary Water Table Aquifer
- MGY: million gallons per year

**Table 2**

**Appropriation Permit Wells in Model Domain  
City of Crookston, Minnesota**

Well No.	Unique ID No.	Permit ID	Coordinates		Pumping Rate (2000-2004 Maximum) (MGY)
			Easting	Northing	
J & S GRAVEL INC	N/A	021081	241684	5293594	26.6
SWANSON JR, JOHN E	N/A	761339	259759	5286852	66.5
BRADSHAW GRAVEL SUP	N/A	781310	252754	5290947	112.4
J & S GRAVEL INC	N/A	901002	249961	5296953	32.6
LEE NURSERY INC	457604	901173	252877	5282867	8.2

**Notes:**

- Well pumping rates were downloaded from the MN DNR Water Appropriation Permit Website
- The five year maximum rate from 2000 to 2004 was used in the table
- Coordinates are UTM, Zone 15, NAD83, and are from the MN County Well Index (CWI)
- MGY: million gallons per year

**Table 3**

**Model Input Data  
City of Crookston, Minnesota**

<b>Geologic Unit</b>	<b>Horiz. Hydraulic Conductivity (m/s)</b>	<b>Vert. Hydraulic Conductivity (m/s)</b>	<b>Porosity</b>	<b>Effective Porosity</b>	<b>Storativity</b>
Unconfined/Semiconfined	2.90E-04	7.00E-05	0.3	0.25	2.9e-5
Till	3.50E-06	7.00E-08	0.3	0.25	2.9e-5
Shallow Confined	1.80E-04	1.50E-05	0.3	0.25	2.9e-5

**Notes:**

-Conductivities for all aquifers are from USGS and pumping test estimates, then modified through calibration process.

**Table 4**  
**Calibration Data**  
**City of Crookston, Minnesota**

<b>Well/Obs. Point</b>	<b>Observed Head (m- amsl)</b>	<b>Calculated Head (m- amsl)</b>	<b>Calculated vs. Observed Head (meters)</b>
101562/1	347.7768	349.2531	1.476282
101563/1	354.7872	349.9706	-4.81665
101564/1	349.3008	348.7344	-0.56643
101565/1	351.7392	357.2031	5.463925
101566/1	351.7392	353.8297	2.090512
101567/1	359.9688	355.8866	-4.08223
101571/1	350.2152	353.9591	3.743876
101771/1	348.6912	353.2289	4.537651
101801/1	295.3512	297.6739	2.322659
101802/1	290.1696	289.6085	-0.56114
101804/1	313.3344	321.7032	8.368756
101805/1	291.6936	301.5193	9.825718
101818/1	291.6936	296.8771	5.183475
101819/1	290.7792	296.0828	5.303594
101821/1	294.132	297.3734	3.241444
101823/1	281.3304	287.9879	6.657454
101824/1	284.0736	290.6126	6.538979
101826/1	306.0192	301.1652	-4.85401
101832/1	292.9128	298.4007	5.487865
101833/1	291.9984	295.2822	3.283766
101835/1	308.1528	312.7914	4.638551
102611/1	331.0128	330.9534	-0.05943
102612/1	331.0128	330.5305	-0.48228
102613/1	328.5744	327.4243	-1.15008
102614/1	322.1736	319.9188	-2.25478
103139/1	288.2494	291.3333	3.083892
103180/1	303.5808	308.892	5.311198
103197/1	302.3616	309.1235	6.761874
105609/1	272.796	276.535	3.738973
107901/1	282.8544	285.3349	2.480469
107904/1	357.5304	357.0111	-0.51926
107921/1	277.6728	276.3887	-1.28407
107926/1	288.036	287.1071	-0.92888
107932/1	345.6432	340.7681	-4.87513
107933/1	342.2904	340.7701	-1.52032
107949/1	306.9336	310.9151	3.98147
125721/1	323.3928	319.8639	-3.52891
128427/1	356.9208	357.5816	0.660835
132719/1	284.6832	290.8568	6.173612
132798/1	352.9584	354.1935	1.235112

**Table 4**

**Calibration Data  
City of Crookston, Minnesota**

<b>Well/Obs. Point</b>	<b>Observed Head (m- amsl)</b>	<b>Calculated Head (m- amsl)</b>	<b>Calculated vs. Observed Head (meters)</b>
101562/1	347.7768	351.2079	3.431147
101563/1	354.7872	351.2286	-3.55862
101564/1	349.3008	350.6818	1.381024
101565/1	351.7392	357.1277	5.388486
101566/1	351.7392	354.3451	2.605893
101567/1	359.9688	356.0659	-3.90291
101571/1	350.2152	354.4207	4.205515
101771/1	348.6912	352.5237	3.832482
101801/1	295.3512	297.5713	2.22012
101802/1	290.1696	289.8186	-0.35097
101804/1	313.3344	319.1725	5.838085
101805/1	291.6936	300.8383	9.144718
101818/1	291.6936	296.8691	5.17551
101819/1	290.7792	296.1602	5.381017
101821/1	294.132	297.3242	3.192188
101823/1	281.3304	288.8567	7.52632
101824/1	284.0736	291.31	7.236428
101826/1	306.0192	300.6707	-5.34849
101832/1	292.9128	298.1527	5.239879
101833/1	291.9984	295.7352	3.736799
101835/1	308.1528	311.6222	3.469362
102611/1	331.0128	328.1217	-2.8911
102612/1	331.0128	327.6133	-3.39955
102613/1	328.5744	325.7078	-2.86661
102614/1	322.1736	317.5718	-4.60182
103139/1	288.2494	291.4193	3.169952
103180/1	303.5808	308.2396	4.658763
103197/1	302.3616	308.2386	5.876986
105609/1	272.796	276.6185	3.822469
107901/1	282.8544	287.7464	4.891968
107904/1	357.5304	357.2783	-0.25214
107921/1	277.6728	276.609	-1.06379
107926/1	288.036	288.1856	0.149608
107932/1	345.6432	339.3167	-6.32652
107933/1	342.2904	339.3347	-2.95574
107949/1	306.9336	307.3802	0.446619
125721/1	323.3928	317.4179	-5.97486
128427/1	356.9208	357.6913	0.770515
132719/1	284.6832	290.9506	6.267392
132798/1	352.9584	353.528	0.569646
138857/1	272.796	279.5111	6.715139
140705/1	288.9504	296.3472	7.396829
147225/1	321.564	319.2697	-2.29432
147243/1	320.4972	314.8822	-5.61497

**Table 4**

**Calibration Data  
City of Crookston, Minnesota**

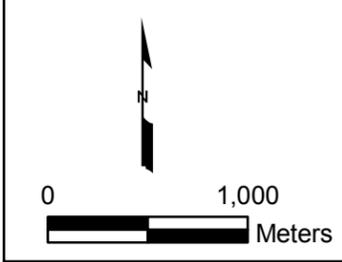
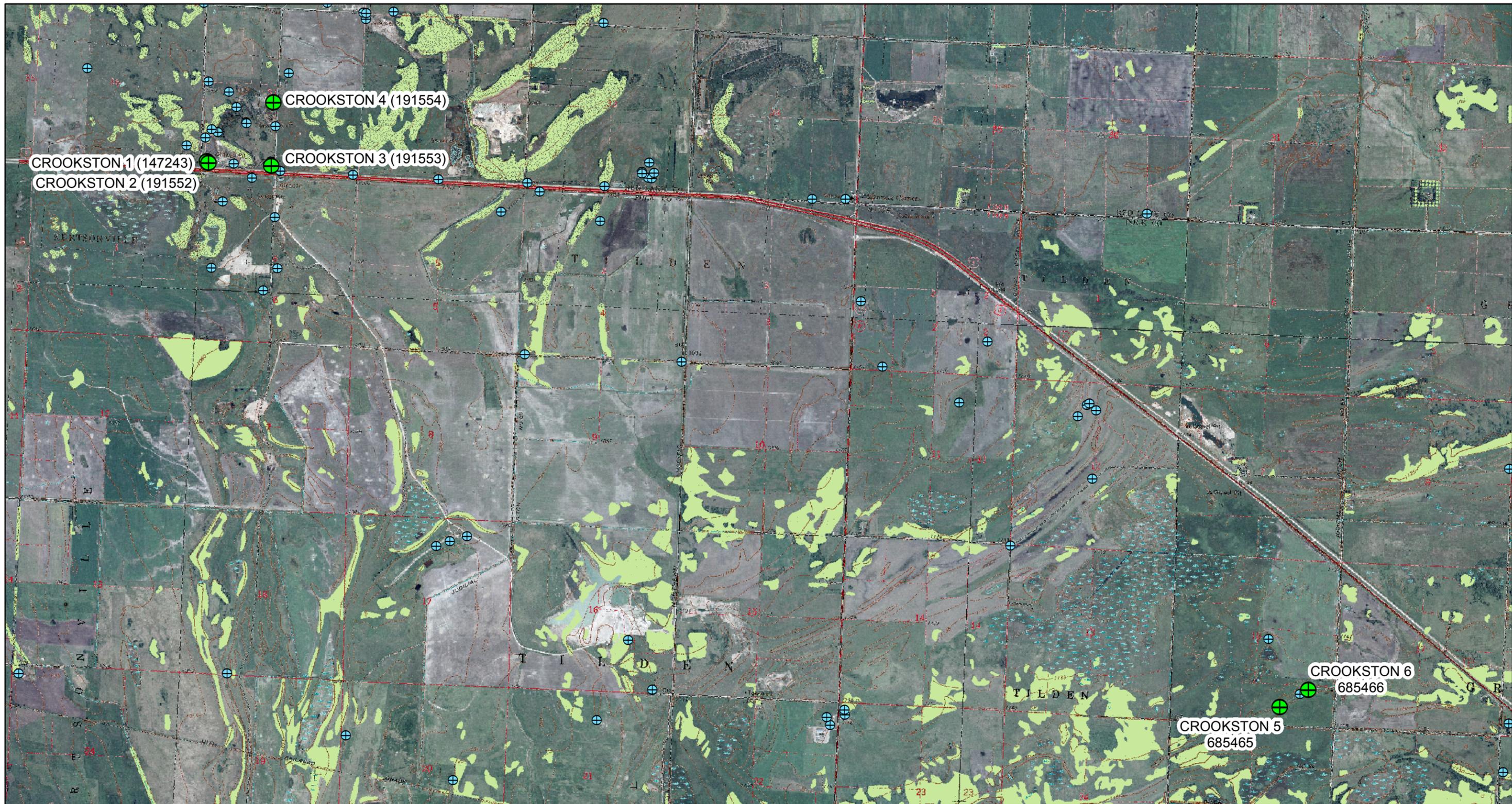
<b>Well/Obs. Point</b>	<b>Observed Head (m- amsl)</b>	<b>Calculated Head (m- amsl)</b>	<b>Calculated vs. Observed Head (meters)</b>
155355/1	290.7792	298.4043	7.625127
158520/1	298.0944	307.995	9.900595
158522/1	305.4096	303.4598	-1.94982
174703/1	302.9712	307.1526	4.181388
187495/1	351.1296	352.4154	1.285836
191552/1	324.2462	316.8755	-7.37078
191553/1	324.9473	318.1469	-6.80043
191554/1	321.3506	316.9001	-4.45052
215388/1	266.3952	261.3448	-5.05044
215408/1	288.6456	283.7829	-4.8627
221001/1	325.2216	318.3561	-6.86546
221002/1	324.612	319.9619	-4.65009
221003/1	331.6224	331.5645	-0.05795
221004/1	328.5744	326.7087	-1.86566
221005/1	328.8792	323.7575	-5.12172
221006/1	327.9648	321.2349	-6.72994
221063/1	338.328	337.2425	-1.08554
221629/1	333.4512	335.4641	2.012881
221630/1	321.8688	318.0381	-3.83065
221631/1	325.8312	324.0599	-1.77129
221633/1	323.088	318.9903	-4.09771
221640/1	273.4056	267.437	-5.96862
221641/1	271.272	262.7942	-8.47778
226291/1	343.2048	339.1622	-4.04257
267672/1	320.04	317.6712	-2.36883
267833/1	321.564	317.9176	-3.6464
267836/1	313.944	318.8109	4.866883
267838/1	313.6392	316.2393	2.600119
267839/1	326.7456	323.6263	-3.11929
267840/1	340.5835	351.759	11.17548
409821/1	285.9024	300.2863	14.38395
409905/1	354.7872	352.6357	-2.15149
429602/1	358.4448	356.9551	-1.48972
429618/1	306.0192	309.8699	3.850734
529377/1	355.3968	357.5037	2.106893
550683/1	352.3488	354.7709	2.422074
612927/1	358.4448	356.7927	-1.65214
617868/1	356.616	358.1677	1.551694
620657/1	335.2251	336.2015	0.976372
620661/1	324.548	323.6895	-0.85845
620663/1	329.2968	327.3119	-1.98489
620664/1	329.4553	325.4097	-4.04557
620665/1	330.8878	329.8082	-1.07964
620666/1	330.897	330.2117	-0.68528

**Table 4**

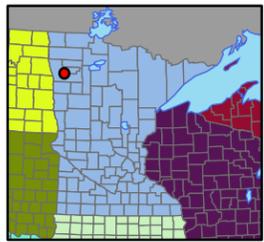
**Calibration Data  
City of Crookston, Minnesota**

<b>Well/Obs. Point</b>	<b>Observed Head (m- amsl)</b>	<b>Calculated Head (m- amsl)</b>	<b>Calculated vs. Observed Head (meters)</b>
620668/1	330.6928	328.9077	-1.78502
620669/1	352.2208	345.9584	-6.26241
620670/1	358.3534	350.1015	-8.25186
620671/1	343.9668	339.0861	-4.88074
620672/1	339.9922	339.3738	-0.61843

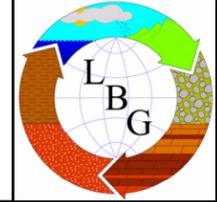
# **FIGURES**



-  Crookston City Well
-  Appropriations Well
-  MN CWI Well

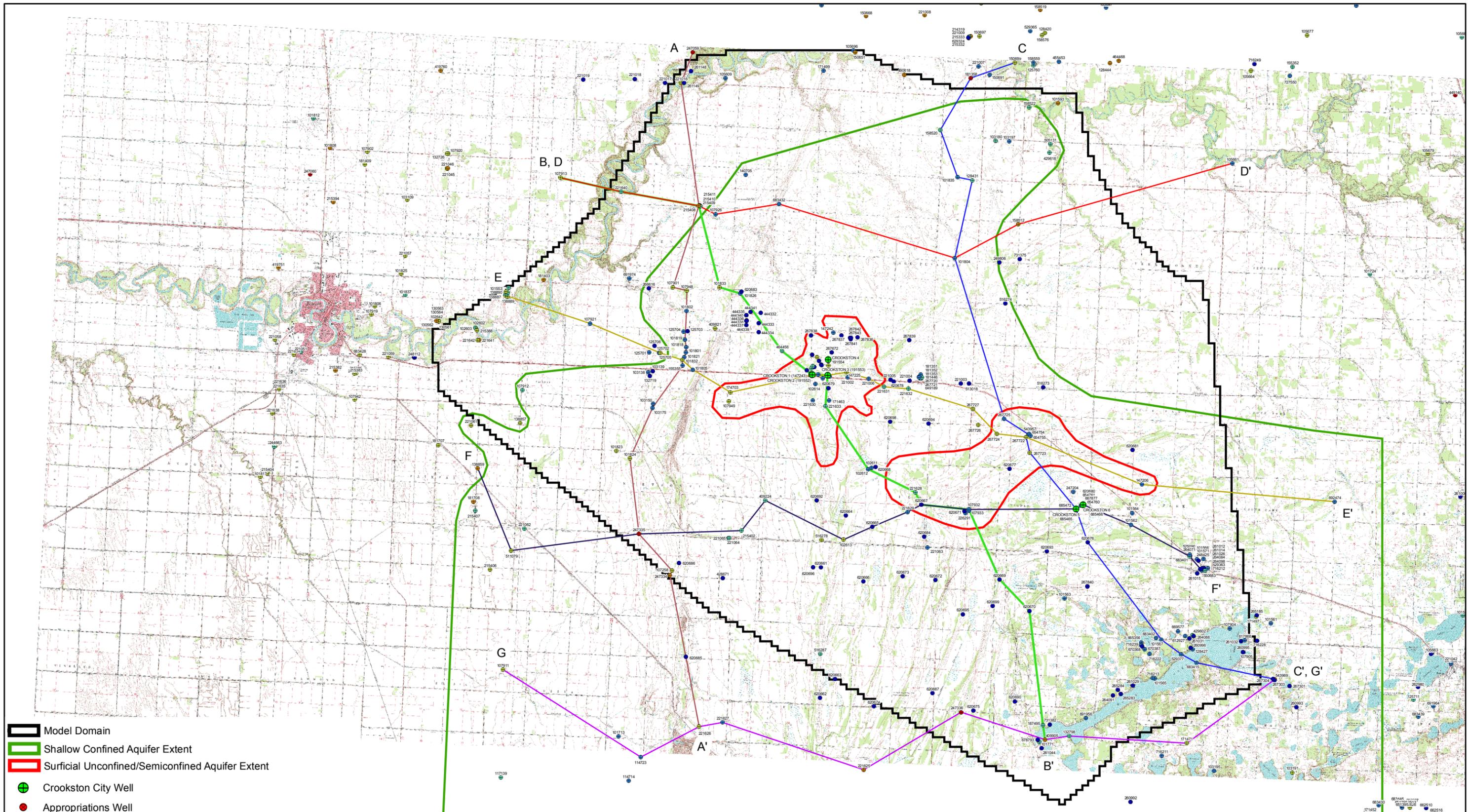


Source: MN CWI, MDH, and MN DNR Data Deli. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles. 2003-2004 Farm Services Administration Orthophotos.



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<b>CITY OF CROOKSTON</b>		
PART I WHP AND VULNERABILITY ASSESSMENT REPORT		
CROOKSTON, MINNESOTA		
<b>SITE LOCATION</b>		
FILE: G3CRKSTNWHP01G.MXD	DATE: 08/01/2006	FIGURE: 1

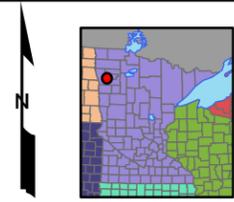


- Model Domain
- Shallow Confined Aquifer Extent
- Surficial Unconfined/Semiconfined Aquifer Extent

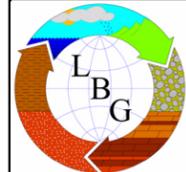
- ⊕ Crookston City Well
- Appropriations Well

- MN CWI Well (by depth in feet)**
- 0.00 - 50.00
  - 50.01 - 120.00
  - 120.01 - 180.00
  - 180.01 - 260.00
  - 260.01 - 360.00
  - 360.01 - 539.00

- Cross-Section Line**
- A-A'
  - B-B'
  - C-C'
  - D-D'
  - E-E'
  - F-F'
  - G-G'

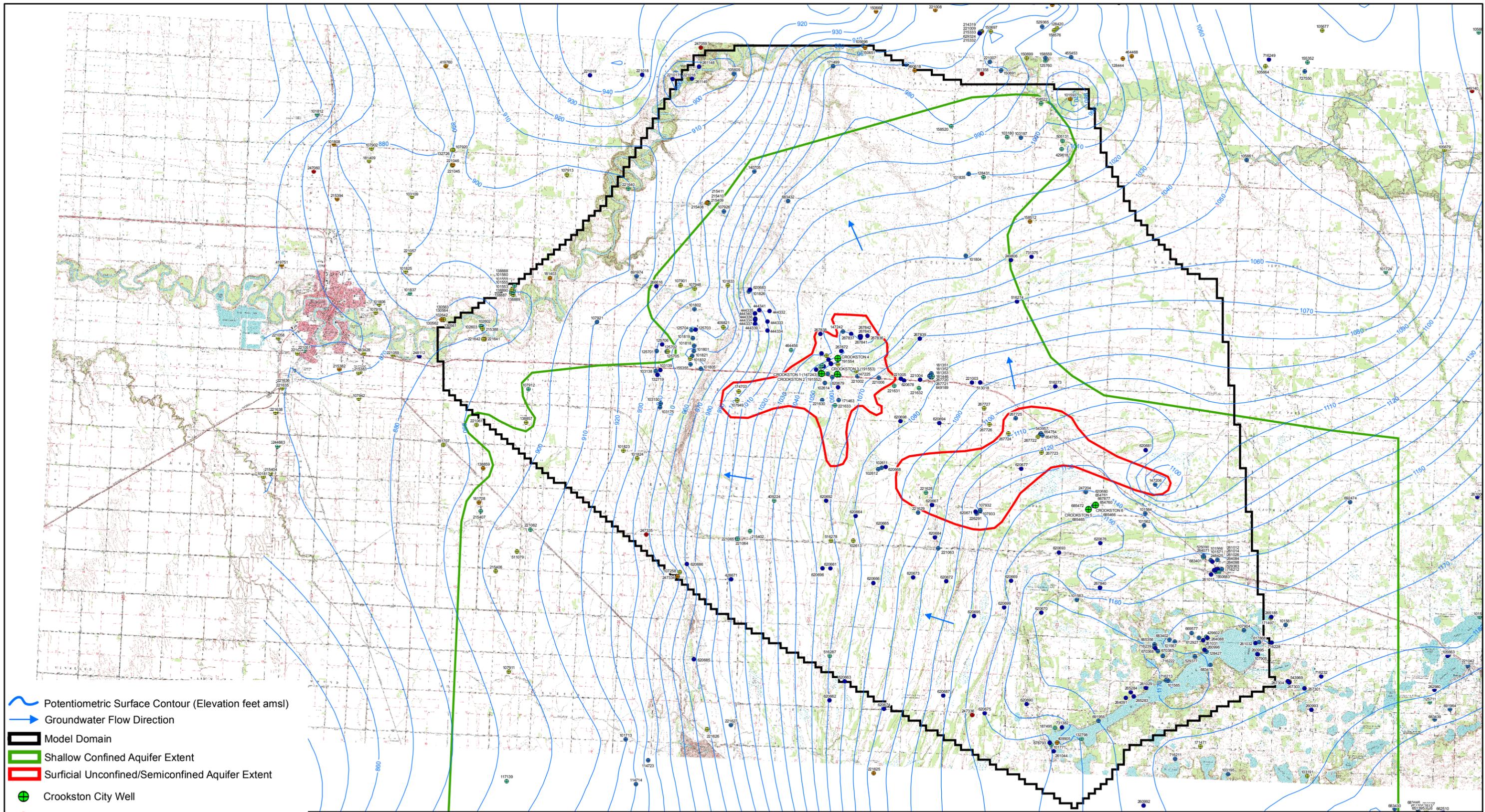


Source: MN CWI, MDH, and MN DNR Data Deli. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



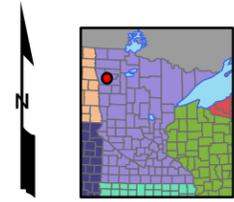
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<b>CITY OF CROOKSTON</b>		
PART I WHP AND VULNERABILITY ASSESSMENT REPORT		
CROOKSTON, MINNESOTA		
AQUIFER EXTENT, MODEL DOMAIN, AND HYDROGEOLOGIC		
CROSS-SECTION LOCATION MAP		
FILE: G3CRKSTNWHPO1H.MXD	DATE: 08/01/2006	FIGURE: 2

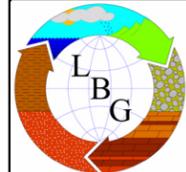


- Potentiometric Surface Contour (Elevation feet amsl)
- Groundwater Flow Direction
- Model Domain
- Shallow Confined Aquifer Extent
- Surficial Unconfined/Semiconfined Aquifer Extent
- Crookston City Well
- Appropriations Well

- MN CWI Well (by depth in feet)**
- 0.00 - 50.00
  - 50.01 - 120.00
  - 120.01 - 180.00
  - 180.01 - 260.00
  - 260.01 - 360.00
  - 360.01 - 539.00



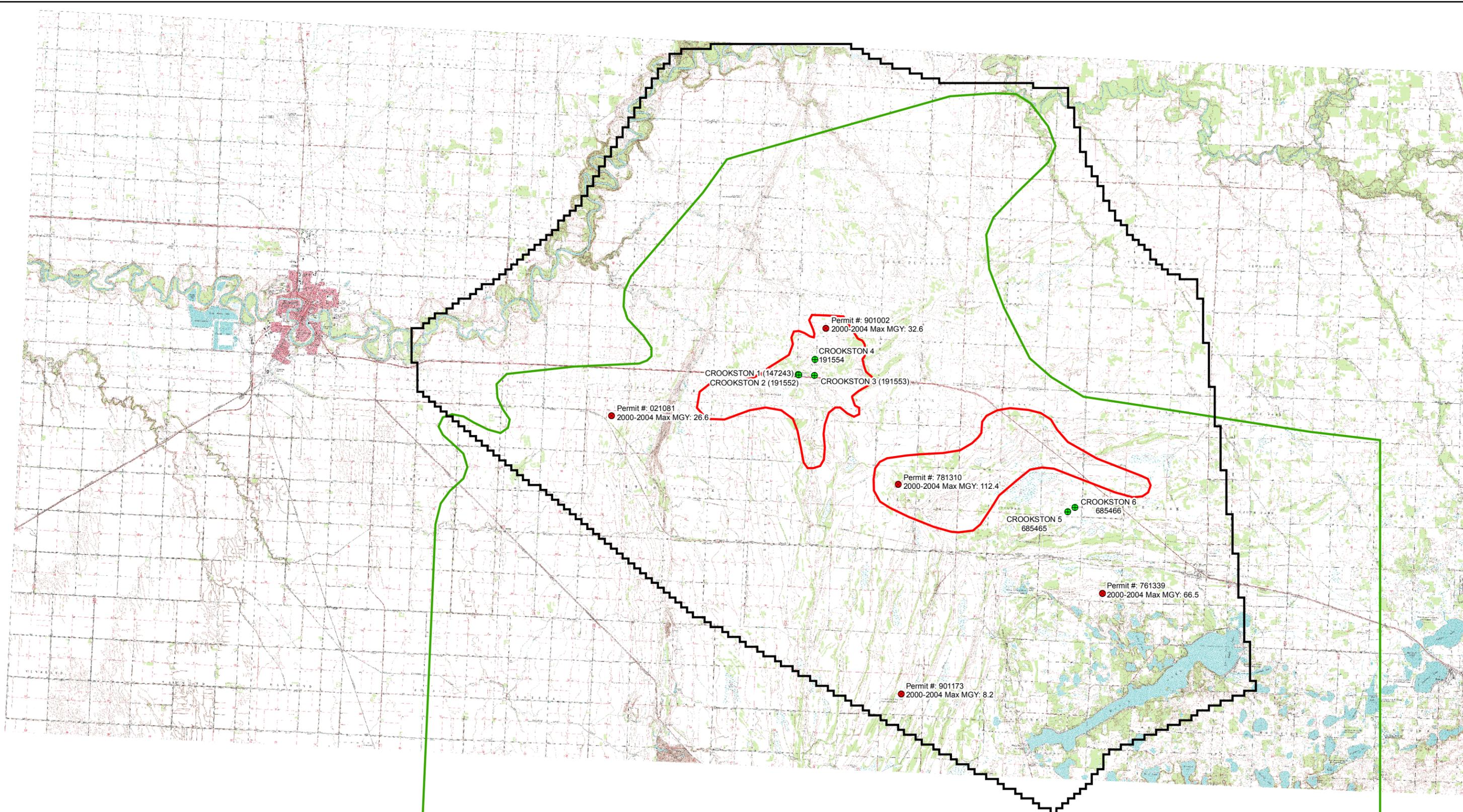
Source: MN CWI, MDH, and MN DNR Data Deli. USGS potentiometric contours. Gently, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles. Potentiometric surface created by kriging MN CWI water elevation data in Surfer 7, the same data used for model calibration.



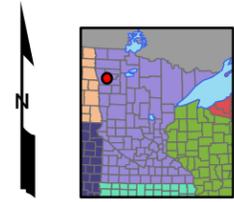
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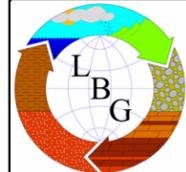
**POTENTIOMETRIC SURFACE MAP**



-  Model Domain
-  Shallow Confined Aquifer Extent
-  Surficial Unconfined/Semiconfined Aquifer Extent
-  Crookston City Well
-  Appropriations Well

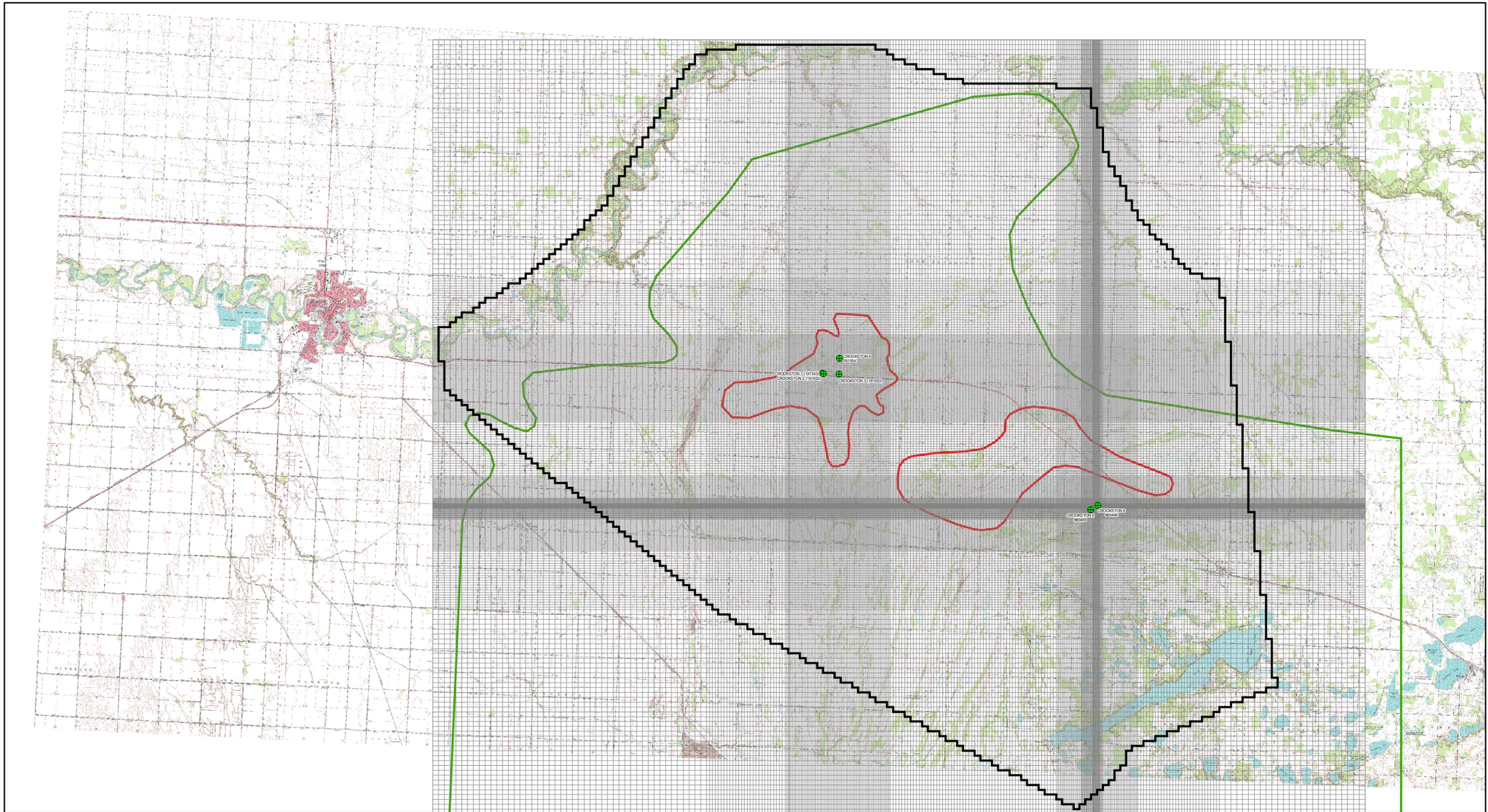


Source: MN CWI, MDH, and MN DNR Data Deli. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles. MN DNR Water Appropriations Permit Program [http://www.dnr.state.mn.us/waters/watermgmt\\_section/appropriations/wateruse.html](http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html)



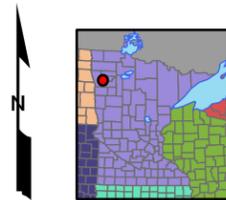
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LOCATION OF CITY AND SURROUNDING		
HIGH CAPACITY WATER DISCHARGE LOCATIONS		
FILE: G3CRKSTNWHPO10.MXD	DATE: 08/01/2006	FIGURE: 4

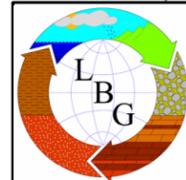


- Model Gridlines
- ▭ Model Domain
- ▭ Shallow Confined Aquifer Extent
- ▭ Surficial Unconfined/Semiconfined Aquifer Extent
- Crookston City Well

0 3,500  
Meters



Source: MN CWI, MDH, and MN DNR Data Deli. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



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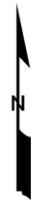
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MODEL FINITE DIFFERENCE GRID

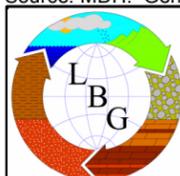
FILE: G3CRKSTNWHPO1J.MXD DATE: 08/01/2006 FIGURE: 5



-  Model Gridlines
-  Model Domain
-  Shallow Confined Aquifer Extent
-  Surficial Unconfined/Semiconfined Aquifer Extent
-  Crookston City Well



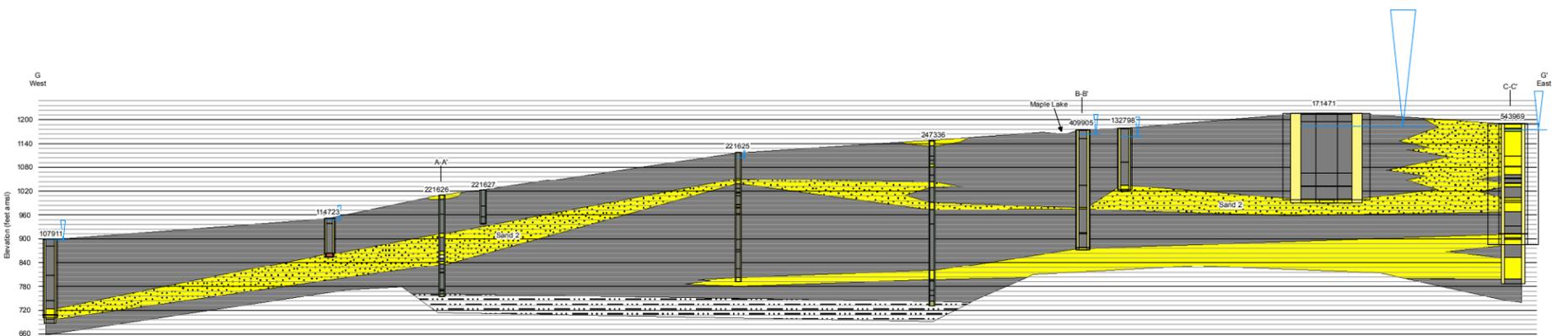
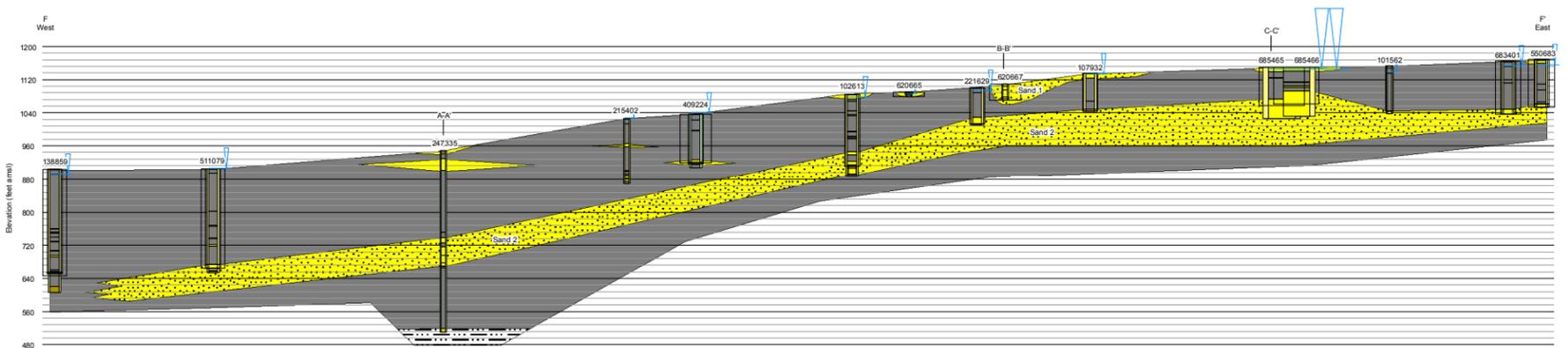
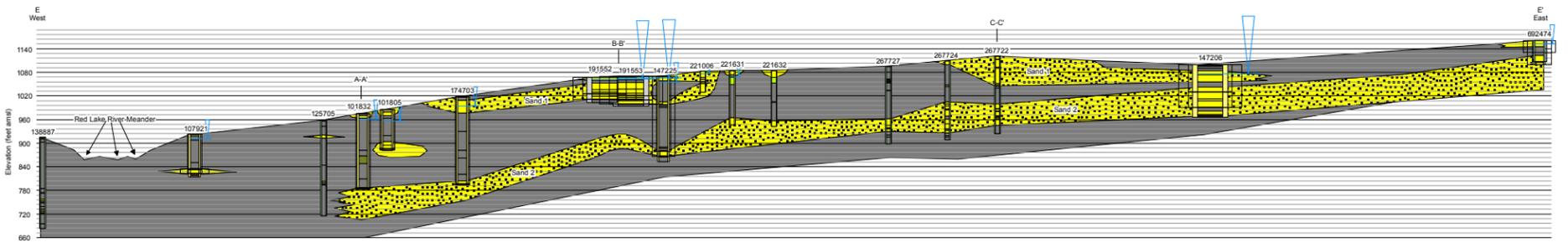
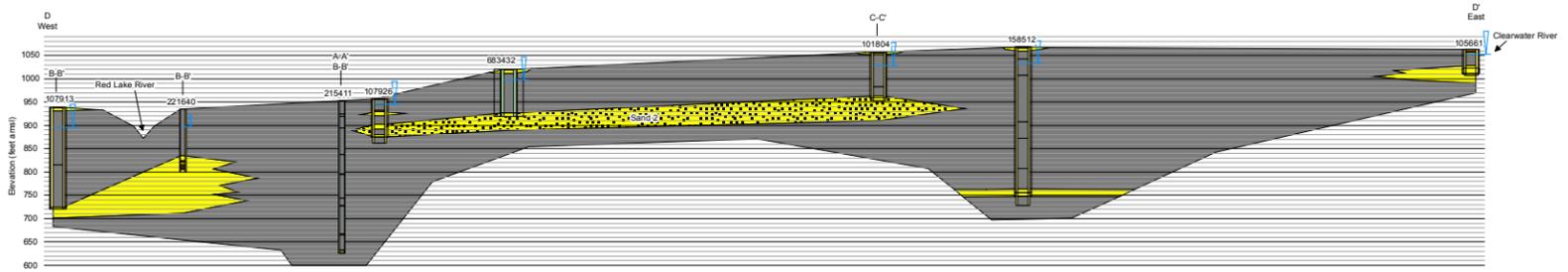
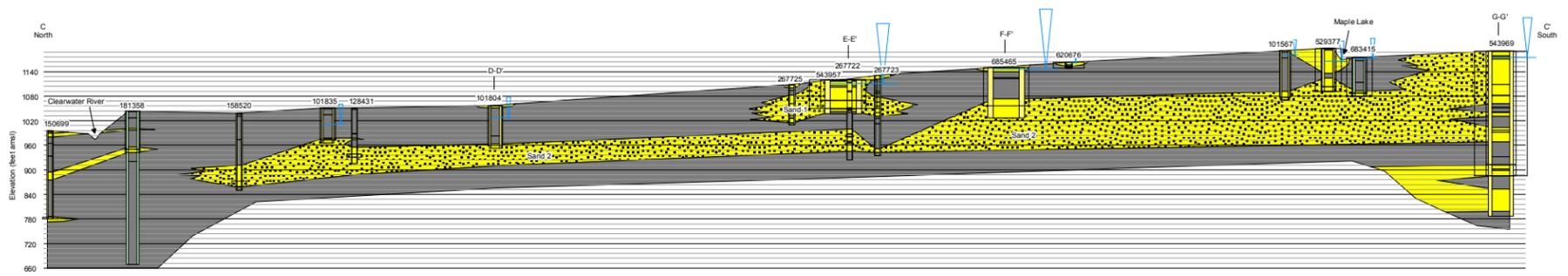
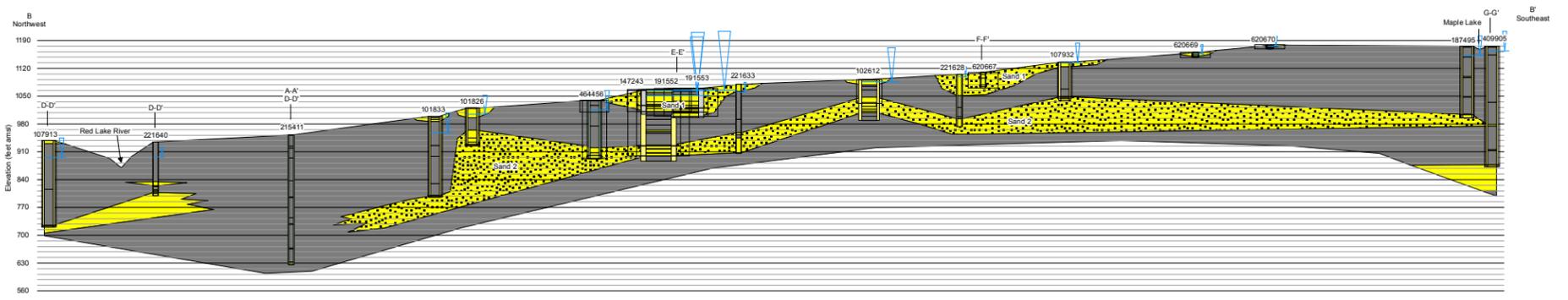
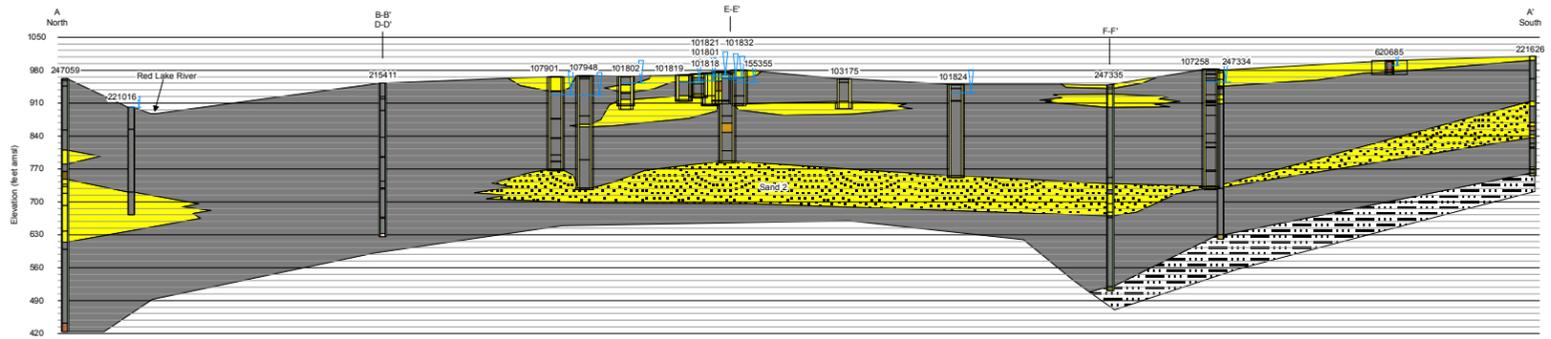
Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



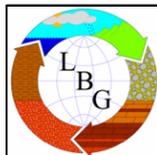
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**CITY OF CROOKSTON**  
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**MODEL GRID IN VICINITY OF CITY WELLS**



- Lithology**
- Bedrock
  - Clay
  - Sand
  - Sand 1 or Sand 2



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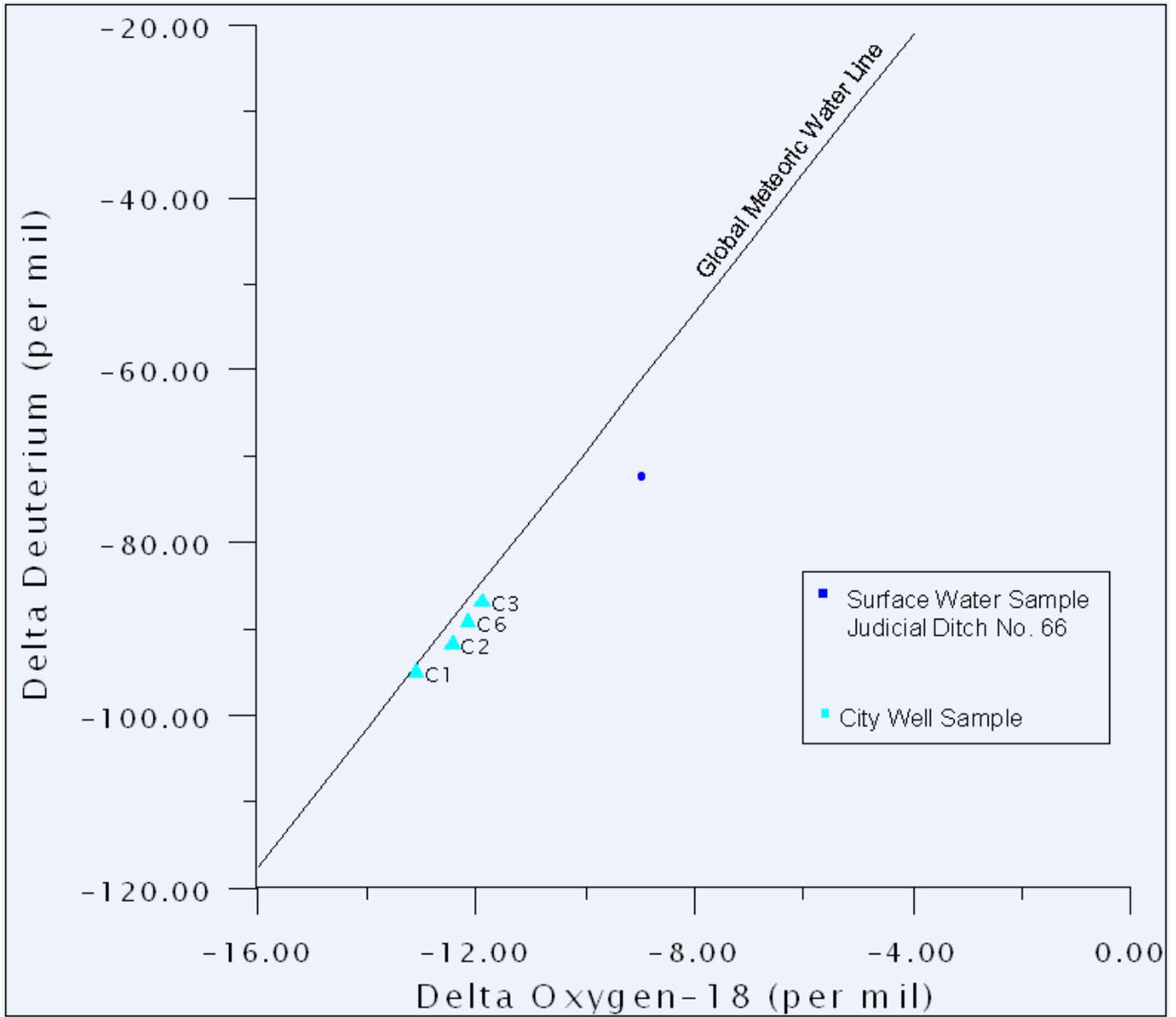
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HYDROGEOLOGIC CROSS-SECTIONS A-A' THROUGH G-G'

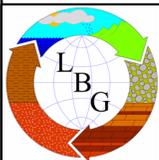
FILE: G3CRKSTNWHPO1F.MXD

DATE: 02/02/2006

FIGURE: 7



Source: Isotope data provided by MDH staff.

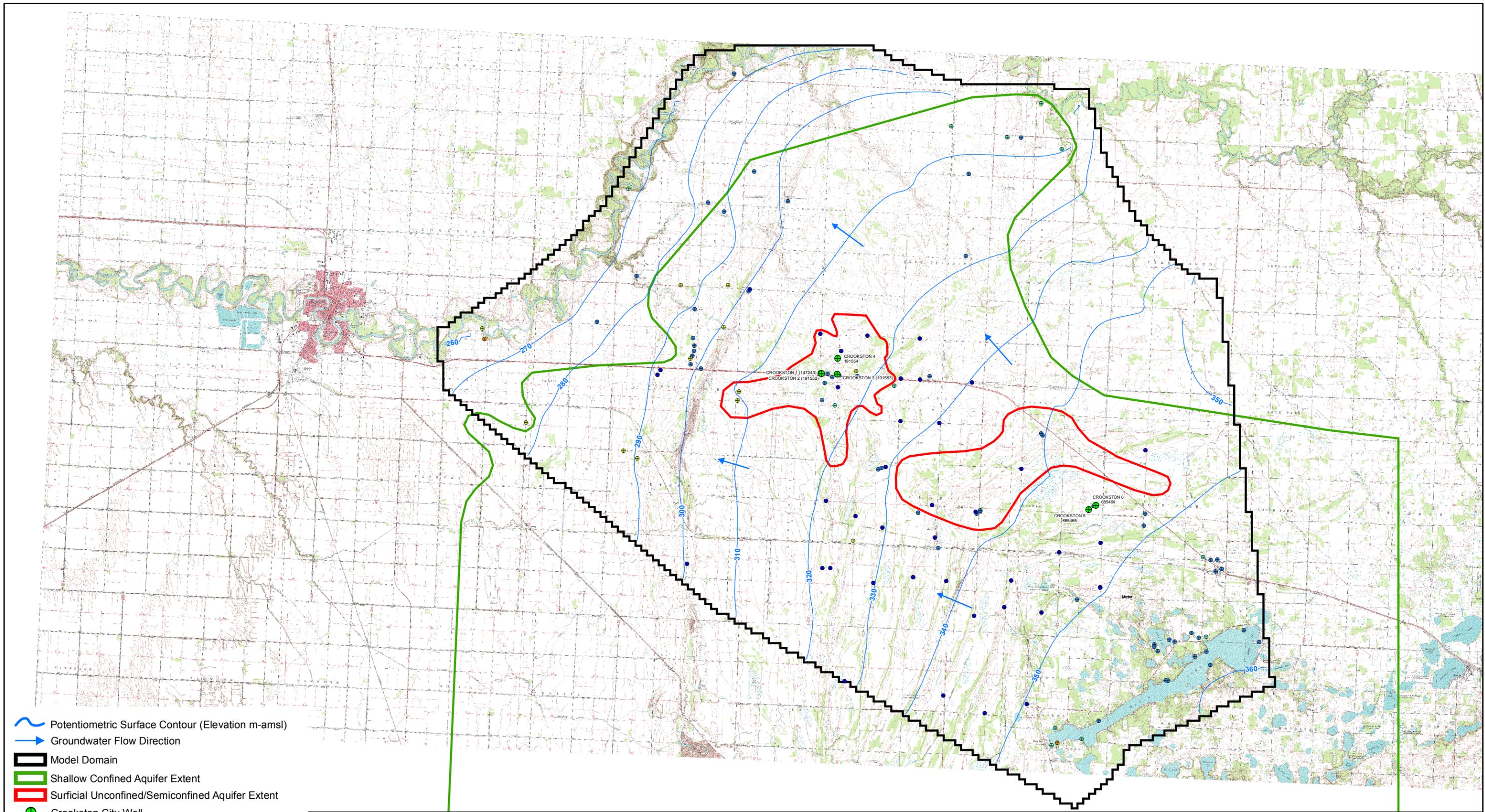


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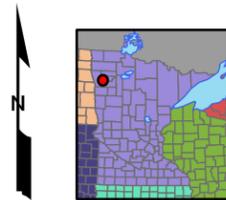
ISOTOPE DATA

FILE: G3CRKSTNWHP02G.MXD | DATE: 08/01/2006 | FIGURE: 8

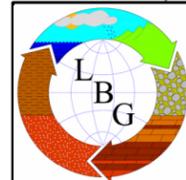


**Model Calibration Well (by depth in feet)**

- 0.00 - 50.00
- 50.01 - 120.00
- 120.01 - 180.00
- 180.01 - 260.00
- 260.01 - 360.00
- 360.01 - 539.00



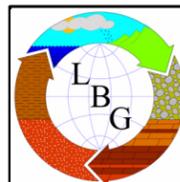
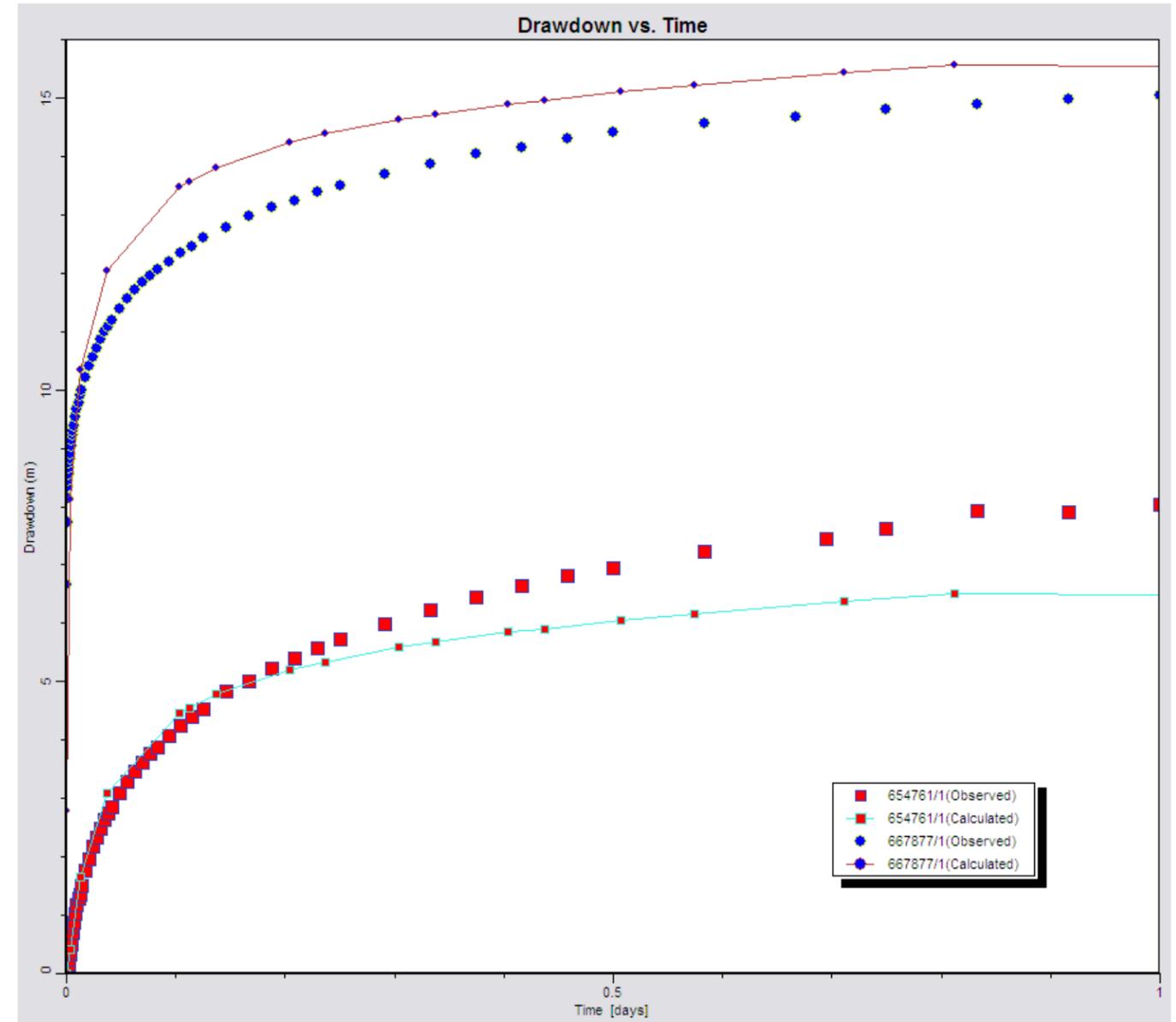
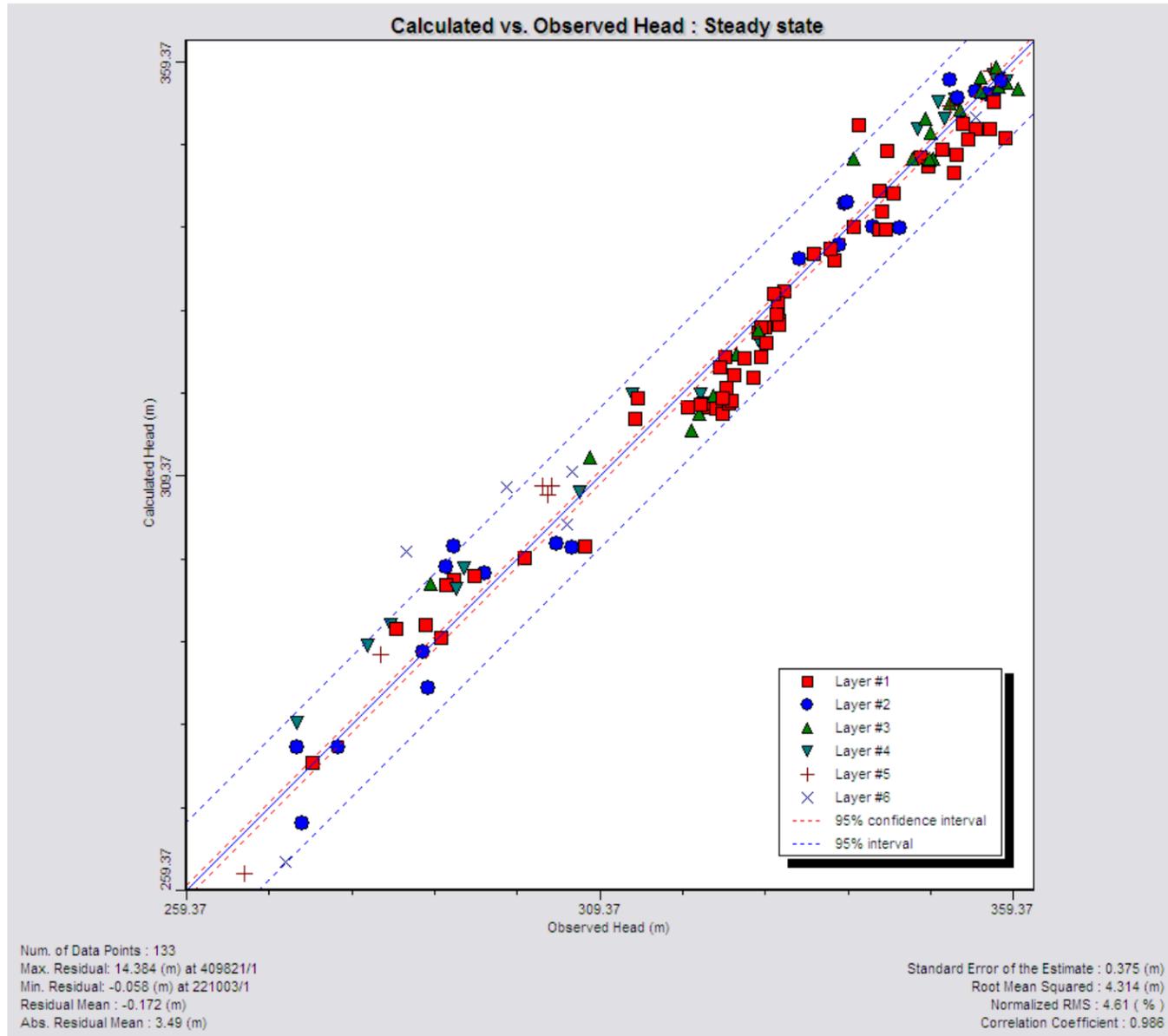
Source: MN CWI, MDH, and MN DNR Data Deli. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



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**CITY OF CROOKSTON**  
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SIMULATED GROUND-WATER EQUIPOTENTIAL  
 AND CALIBRATION WELL LOCATIONS



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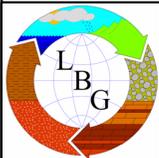
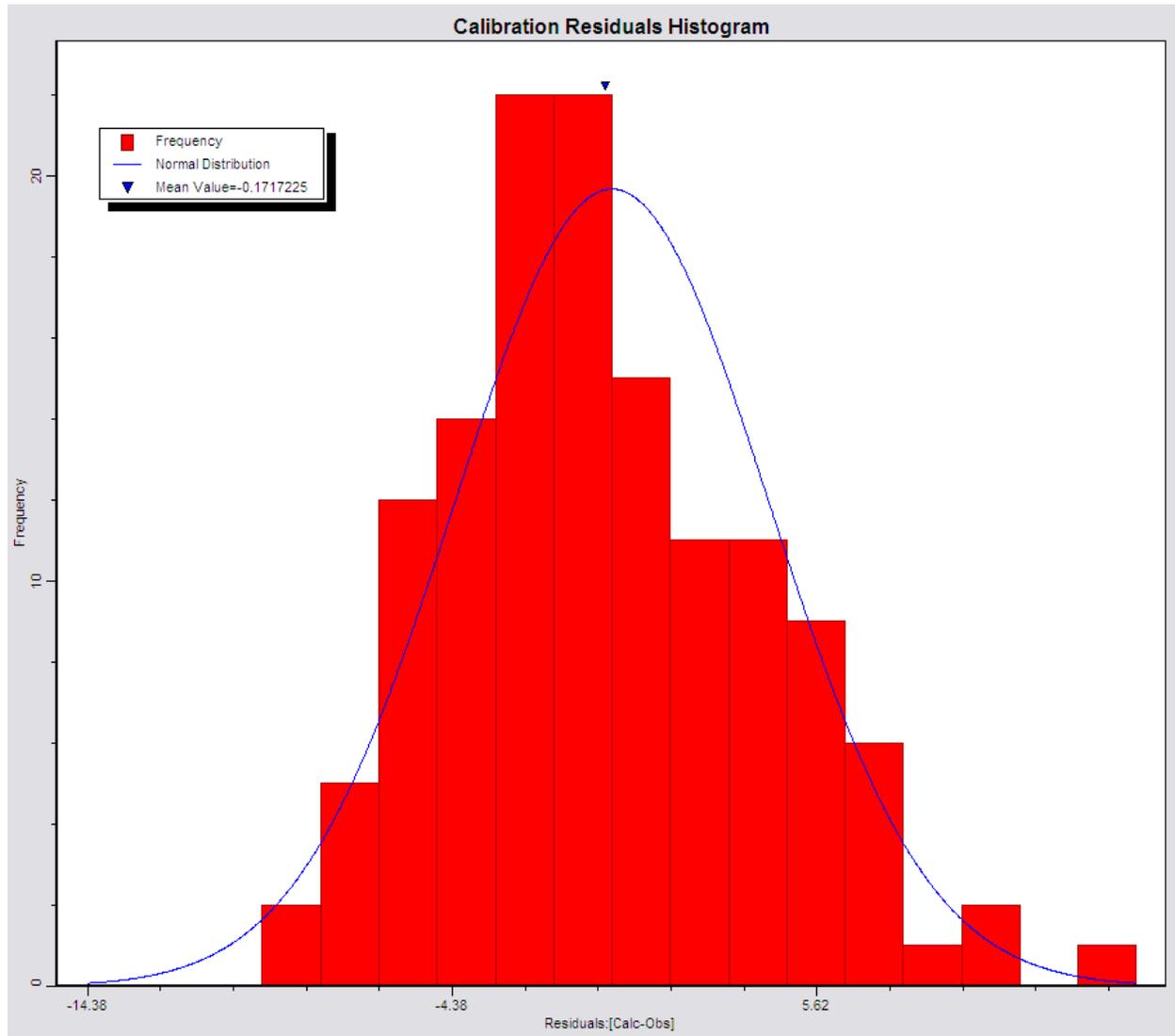
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STEADY-STATE AND TRANSIENT MODEL CALIBRATION DATA

FILE: G3CRKSTNWHPO1X.MXD

DATE: 08/01/2006

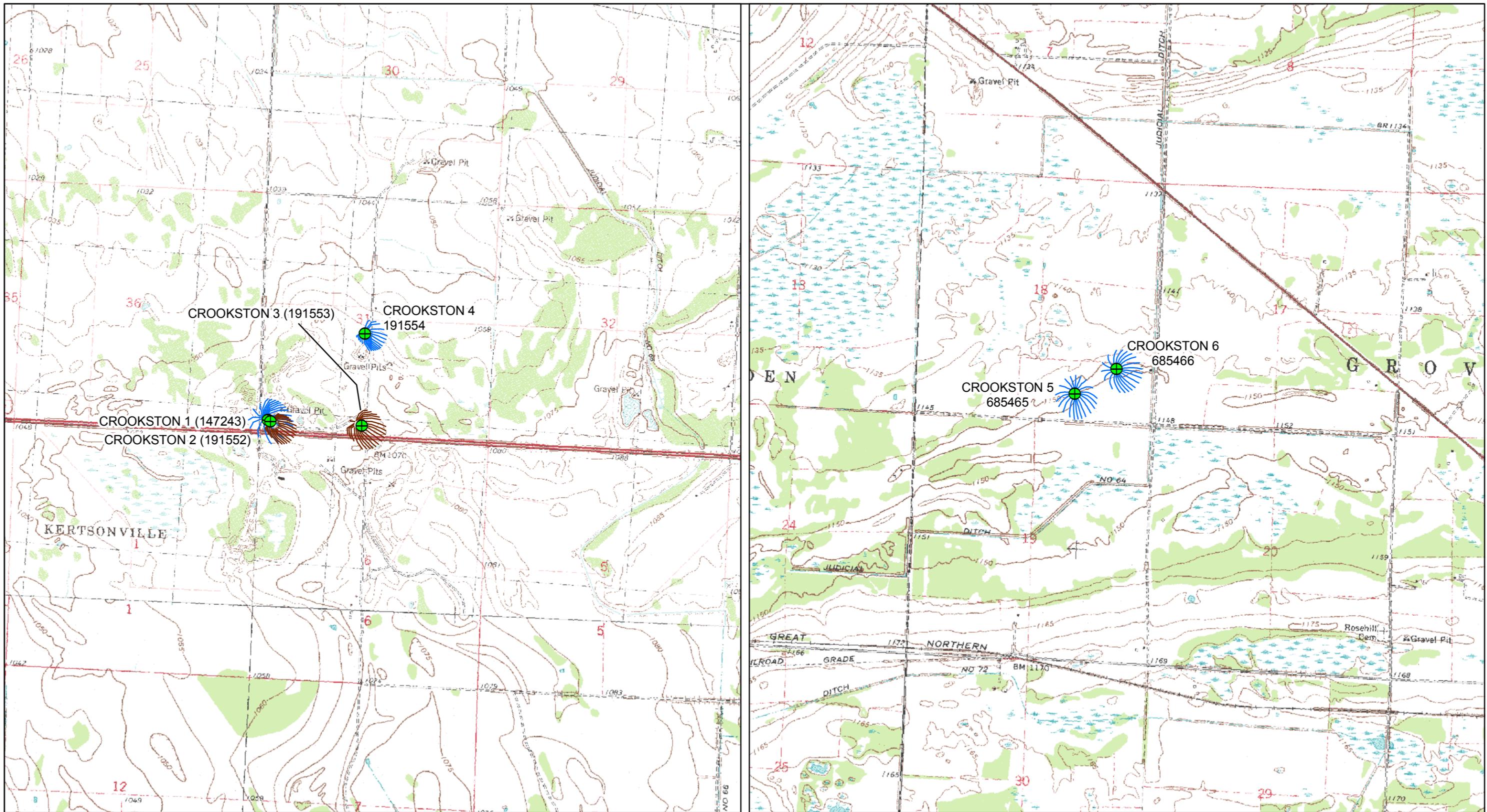
FIGURE: 10



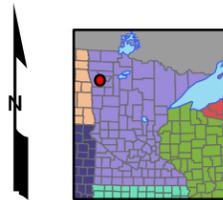
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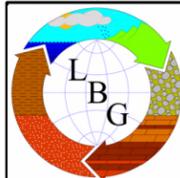
STEADY-STATE MODEL HISTOGRAM



-  1-Year Time-of-Travel Pathlines - Shallow Confined Aquifer
-  1-Year Time-of-Travel Pathlines - Unconfined/Semiconfined Aquifer
-  Crookston City Well



Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.

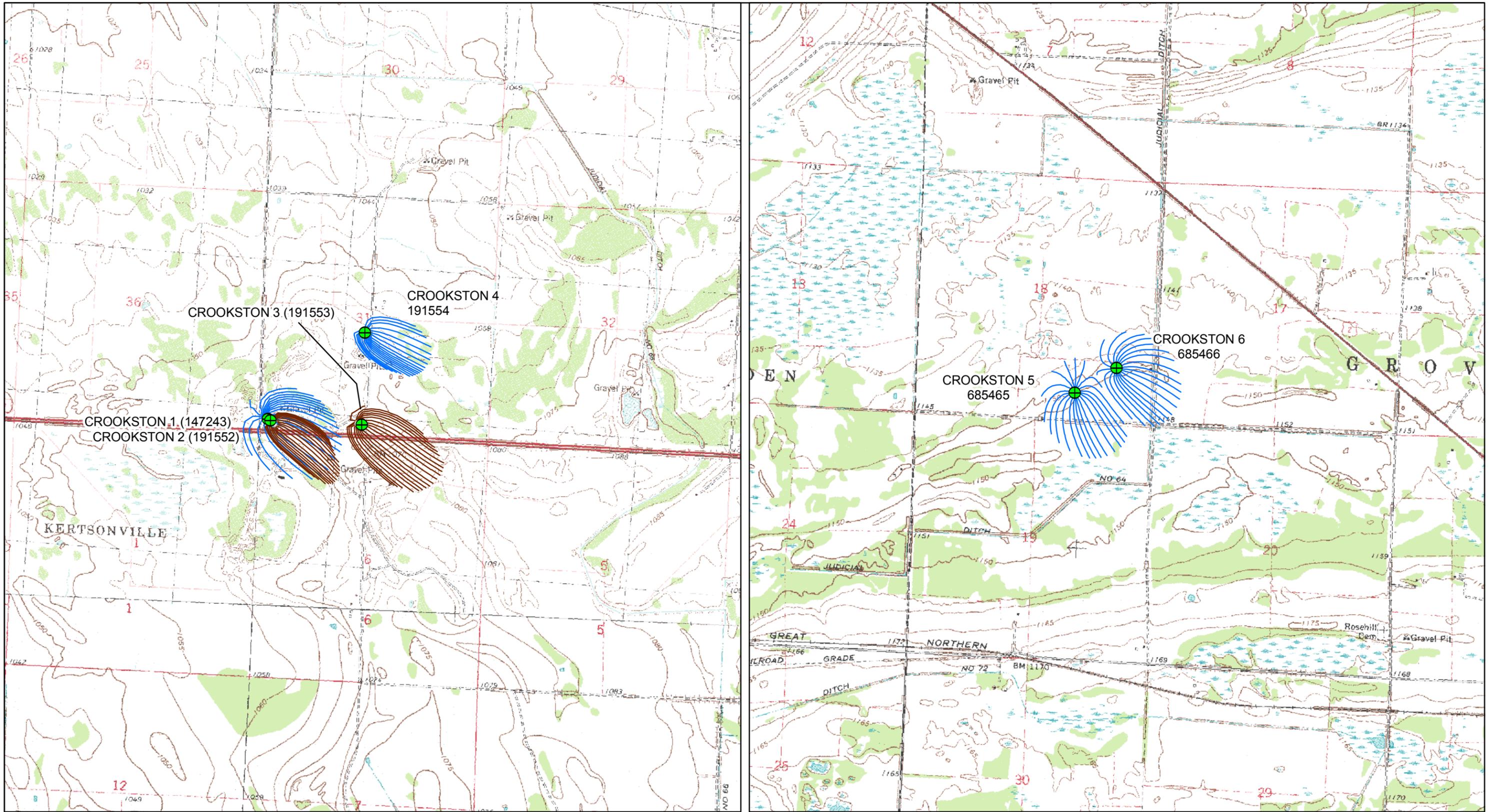


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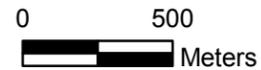
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**1-YEAR TIME-OF-TRAVEL PATHLINES**

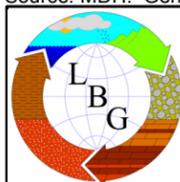
FILE: G3CRKSTNWHPO1Z.MXD    DATE: 08/01/2006    FIGURE: 12



- 5-Year Time-of-Travel Pathlines - Shallow Confined Aquifer
- 5-Year Time-of-Travel Pathlines - Unconfined/Semiconfined Aquifer
- Crookston City Well



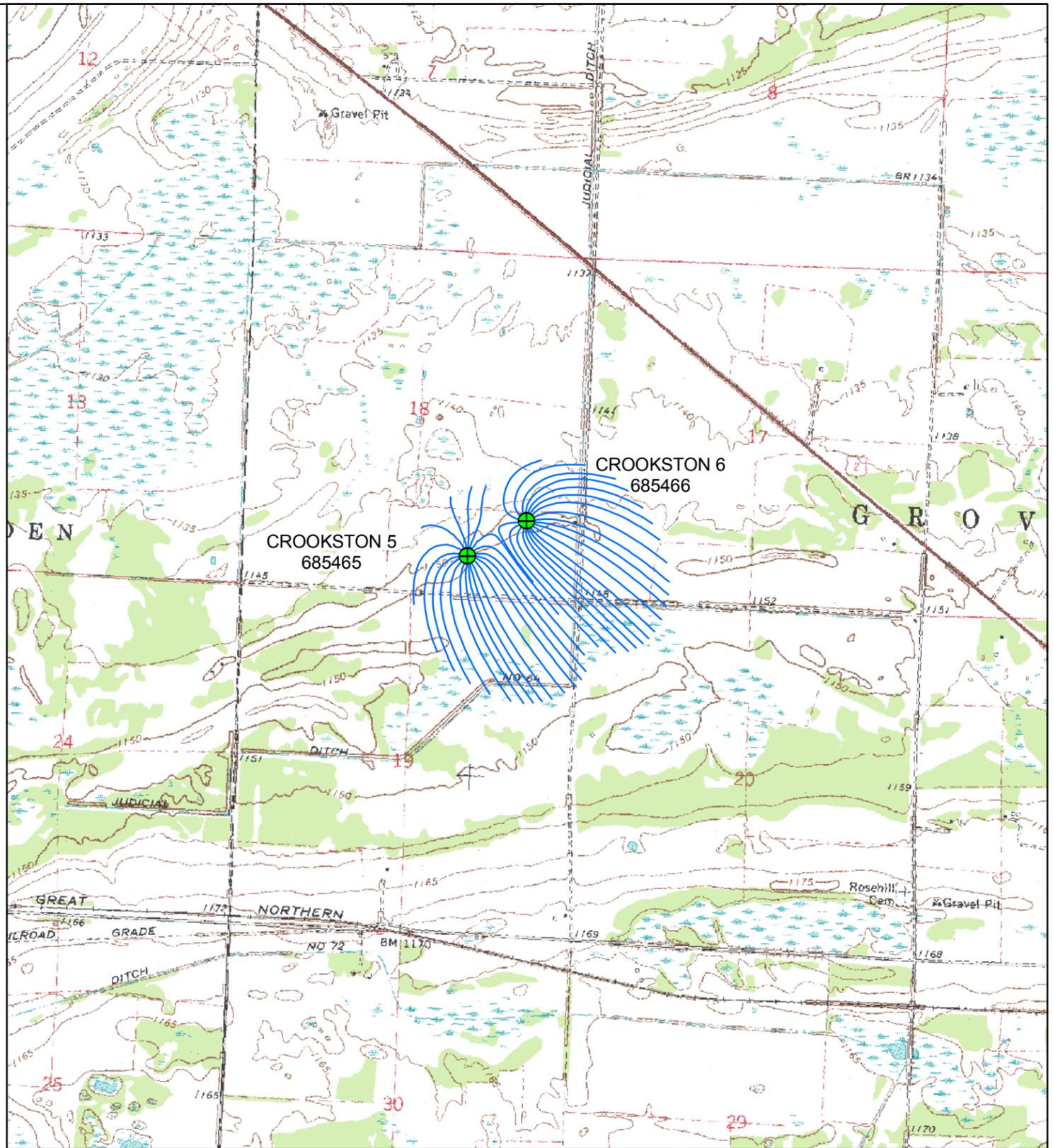
Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



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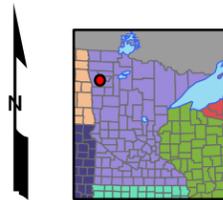
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**5-YEAR TIME-OF-TRAVEL PATHLINES**

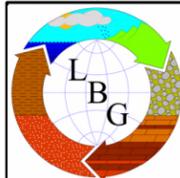


- 10-Year Time-of-Travel Pathlines - Shallow Confined Aquifer
- 10-Year Time-of-Travel Pathlines - Unconfined/Semiconfined Aquifer
- Crookston City Well

0 500  
Meters



Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.

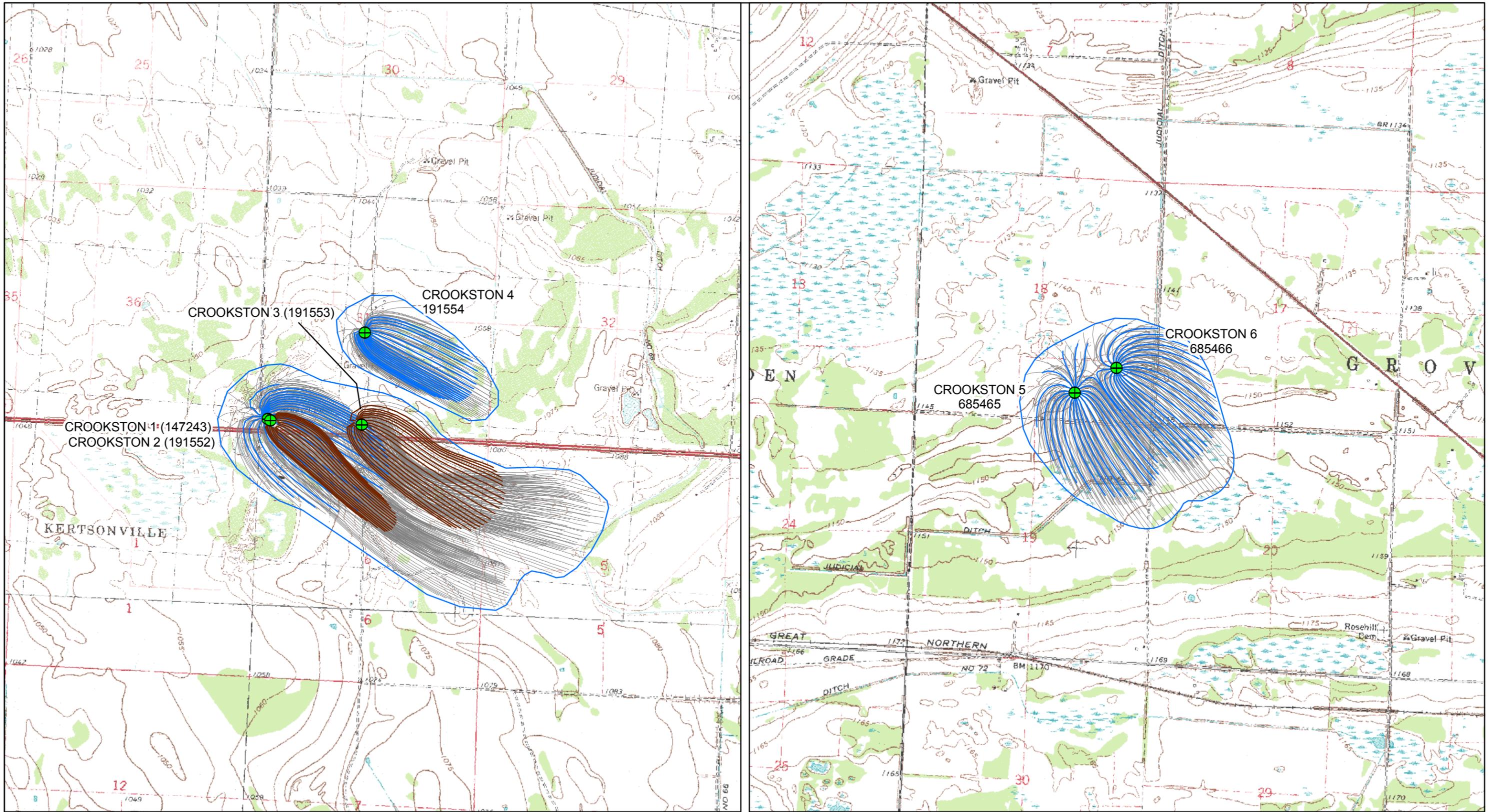


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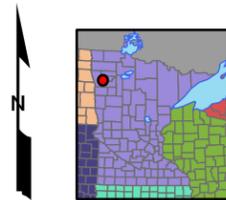
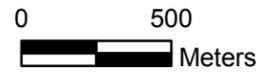
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 CROOKSTON, MINNESOTA

10-YEAR TIME-OF-TRAVEL PATHLINES

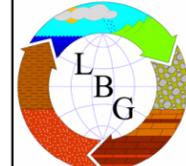
FILE: G3CRKSTNWHPO2B.MXD DATE: 08/01/2006 FIGURE: 14



- Wellhead Protection Area (WHPA) Boundary - Inclusive of All Scenarios
- 10-Year Time-of-Travel Pathlines - Shallow Confined Aquifer
- 10-Year Time-of-Travel Pathlines - Unconfined/Semiconfined Aquifer
- 10-Year Time-of-Travel Pathlines - Sensitivity Analysis Scenarios
- Crookston City Well



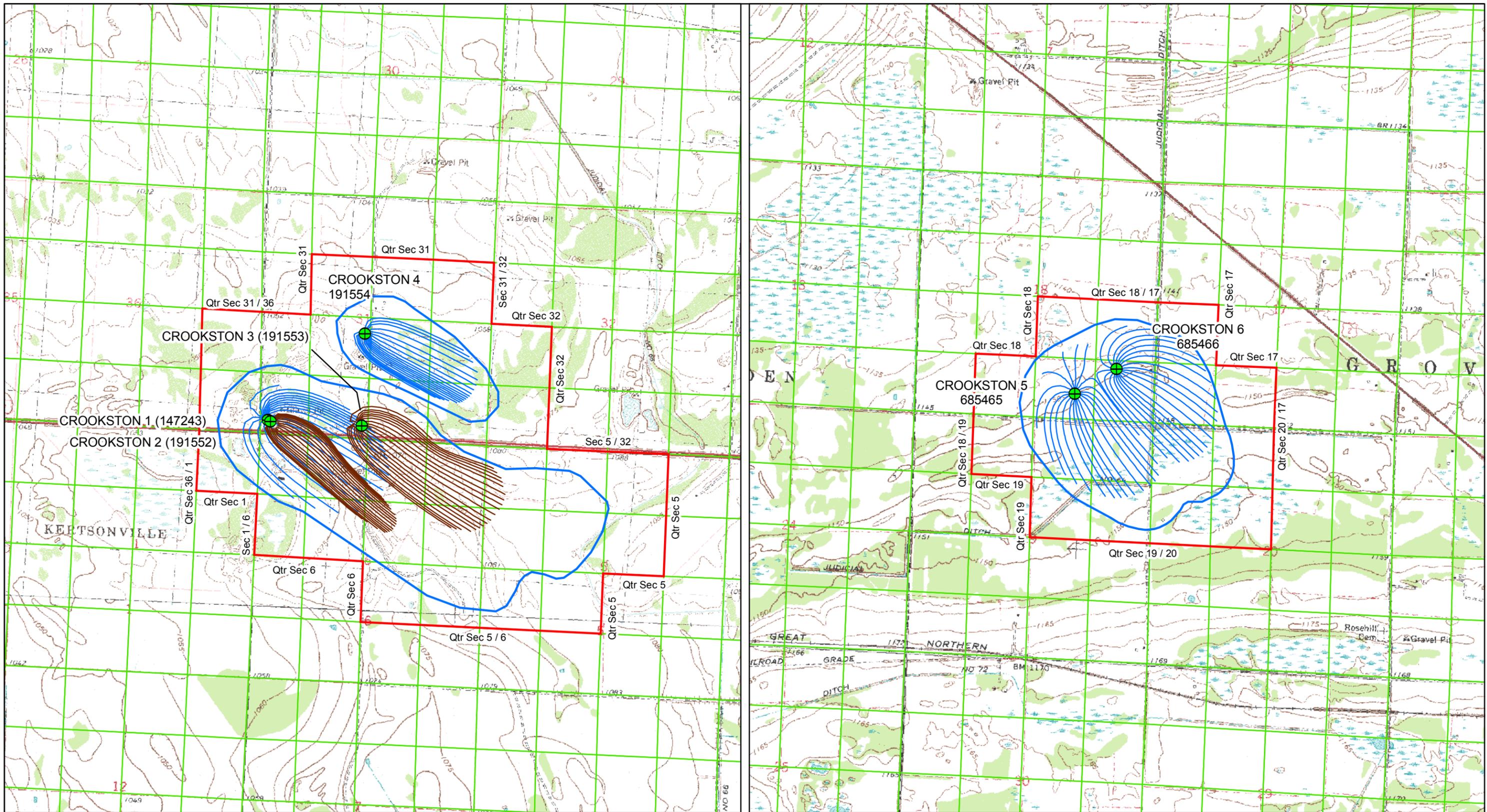
Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



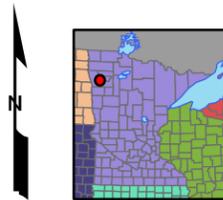
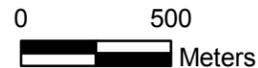
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 CROOKSTON, MINNESOTA

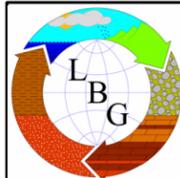
**WELLHEAD PROTECTION AREA BOUNDARIES**



- DWSMA Boundary (inclusive of both aquifers)
- 10-Year WHPA - Inclusive of All Scenarios
- 10-Year Time-of-Travel Pathlines - Shallow Confined Aquifer
- 10-Year Time-of-Travel Pathlines - Unconfined/Semiconfined Aquifer
- Crookston City Well



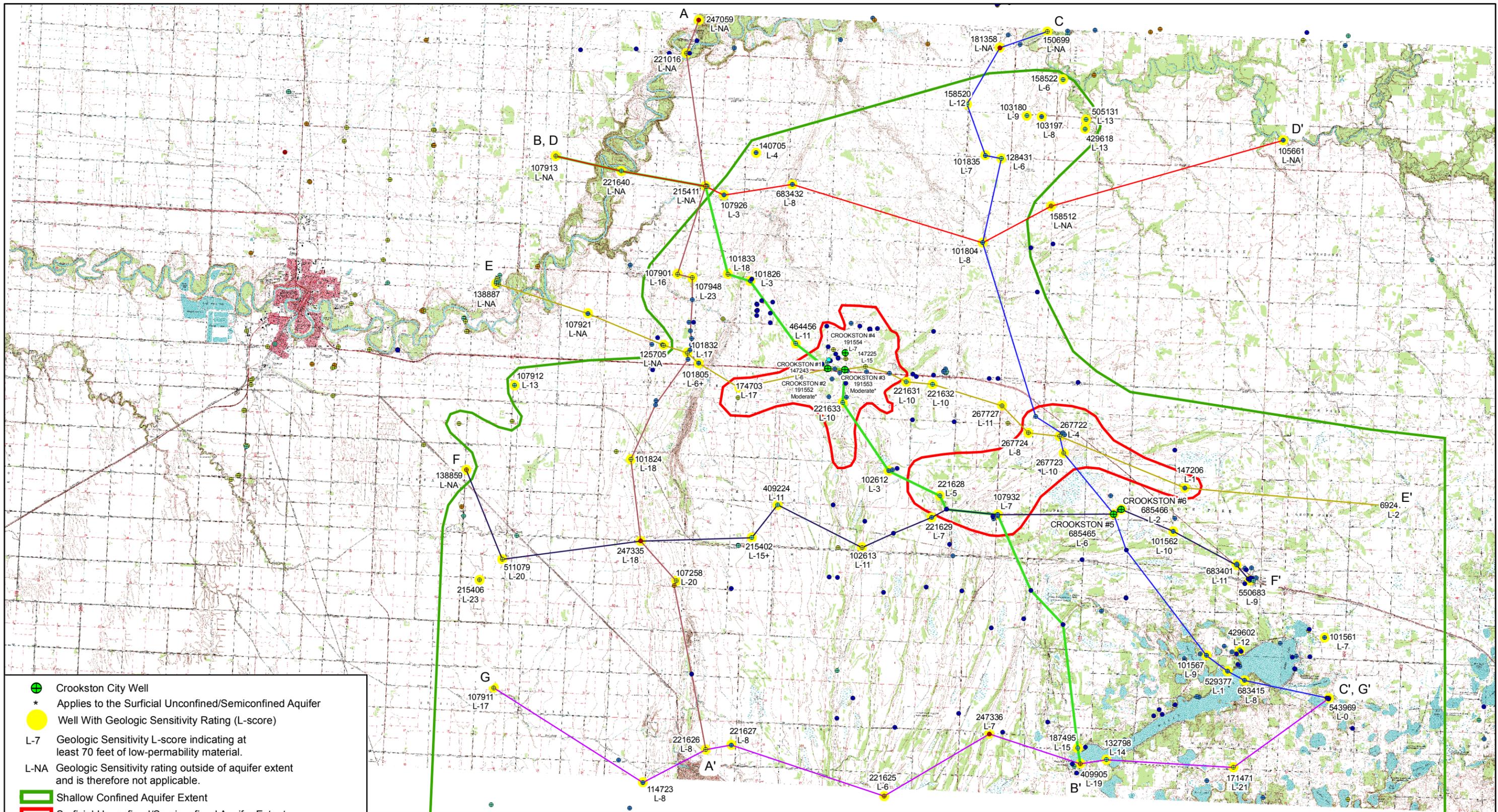
Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



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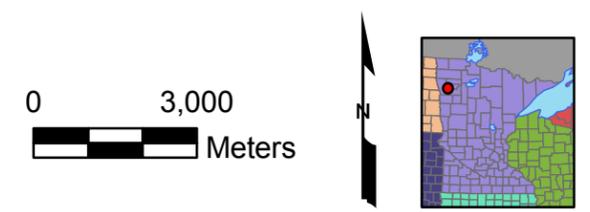
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**DWSMA DELINEATION**

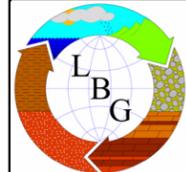


- ⊕ Crookston City Well
- \* Applies to the Surficial Unconfined/Semiconfined Aquifer
- Well With Geologic Sensitivity Rating (L-score)
- L-7 Geologic Sensitivity L-score indicating at least 70 feet of low-permeability material.
- L-NA Geologic Sensitivity rating outside of aquifer extent and is therefore not applicable.
- Shallow Confined Aquifer Extent
- Surficial Unconfined/Semiconfined Aquifer Extent

MN CWI Well (by depth in feet)	Cross-Section Line
<span style="color: blue;">●</span> 0.00 - 50.00	<span style="color: red;">—</span> A-A'
<span style="color: green;">●</span> 50.01 - 120.00	<span style="color: blue;">—</span> B-B'
<span style="color: yellow;">●</span> 120.01 - 180.00	<span style="color: orange;">—</span> C-C'
<span style="color: orange;">●</span> 180.01 - 260.00	<span style="color: green;">—</span> D-D'
<span style="color: green;">●</span> 260.01 - 360.00	<span style="color: blue;">—</span> E-E'
<span style="color: blue;">●</span> 360.01 - 539.00	<span style="color: red;">—</span> F-F'
	<span style="color: purple;">—</span> G-G'

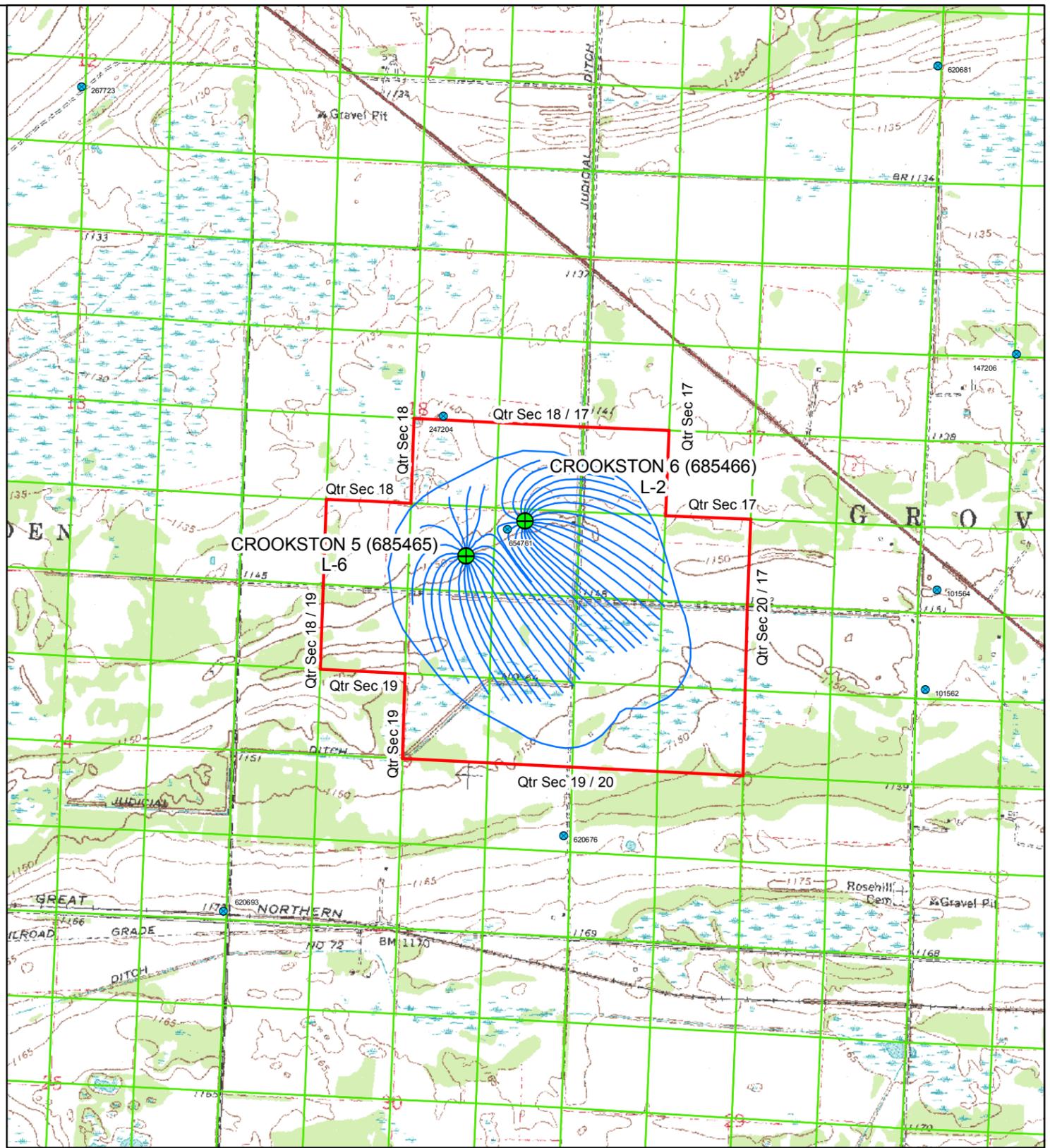
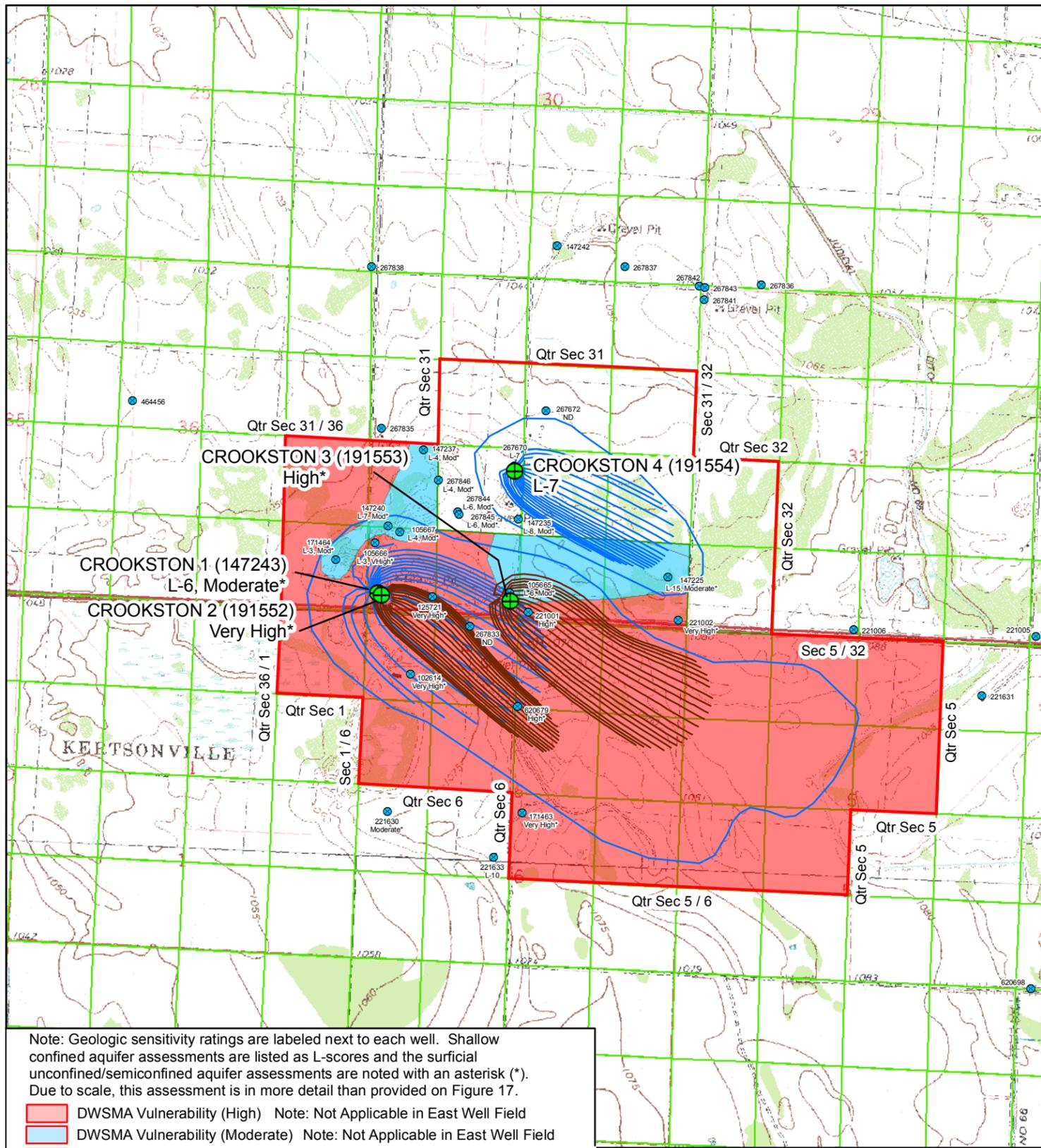


Source: MN CWI, MDH, and MN DNR Data Deli. Gently, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



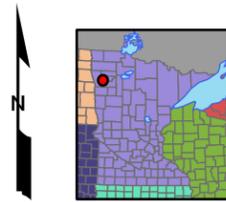
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CROOKSTON, MINNESOTA		
GEOLOGIC SENSITIVITY ASSESSMENT		
OF SHALLOW CONFINED AQUIFER		
FILE: G3CRKSTNWHPO1E.MXD	DATE: 08/01/2006	FIGURE: 17

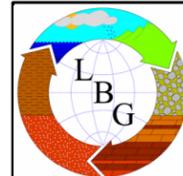


Note: Geologic sensitivity ratings are labeled next to each well. Shallow confined aquifer assessments are listed as L-scores and the surficial unconfined/semiconfined aquifer assessments are noted with an asterisk (\*). Due to scale, this assessment is in more detail than provided on Figure 17.

- DWSMA Vulnerability (High) Note: Not Applicable in East Well Field
- DWSMA Vulnerability (Moderate) Note: Not Applicable in East Well Field
- DWSMA Boundary (inclusive of both aquifers) Note: The vulnerability assessment is not applicable in the northern part of the DWSMA because the surficial unconfined/semiconfined aquifer WHPA is constrained to the southern half of the DWSMA.
- 10-Year WHPA - Inclusive of All Scenarios
- 10-Year Time-of-Travel Pathlines - Shallow Confined Aquifer
- 10-Year Time-of-Travel Pathlines - Unconfined/Semiconfined Aquifer
- Crookston City Well



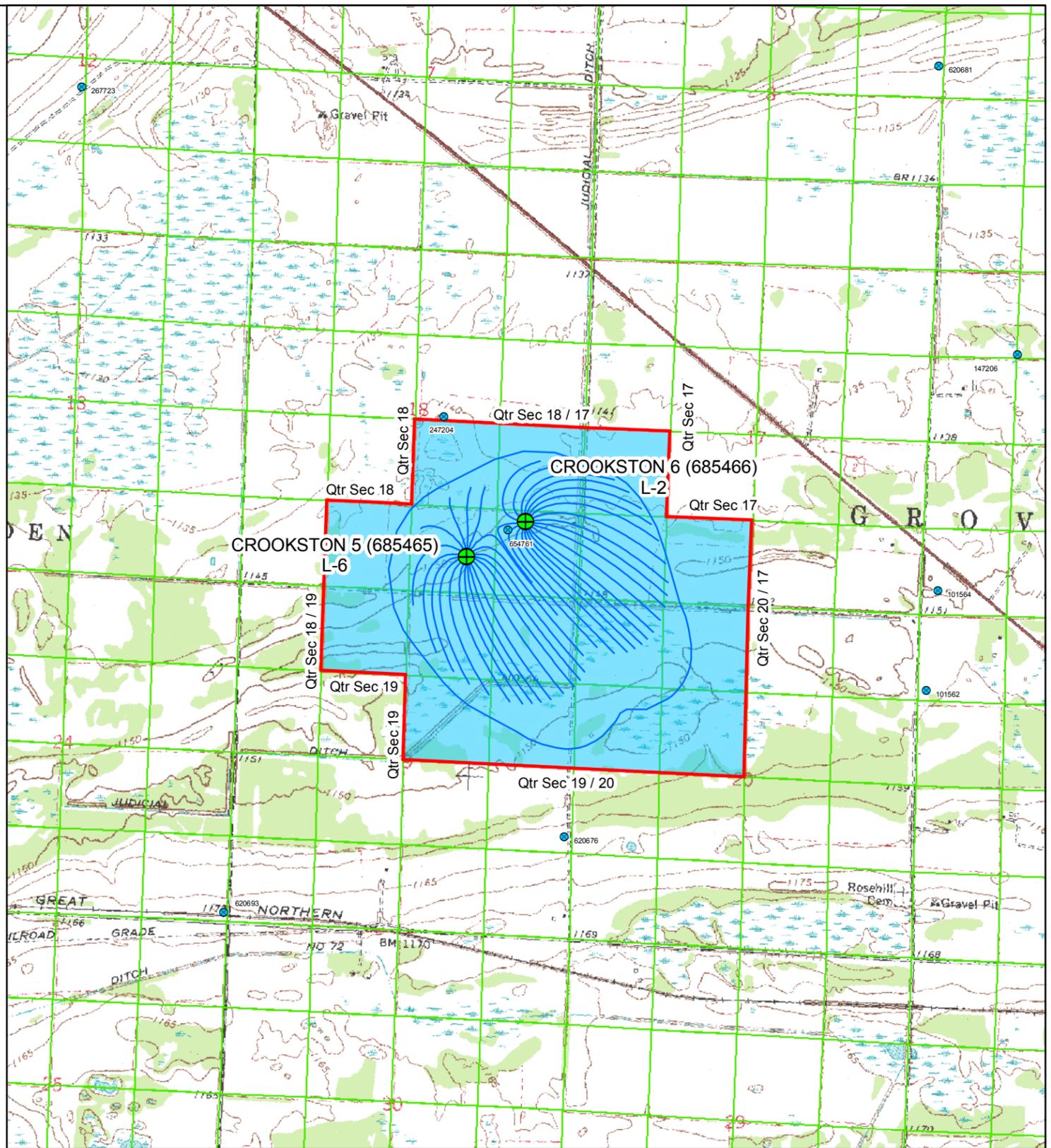
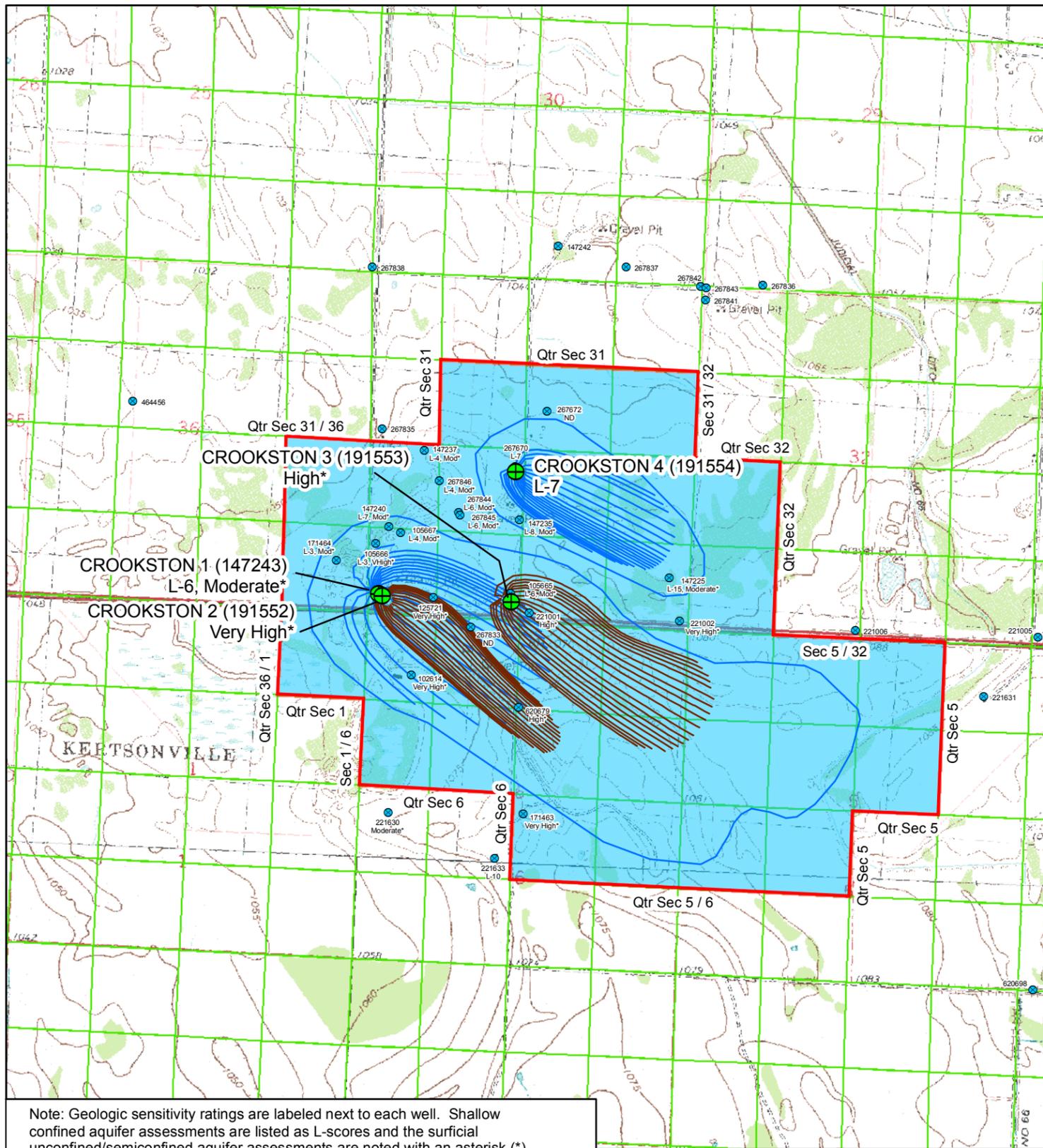
Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



Prepared By:  
**LEGGETTE, BRASHEARS & GRAHAM, INC.**  
 Professional Ground-Water and  
 Environmental Engineering Services  
 8 Pine Tree Drive, Suite 250  
 St. Paul, Minnesota 55112  
 651-490-1405

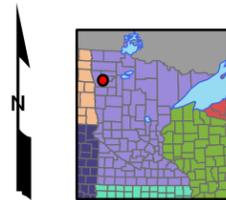
**CITY OF CROOKSTON**  
 PART I WHP AND VULNERABILITY ASSESSMENT REPORT  
 CROOKSTON, MINNESOTA  
 DWSMA VULNERABILITY ASSESSMENT OF  
 THE SURFICIAL UNCONFINED/SEMICONFINED AQUIFER

FILE: G3CRKSTNWHPO2E.MXD      DATE: 08/01/2006      FIGURE: 18

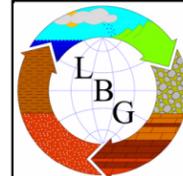


Note: Geologic sensitivity ratings are labeled next to each well. Shallow confined aquifer assessments are listed as L-scores and the surficial unconfined/semiconfined aquifer assessments are noted with an asterisk (\*). Due to scale, this assessment is in more detail than provided on Figure 17.

- DWSMA Vulnerability (Moderate)
- DWSMA Boundary (inclusive of both aquifers)
- 10-Year WHPA - Inclusive of All Scenarios
- 10-Year Time-of-Travel Pathlines - Shallow Confined Aquifer
- 10-Year Time-of-Travel Pathlines - Unconfined/Semiconfined Aquifer
- Crookston City Well



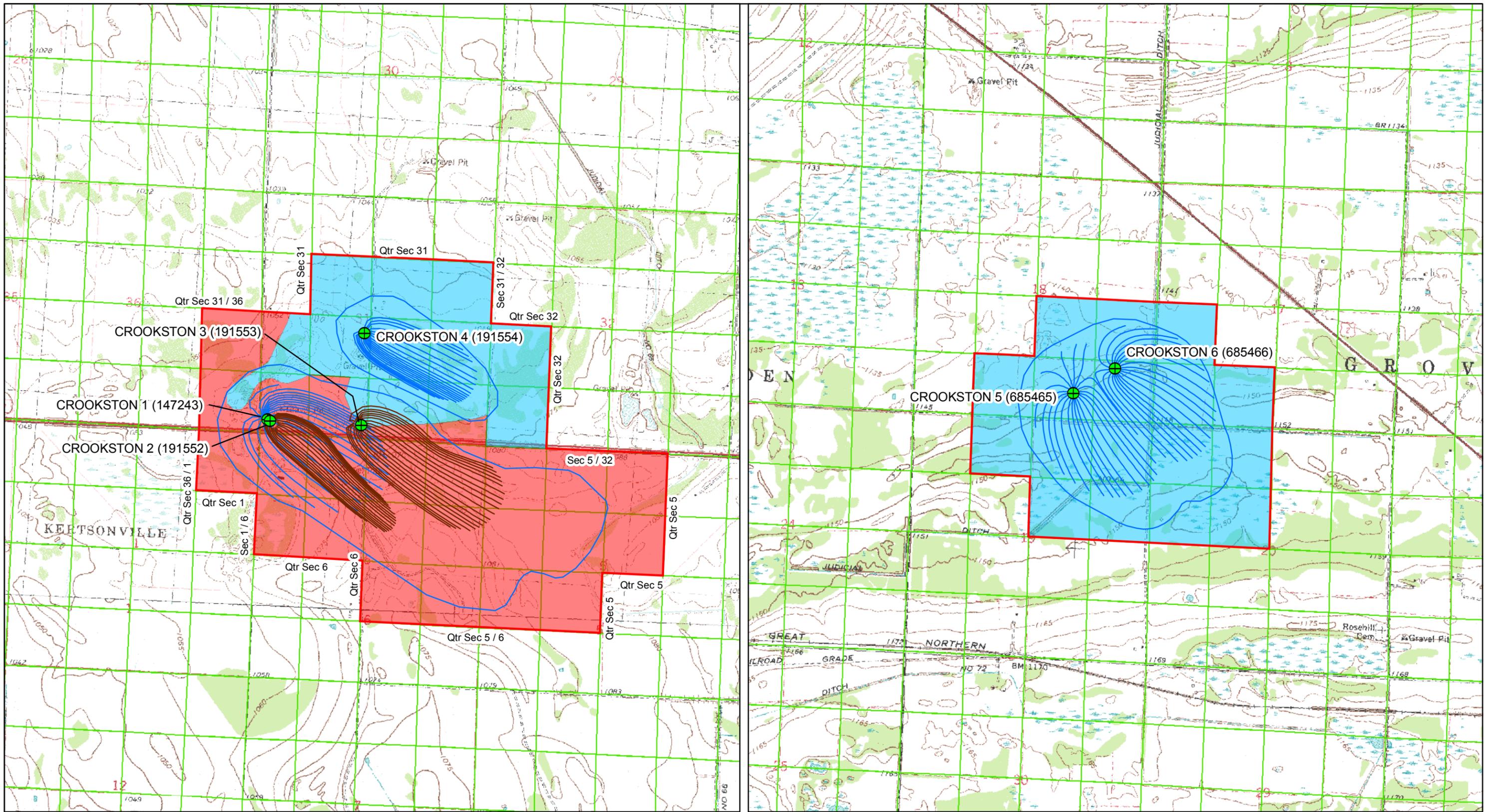
Source: MDH. Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



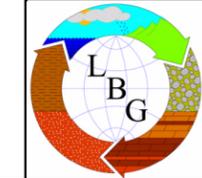
Prepared By:  
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**CITY OF CROOKSTON**  
 PART I WHP AND VULNERABILITY ASSESSMENT REPORT  
 CROOKSTON, MINNESOTA  
 DWSMA VULNERABILITY ASSESSMENT OF  
 THE SHALLOW CONFINED AQUIFER

FILE: G3CRKSTNWHPO2F.MXD      DATE: 08/01/2006      FIGURE: 19



Source: MDH, Gentilly, Marcoux Corners, Harold, Dugdale, Terrebonne, and Mentor USGS 7.5-Minute Quadrangles.



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**CITY OF CROOKSTON**  
 PART I WHP AND VULNERABILITY ASSESSMENT REPORT  
 CROOKSTON, MINNESOTA  
 CUMULATIVE DWSMA VULNERABILITY ASSESSMENT  
 BOTH AQUIFERS

FILE: G3CRKSTNWHPO2H.MXD    DATE: 08/01/2006    FIGURE: 20

**APPENDIX I**  
**Municipal Well Logs**

Unique No. 00147243

MINNESOTA DEPARTMENT OF HEALTH  
WELL AND BORING RECORD

Update Date 2003/01/18

County Name Redlake

Minnesota Statutes Chapter 1031

Entry Date 1988/04/17

Township Name Township Range Dir Section Subsection  
150 44 W 31 CCCCAC

Well Depth Depth Completed Date Well Completed  
177 ft. 164 ft. 1978/11/22

Well Name CROOKSTON 1

Drilling Method Non-specified Rotary

Well Owner's Name CROOKSTON 1

Drilling Fluid Well Hydrofractured?  Yes  No  
From ft. to ft.

CROOKSTON MN 56716-

Use Community Supply (municipal)

Casing Drive Shoe?  Yes  N Hole Diameter  
in. to 164 ft

GEOLOGICAL MATERIAL COLOR HARDNESS FROM TO

Casing Diameter Weight(lbs/ft)  
12 in. to 140 ft 49.56

TOP SOIL SAND GRAVEL BROW 0 7

HARD SANDY CLAY ROCKY BLUE 7 16

HARD SILTY SANDY CLAY GRAY 16 24

SAND W/LAYERS CLAY GRAY 24 29

SAND GRAVEL VARIE 29 47

SAND GRAVEL MIXED W/CL GRAY 47 52

HARD SANDY CLAY ROCKY GRAY 52 63

HARD SANDY CLAY W/LEN GRAY 63 72

HARD SANDY CLAY ROCKY GRAY 72 87

SANDY CLAY W/ LENSES S GRAY 87 99

SAND GRAVEL VARIE 99 104

HARD SANDY CLAY ROCKY GRAY 104 107

BOULDER RED 107 108

HARD SANDY CLAY ROCKY GRAY 108 137

SAND GRAVEL VARIE 137 146

BOULDER RED 146 147

GRAVEL ROCKS VARIE 147 157

BOULDER RED 157 158

GRAVEL ROCKS VARIE 158 164

SANDY SILTY CLAY W/LEN GRAY 164 177

Screen Y Open Hole From ft. to ft.  
Make JOHNSON Type L  
Diameter Slot Length Set Fitting  
12 100 23 138 ft. to 164 ft

Static Water Level 13 ft. from Land surface Date 1978/11/16

PUMPING LEVEL (below land surface)  
99.4 ft. after 120 hrs. pumping 760 g.p.m.

Well Head Completion  
Pitless adapter mfr Model  
Casing Protection  12 in. above grade  
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted?  Yes  No  
Material From To (ft.) Amount(yds/bags)  
G 0 60

Nearest Known Source of Contamination  
ft. direction type  
Well disinfected upon completion?  Yes  No

Pump  Not Installed Date Installed N  
Mfr name  
Model HP Volts  
Drop Pipe Length ft. Capacity g.p.m.  
Type

Any not in use and not sealed well(s) on property?  Yes  No

Was a variance granted from the MDH for this Well?  Yes  No

USGS Quad: Elevation: 1069  
Aquifer: QBAA Alt Id: 76-1240

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91353  
License Business Name  
Name of Driller SCHROEDER, F.

Report Copy

Unique No. 191552

MINNESOTA DEPARTMENT OF HEALTH  
**WELL AND BORING RECORD**

Update Date 2001/06/01

County Name Redlake

Minnesota Statutes Chapter 1031

Entry Date 2000/07/14

Township Name Township Range Dir Section Subsection  
150 44 W 31 C

Well Depth 63 ft. Depth Completed 56 ft. Date Well Completed 1982/08/06

Well Name CROOKSTON 2

Drilling Method Non-specified Rotary

Well Owner's Name CROOKSTON 2  
CROOKSTON MN 56716-

Drilling Fluid Well Hydrofractured?  Yes  No  
From ft. to ft.

Use Community Supply (municipal)

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
SAND & GRAVEL	BROW		0	8
HARD SANDY CLAY	BROW		8	14
SAND & GRAVEL 25 SLOT &	VARIE		14	31
SAND (DRILLED POOR)	VARIE		31	38
SAND & GRAVEL W/ROCK	VARIE		38	43
SAND & ROCK (DRILLED PO	VARIE		43	48
SAND & GRAVEL W/ROCK	VARIE		48	56
SANDY CLAY	BLUE		56	63

Casing Drive Shoe?  Yes  N Hole Diameter

Casing Diameter 12 in. to 41 ft. Weight(lbs/ft) 49.56

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type L

Diameter Slot Length Set Fitting  
12 45 15 41 ft. to 56 ft

Static Water Level 3.2 ft. from Land surface Date 1982/08/06

PUMPING LEVEL (below land surface)  
41.1 ft. after 72 hrs. pumping 575 g.p.m.

Well Head Completion  
Pitless adapter mfr MONITOR Model 8PS1214WBW  
Casing Protection  12 in. above grade  
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted?  Yes  No  
Material From To (ft.) Amount(yds/bags)  
G 10 41

Nearest Known Source of Contamination  
ft. direction type  
Well disinfected upon completion?  Yes  No

Pump  Not Installed Date Installed  
Mfr name BERKLEY  
Model 783M-2 HP 15 Volts 460  
Drop Pipe Length 35 ft. Capacity 150 g.p.m.  
Type S

REMARKS, ELEVATION, SOURCE OF DATA, etc.  
18 IN. SURFACE CASING GROUTED IN TO 41 FT.  
12 IN. GROUTED TO WITHIN 10 FT. OF SURFACE.  
USGS Quad: Elevation: 1064  
Aquifer: Alt Id: 76-1240

Any not in use and not sealed well(s) on property?  Yes  No

Was a variance granted from the MDH for this Well?  Yes  No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91353  
License Business Name  
Name of Driller HEJMANEK, D.

Unique No. 191553

County Name Redlake

MINNESOTA DEPARTMENT OF HEALTH  
**WELL AND BORING RECORD**

Minnesota Statutes Chapter 1031

Update Date 2001/12/03

Entry Date 2000/07/14

Township Name Township Range Dir Section Subsection  
150 44 W 31 C

Well Depth Depth Completed Date Well Completed  
75 ft. 70 ft. 1982/05/16

Well Name CROOKSTON 3

Drilling Method Non-specified Rotary

Well Owner's Name CROOKSTON  
3  
CROOKSTON MN 56716-

Drilling Fluid Well Hydrofractured?  Yes  No  
From ft. to ft.

Use Community Supply (municipal)

Casing Drive Shoe?  Yes  N Hole Diameter

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
TOP SOIL	BLACK		0	1
SAND & LIGHT GRAVEL	BROW		1	9
SANDY CLAY	BLUE		9	16
SAND	VARIE		16	33
SAND/LIGHT GRAVEL	VARIE		33	43
SAND 18 SLOT	VARIE		43	48
SAND 12 SLOT	VARIE		48	53
SAND 12 SLOT	VARIE		53	58
SAND & GRAVEL 35 SLOT T	VARIE		58	63
GRAVEL TOOK WATER 35-5	VARIE		63	70
CLAY	BLUE		70	75

Casing Diameter Weight(lbs/ft)  
12 in. to 50 ft 49.56

in. to 70 ft

Screen Y Open Hole From ft. to ft.  
Make JOHNSON Type L  
Diameter Slot Length Set Fitting  
12 40 10 50 ft. to 60 ft  
12 50 10 60 ft. to 70 ft

Static Water Level 3.9 ft. from Land surface Date 1982/05/16

PUMPING LEVEL (below land surface)  
45.1 ft. after 72 hrs. pumping 700 g.p.m.

Well Head Completion  
Pitless adapter mfr MONTOR Model 8PS1214WBW  
Casing Protection  12 in. above grade  
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted?  Yes  No  
Material From To (ft.) Amount(yds/bags)  
G 10 50

Nearest Known Source of Contamination  
ft. direction type  
Well disinfected upon completion?  Yes  No

Pump  Not Installed Date Installed  
Mfr name BERKELEY  
Model 8SSM-2 HP 25 Volts 460  
Drop Pipe Length 43 ft. Capacity 800 g.p.m  
Type S

Any not in use and not sealed well(s) on property?  Yes  No

Was a variance granted from the MDH for this Well?  Yes  No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No.

REMARKS, ELEVATION, SOURCE OF DATA, etc.

18 IN. SURFACE CASING GROUTED IN TO 50 FT.

12 IN. CASING GROUTED TO WITH IN 10 FT. OF SURFACE.

USGS Quad: Elevation: 1070  
Aquifer: Alt Id: 76-1240

License Business Name

Unique No. 191554

County Name Redlake

MINNESOTA DEPARTMENT OF HEALTH  
**WELL AND BORING RECORD**

Minnesota Statutes Chapter 1031

Update Date 2001/06/01

Entry Date 2000/07/14

Township Name Township Range Dir Section Subsection  
150 44 W 31 C

Well Depth 166 ft. Depth Completed 156 ft. Date Well Completed 1982/08/05

Well Name CROOKSTON 4

Drilling Method Non-specified Rotary

Well Owner's Name CROOKSTON 4

Drilling Fluid

Well Hydrofractured?  Yes  No  
From ft. to ft.

CROOKSTON MN 56716-

Use Community Supply (municipal)

Casing Drive Shoe?  Yes  N

Hole Diameter  
in. to 156 ft

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
SAND & GRAVEL	BROW		0	10
SAND FINE/SMALL LENSES	BROW		10	34
FINE SAND	GRAY		34	55
SANDY CLAY/ROCK	BLUE		55	126
SAND & LIGHT GRAVEL	VARIE		126	131
DIRTY SAND	BLUE		131	133
SAND & GRAVEL 35 SLOT	VARIE		133	138
GRAVEL 40 SLOT	VARIE		138	143
LENSES OF GRAVEL & CLA	VARIE		143	148
GRAVEL	VARIE		148	156
FINE SAND & CLAY	BLUE		156	166

Casing Diameter 12 in. to 127 ft. Weight(lbs/ft) 49.56

Screen Y Open Hole From ft. to ft.

Make JOHNSON Type L

Diameter Slot 12 Length 70 Set 29 Fitting 127 ft. to 156 ft

Static Water Level 13 ft. from Land surface Date 1982/08/05

PUMPING LEVEL (below land surface)  
122.8 ft. after 72 hrs. pumping 350 g.p.m.

Well Head Completion  
Pitless adapter mfr MONITOR Model 8PS1214WBW  
Casing Protection  12 in. above grade  
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted?  Yes  No  
Material G From 10 To (ft.) 127 Amount(yds/bags)

Nearest Known Source of Contamination  
ft. direction type  
Well disinfected upon completion?  Yes  No

Pump  Not Installed Date Installed  
Mfr name BERKELEY  
Model 7S3L-3 HP 20 Volts 460  
Drop Pipe Length 19 ft. Capacity 350 g.p.m  
Type S

REMARKS, ELEVATION, SOURCE OF DATA, etc.

18 IN. SURFACE CASING GROUTED IN TO 126.5 FT.

12 IN. CASING GROUTED TO WITHIN 10 FT. OF SURFACE.

USGS Quad: Elevation: 1067  
Aquifer: Alt Id: 76-1240

Any not in use and not sealed well(s) on property?  Yes  No

Was a variance granted from the MDH for this Well?  Yes  No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91353

License Business Name

Name of Driller

HEJTMANEK, D.

Report Copy

Unique No. 685465

MINNESOTA DEPARTMENT OF HEALTH  
**WELL AND BORING RECORD**  
Minnesota Statutes Chapter 1031

Update Date 2004/01/27

County Name Polk

Entry Date

Township Name Township Range Dir Section Subsection  
149 43 W 18 SWSWSE

Well Depth 123 ft. Depth Completed 123 ft. Date Well Completed 2003/06/09

Well Name THE NATURE CONSERVANCY Crookston #5

Drilling Method Non-specified Rotary

Well Owner's Name THE NATURE CONSERVANCY OF MINNE  
1313 5TH SE ST  
MINNEAPOLIS MN 55414

Drilling Fluid Water Well Hydrofractured?  Yes  No  
From ft. to ft.

Use Community Supply (municipal)

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
TOP SOIL			0	1
SAND & GRAVEL			1	11
CLAY			11	25
GRAVEL & ROCK			25	27
CLAY WITH ROCKS			27	77
SAND			77	123

Casing Drive Shoe?  Yes  N Hole Diameter

Casing Diameter	Weight(lbs/ft)
12 in. to 93 ft	49.56

Screen Y Open Hole From ft. to ft.  
Make JOHNSON Type L

Static Water Level 4.3 ft. from Date 2003/06/27

PUMPING LEVEL (below land surface)  
70.31 ft. after 25 hrs. pumping 1000 g.p.m.

Well Head Completion Pitless adapter mfr MONITOR Model  
Casing Protection  12 in. above grade  
 At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted?  Yes  No

Material	From	To (ft.)	Amount(yds/bags)
G	10	73	81 S

Nearest Known Source of Contamination ft. direction type  
Well disinfected upon completion?  Yes  No

Pump  Not installed Date Installed  
Mfr name GOULDS HP 50 Volts 460  
Model 10RJMC Capacity g.p.m  
Drop Pipe Length 78 ft.  
Type S

REMARKS, ELEVATION, SOURCE OF DATA, etc.  
HWY 2 & 32 3.5 EAST 1 SOUTH

Any not in use and not sealed well(s) on property?  Yes  No

Was a variance granted from the MDH for this Well?  Yes  No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91339  
License Business Name  
Name of Driller LAKO, P.

USGS Quad: Elevation:  
Aquifer: Alt Id:

**Report Copy**

Unique No. 685466

MINNESOTA DEPARTMENT OF HEALTH  
**WELL AND BORING RECORD**

Update Date 2004/01/27

County Name Polk

Minnesota Statutes Chapter 1031

Entry Date

Township Name Township Range Dir Section Subsection  
149 43 W 18 DCC

Well Depth 118 ft. Depth Completed 118 ft. Date Well Completed 2003/06/10

Well Name THE NATURE CONSERVANCY *Crookston #6*

Drilling Method Non-specified Rotary

Well Owner's Name THE NATURE CONSERVANCY OF MINNE  
1313 5TH SE ST  
MINNEAPOLIS MN 55414

Drilling Fluid Water Well Hydrofractured?  Yes  No  
From ft. to ft.

Use Community Supply (municipal)

GEOLOGICAL MATERIAL	COLOR	HARDNESS	FROM	TO
TOPSOIL			0	1
GRAVEL			1	9
CLAY W/ROCK			9	35
SAND			35	37
CLAY			37	45
SAND			45	49
SANDY CLAY			49	57
GRAVEL			57	118

Casing Drive Shoe?  Yes  N Hole Diameter

Casing Diameter 12 in. to 88 ft Weight(lbs/ft) 49.56

Screen Y Open Hole From ft. to ft.  
Make JOHNSON Type L

Static Water Level 4.5 ft. from Date 2003/06/27

PUMPING LEVEL (below land surface)  
70.21 ft. after 25 hrs. pumping 1000 g.p.m.

Well Head Completion  
Pitless adapter mfr MONITOR Model  12 in. above grade  
Casing Protection  At-grade(Environmental Wells and Borings ONLY)

Grouting Information Well grouted?  Yes  No  
Material From To (ft.) Amount(yds/bags)  
G 10 83 95 S

Nearest Known Source of Contamination  
ft. direction type  
Well disinfected upon completion?  Yes  No

Pump  Not Installed Date Installed  
Mfr name GOULDS  
Model 10RJMC HP 50 Volts 460  
Drop Pipe Length 75 ft. Capacity g.p.m.  
Type S

Any not in use and not sealed well(s) on property?  Yes  No

Was a variance granted from the MDH for this Well?  Yes  No

Well CONTRACTOR CERTIFICATION Lic. Or Reg. No. 91339  
License Business Name  
Name of Driller LAKO, P.

USGS Quad: Elevation:  
Aquifer: Alt Id:

**Report Copy**

**APPENDIX II**  
**WSN Aquifer Pumping Test Report**

January 31, 2002

Mr. Keith Mykleseth  
City of Crookston  
124 North Broadway  
Crookston, MN 56716

**RECEIVED**

JAN 18 2005

**Revised Results of Test Drilling and Aquifer Testing  
Proposed New Well Field Location-Nature Conservancy Property**

Source Water Protection Unit

Dear Mr. Mykleseth;

The test drilling, aquifer testing, and water quality analysis for the proposed municipal well location have been completed. This letter summarizes the revised results of the study and discusses the feasibility of further development of this area for a municipal water source. The revision was performed because additional water quality data was collected from the subject area.

**Test Drilling**

L.T.P. Enterprises, Inc. was contracted by the City of Crookston to advance a series of test borings approximately four miles southeast of the intersection of U.S. Highway 2 and Minnesota State Highway 32 (i.e., Marcoux Corner) to assess the potential of an aquifer of sufficient extent and quality exists in the area to warrant further development as a municipal water source for the City of Crookston. Due to the current usage rates and future usage projections of the current City of Crookston well field, it was decided to locate a new well site to provide an auxiliary source of groundwater for the City. This auxiliary well field would be used in conjunction with the current well field to lessen the strain on the existing wells, augment the current supply, diversify the City's water sources, and allow the City to effect repairs on any of the wells or associated pumps without concerns about maintaining sufficient production to meet the City's usage demand. It would also ensure a water source in the event of contamination of the current well field.

The study area is located in Section 18 of Grove Park Township, approximately four miles south east of Marcoux Corner and three miles northwest of Mentor, Minnesota. The study property was formerly owned by Tilden Farms and recently purchased by The Nature Conservancy of Minnesota. This area was chosen by the City of Crookston because of the existence of several older irrigation wells in the area that were reportedly

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Fax: (218) 281-6545  
www.wsn-mn.com

capable of sustained yields of greater than 1,500 gallons per minute (gpm). The study centers around a 12-inch diameter test well (TW-7) installed by L.T.P. Enterprises on September 25, 2001. Test well TW-7 was completed to a depth of 114 feet below land surface (BLS) and was screened from 89 to 114 feet BLS. The location of this well is indicated in Figure 2 and the drillers log is included as Attachment A. Two observation wells (OW-1 and OW-2) were also completed around TW-7 to assist in determining aquifer transmissivity and well efficiency. Observation Well (OW-1) is located approximately 79 feet south-southeast of TW-7 and is completed to a depth of 102 feet BLS. Observation Well (OW-2) is located approximately 296 feet west-southwest of TW-7 and is completed to a depth of 102 feet BLS. Both OW-1 and OW-2 are screened from 98 to 102 feet BLS with static water levels of 2 to 3 feet BLS. See Figure 2 for the locations of these wells and Attachment A for the drillers logs and well records.

Test well TW-8 was installed approximately 1,280 feet west-southwest of TW-7 and was initially installed as part of the exploratory phase of the project to determine the best possible location for a large production well. When TW-7 was chosen by the City of Crookston as the area for the aquifer test, TW-8 was left for use as an observation well during the pumping test. TW-8 was advanced to a depth of 136 feet BLS and screened from 91 to 115 feet BLS. Upon completion of the pumping test on TW-7, observation wells OW-1 and OW-2 were upgraded with protective casings for future use as observation wells and test well/observation well TW-8 and pumping well TW-7 were pulled and holes sealed. The existing well on the subject property was also sealed at this time. Copies of the sealing records are included in Attachment A for reference.

Based on the drillers logs, the test holes encountered sand and gravel to approximately 5 to 11 feet BLS, underlain by a 47 to 60-foot thick sandy clay layer, (see well records in Attachment A). Below this sandy clay layer, the geologic materials are characterized by medium to coarse-grained sands, gravels, and rock to a depth of 118 feet to 122 feet BLS. A sandy clay was again encountered in TW-7 at a depth of 118 feet BLS to the termination of the borings at 122 feet BLS.

### **Aquifer Testing**

Widseth Smith Nolting (WSN) was retained by the City of Crookston to assist with the completion of the pumping test. The pumping well (TW-7) was test pumped at 1,390 gallons per minute (gpm) for 24 hours. This is an average rate obtained by dividing the total gallons pumped by the total length of the test in minutes. The pumping was terminated after 24 hours because sufficient data was acquired to perform transmissivity, specific capacity, and storativity calculations. The drawdown in the pumping well was also approaching the pump intake level at the time the test was terminated. The pumping was performed using a submersible pump set at approximately 84 feet BLS with the pumping rate determined using a flow meter/totalizer. During the pumping test, water level drop was recorded in the test well, both observation wells, and TW-8. Copies of all

drawdown measurements are included as Attachment B for reference. As indicated by the data, water level drops of 76.49 feet in TW-7; 34.58 feet in OW-1; 28.08 feet in OW-2; and 19.33 feet in TW-8 were recorded after 24 hours of sustained pumping of TW-7. Figures 3 through 6 present the time-drawdown data for TW-7, OW-1, OW-2, and TW-8, respectively. Figure 7 presents the maximum drawdown data for all four wells as a distance-drawdown graph.

Figure 7 indicates that the theoretical horizontal influence of the pumping test extends out approximately 40,000 feet from TW-7. The theoretical influence is determined by a straight-line interpretation from the distance-drawdown graph where the distance of the wells from the test well is plotted on a logarithmic scale against drawdown. A straight line is drawn through the three observation wells and the intercept of this line with the zero drawdown line represents the theoretical influence. However, drawdown levels in all four wells had not reached equilibrium at the time the pumping was terminated. If pumping on TW-1 would have been continued until water levels in all three wells had reached their respective static levels, the value for the horizontal influence of sustained pumping may have changed.

Typically, a distance drawdown graph can be used to calculate the efficiency of the pumping well. Efficiency is calculated by dividing the theoretical drawdown (i.e., that point indicated by the intercept of a straight line through the observation wells with the casing radius; see Figure 7) by the actual drawdown measured in the pumping well. By using the distance-drawdown graph an efficiency value of 79% is calculated. An efficiency of 70% is common for a fully developed, well-constructed production well.

The specific capacity of the test well was calculated at 18.17 gallons per minute per foot (gpm/ft) of drawdown. Specific capacity is dependent on aquifer characteristics and well construction and is a general indication of the production capacity of a well. High capacity wells have specific capacities of 10 gpm/ft to over 25 gpm/ft. See Figure 12 for the formula used to calculate specific capacity.

Graphical analysis of the drawdown data indicates the aquifer has a moderate transmissivity. Transmissivity is a measure of the ability of an aquifer to produce water. The transmissivity of the target aquifer, as calculated from the time-drawdown graphs (see Figure 4, 5, and 6), ranged from 28,228 to 30,580 gallons per day per foot (gpd/ft). See Figure 12 for the formulas used to calculate transmissivity volumes. A municipal well requires at least 10,000 gpd/ft, with a highly productive well being situated in an aquifer with a transmissivity of more than 100,000 gpd/ft. The analysis also indicates the aquifer has an average storativity of  $3.8 \times 10^{-3}$ , which falls in the range of values for a confined aquifer. Storativity is a dimensionless value that represents the volume of water per area of the aquifer per unit change in water levels.

## Water Quality

A raw water sample was collected from the test well TW-7 and submitted to independent laboratories for analysis of water chemistry. These analyses included parameters such as specific conductance, ph, total dissolved solids (TDS), total organic carbon (TOC), iron, manganese, calcium, magnesium, arsenic, alkalinity, anions, and hardness. Laboratory analyses for possible contaminants such as, nitrate, nitrite, volatile organic compounds (VOCs), pesticides, and radionuclides were also obtained. Copies of the laboratory analytical results are included as Attachment C, for reference.

The water chemistry analyses indicate that the water sample from Test Well (TW-7) contained moderate levels of iron and manganese. Iron was detected at a concentration of 0.57 to 0.87 milligrams per liter (mg/l) and manganese at a concentration of 0.063 to 0.067 mg/L. Both of these values are similar to levels commonly found in groundwater throughout Minnesota. However, they are slightly higher than the secondary drinking water standards of 0.3 mg/L for iron and 0.05 mg/L for manganese. In addition, hardness was reported at a concentration of 272 to 280 mg/L. A range of concentrations for iron, manganese, and hardness was obtained because two samples were analyzed.

The analytical results indicate that no VOCs or pesticides were detected in the water sample from TW-7 and all nitrogen compounds were below the practical quantitation limit. The analytical results indicated that radon was detected at a concentration of  $240 \pm 25$  pico Curies per liter (pCi/L), a gross alpha activity of  $2.0 \pm 0.6$  pCi/L, and a total radium activity of  $0.9 \pm 0.3$  pCi/L. This value is below the maximum contaminant level (MCL) of 300 pCi/L set by the Environmental Protection Agency. Groundwater systems that exceed the allowable concentrations will have to implement treatment procedures, such as aeration, to reduce radon concentrations.

Because arsenic is a common constituent in this area, groundwater samples from Test Well (TW-7), were also analyzed for this parameter. Groundwater samples were collected from TW-7 on two separate dates. On 6-20-01, a groundwater sample was collected from TW-7, upon completion of well development and on 9-27-01, a groundwater sample was collected after several hours of the sustained pumping test. The arsenic results from the two sampling events are presented in Table 1. As indicated in Table 1, an arsenic concentration of 5.3 parts per billion was detected in the 6-20-01 sample and <5.0 parts per billion (ppb) in the 9-27-01 sample. However, the method detection limits for these two analyses was 5.0 ppb.

Additional groundwater samples were collected from Observation Wells 1 & 2, Test Well/Observation Well #8, and the existing Irrigation Well in Section 18, and analyzed for arsenic. These additional samples were collected to provide a better understanding of the local distribution of arsenic in the subject aquifer. Table 1 presents the laboratory analytical results for arsenic from the above-mentioned wells. As you will note, arsenic was detected in Observation Well 1 (5.88 ppb), Observation Well 2 (4.52 ppb), and the

existing Irrigation Well (5.6 – 6.79 ppb), at concentrations above the method detection limit of 0.400 ppb.

The groundwater sample collected from Test Well #8 was below the method detection limit of 5.0 ppb in the 7-02-01 sampling event. Test Well #8 was sealed upon completion of the pumping test and was therefore, not resampled and analyzed for arsenic at the lower method detection limit of 0.400 ppb. However, based on the laboratory analytical results obtained from the other wells completed in the same aquifer (i.e., TW-7, OW-1, OW-2, & the existing Irrigation Well), an arsenic concentration of 5 to 6 ppb is characteristic of this area. Therefore, if another groundwater sample was collected from the area near the former location of TW #8, an arsenic concentration, at or near the 5 to 6 ppb range, is probable.

Based on a recent ruling by the US Environmental Protection Agency (EPA), the maximum allowable limit for arsenic in drinking water is 10 ppb. As you will note from Table 1, all of the analyzed sample concentrations were below the current maximum allowable limit.

Groundwater samples from the current City of Crookston wells, were also collected upon request by the City, to check the existing wells for the presence of arsenic and attempt to assess the effectiveness of the current water treatment plant to remove arsenic. The results of these analyses are presented in Table 2. As indicated in Table 2, the existing deep well (#1) was below the method detection limit (MDL) of 0.4 ppb and the two shallow wells (#2 and #3) were slightly above the MDL at 1.03 ppb and 1.18 ppb, respectively.

Water samples were also collected from the input and output of the water treatment plant to assess the effectiveness of the treatment plant to remove arsenic (see Table 2). Two sampling events were performed to provide more accurate results. As indicated in Table 2, arsenic concentrations from the input samples (i.e., 0.448 and 0.460 ppb) were just above the MDL of 0.4 ppb. The output concentrations of 1.19 ppb and 0.712 ppb were also above the MDL of 0.4 ppb. Based on the laboratory analytical results, no evidence of any reduction in arsenic concentrations was observed.

## Conclusions

Based on the pumping test data and on the aquifer characteristics obtained from the data graphs, the aquifer appears to be confined. Review of the aquifer's production capacity, transmissivity, and specific capacity indicate that this area should support the development of a municipal well field for the City of Crookston. The geology observed on the driller's logs, for wells installed, indicate the aquifer is laterally extensive and should be adequate for the City's needs. However, this is based only on the driller's geologic descriptions. WSN was not present during the drilling phase of this project and therefore, can neither confirm nor deny the geologic units encountered in the logs. The

test data also indicated that sustained pumping in this area could have an influence on the aquifer as far as 40,000 feet (i.e.,  $\approx$  7.5 miles) distant.

The quality of the water is acceptable, with only one constituent of concern (i.e., arsenic). As stated earlier, arsenic concentrations ranging from 4.52 ppb to 6.79 ppb were detected in water samples collected from several wells developed in the subject aquifer. However, all detected concentrations are below the current maximum allowable level of 10 ppb.

In addition, groundwater samples collected from the existing wells and water treatment plant input/output and analyzed for arsenic, do not provide any evidence that the current treatment system is effective in removing arsenic from groundwater.

All other potential pollutant constituents were either non-detect or below the Minnesota Health Risk Limits. The water is slightly hard and has iron and manganese concentrations slightly above the secondary drinking water standards. Concentrations of iron and manganese above the secondary limits can cause staining problems for fixtures and laundry. The City's current treatment process should minimize these concerns. Also, because the water chemistry results are similar to the current water supply, mixing of this water with the current supplies should not warrant any concerns.

### **Recommendations**

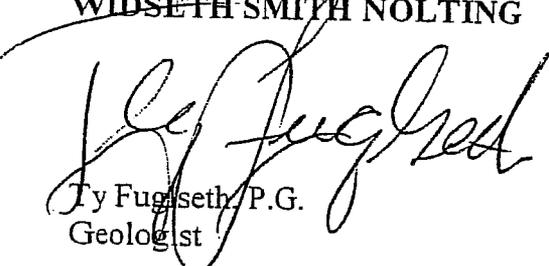
Based on the results of the test drilling, aquifer characteristics testing, and laboratory analytical results, if the City of Crookston decides to proceed with the development of the site for a municipal well field, two production wells could be installed in this area without significantly affecting the immediate area's water resources. In order to achieve the production goals set by the City of Crookston, two 12-inch production wells should be completed. One well would be located between the existing pole barn and the gravel road to the east, with at least 250 feet separating the well and the road. The second well would be located approximately 1,000 feet west-southwest from the first well to prevent significant interference between the wells when both are pumped simultaneously. The wells would be designed to produce approximately 1,200 gallons per minute, but could be throttled down to meet the 2,200 gpm capability of the gravity feed line between the ground storage reservoir and the treatment plant.

Page 7  
Mr. Keith Mykleseth  
January 31, 2002

Should you have any questions, feel free to contact Brian Ross at (218) 829-5117 or myself at (218) 281-6522.

Sincerely,

**WIDSETH SMITH NOLTING**



Ty Fugseth, P.G.  
Geologist

cc: Brian Ross, WSN  
David Kildahl, WSN

**Table 1**  
**Arsenic Results for Groundwater Samples**  
**Proposed Well Field Site**

Sample Date	Test Well #7	Observation Well #1	Observation Well #2	Test Well #8	Irrigation Well (Section 18)
4-12-01	NS	NS	NS	NS	5.6
6-20-01	5.3	NS	NS	NS	NS
7-02-01	NS	NS	NS	<5.0	NS
9-27-01	<5.0	NS	NS	NS	NS
12-10-01*	NS	5.88	4.52	NS	6.79

Note: Concentrations reported in parts per billion.

NS = Not sampled on this date.

\* = Samples collected on this date were analyzed using an ICP-MS to reduce the detection limit to 0.400 ppb. Earlier analyses were subject to a 5.0 ppb detection limit.

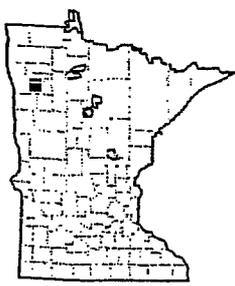
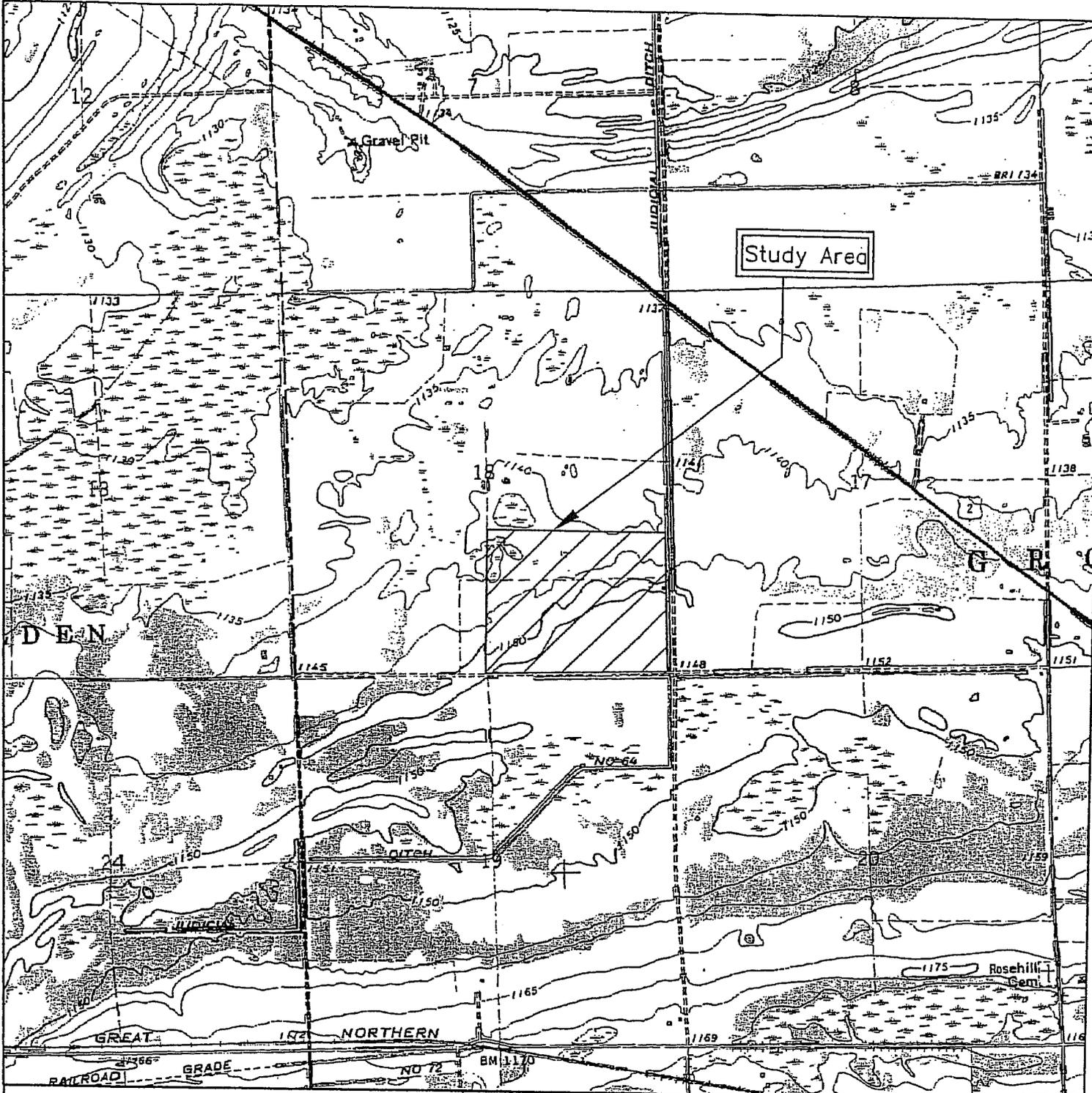
**Table 2**  
**Arsenic Results for Groundwater Samples**  
**Well Field & Water Treatment Plant**

Sample Date	Well #1	Well #2	Well #3	Plant Input	Plant Output
12-10-01	<0.40	1.03	1.18	0.448	1.19
1-07-02	NS	NS	NS	0.460	0.712

Note: Concentrations reported in parts per billion.

NS = Not sampled on this date.

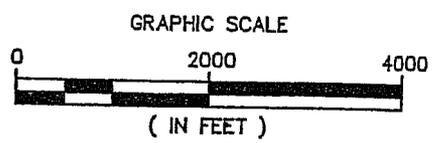
***FIGURES***



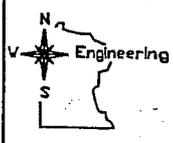
AREA LOCATION

MN 3.5°
   
 UMT Grid & Magnetic
   
 North Declination at
   
 Center of Sheet.

U.S.G.S. QUADRANGLE MAPS: Mentor, MN  
 PUBLISHED: 1966  
 PHOTOREVISED: N/A



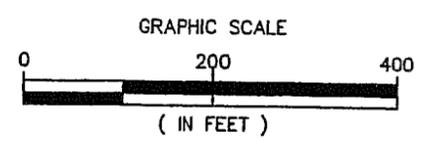
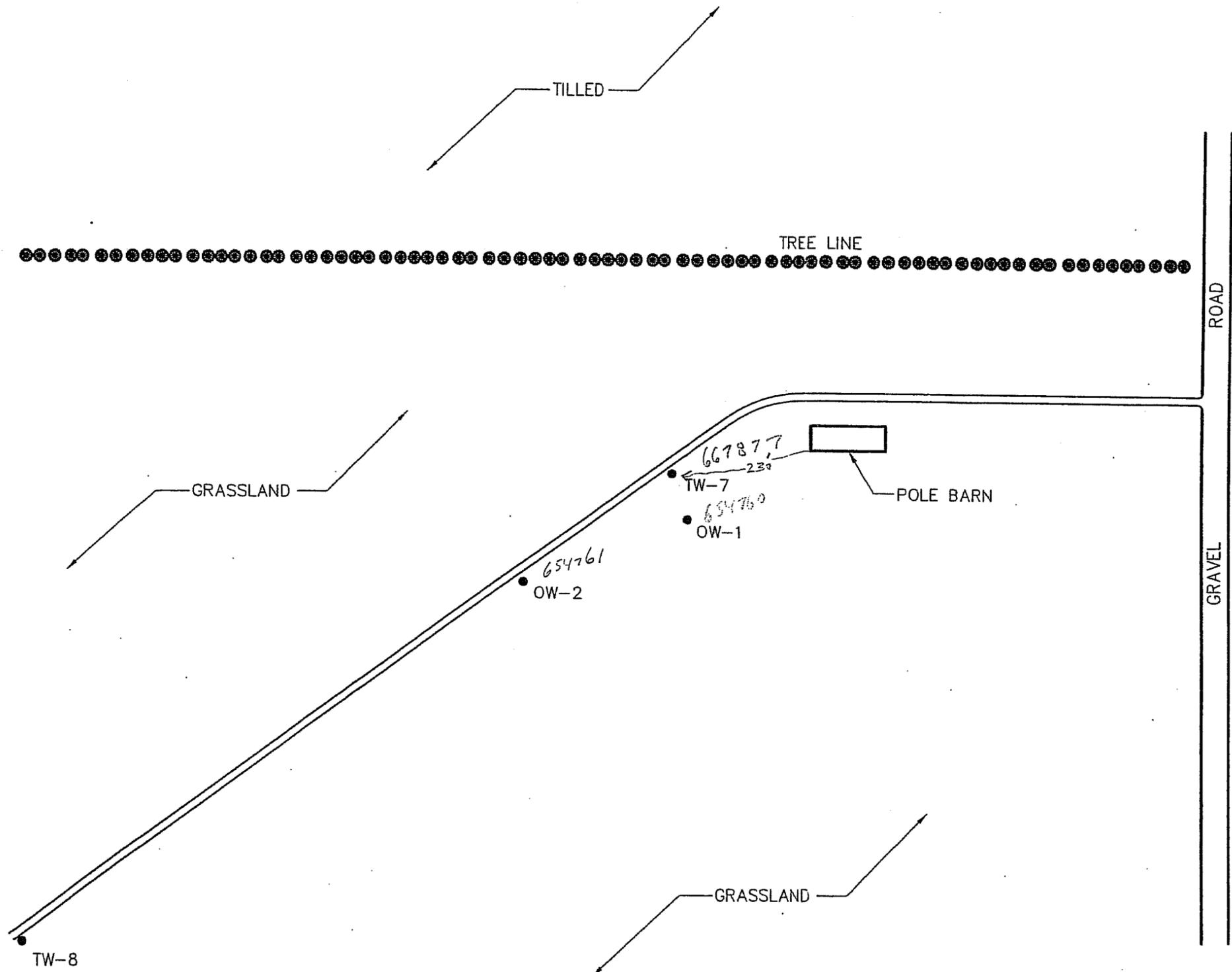
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**WIDSETH SMITH NOLTING**  
 ENGINEERS, ARCHITECTS, LAND SURVEYORS  
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City of Crookston Well Field Study  
 The Nature Conservancy of Minnesota  
 Tilden Farms Property

Figure 1  
 Nov. 2001



LEGEND

Note: Location of structures and utilities are approximate. Verify utilities before starting any subsurface work.

Figure 2	
City of Crookston Auxiliary Well Field Site	
The Nature Conservancy of Minnesota Tilden Farms Property	
501CROX\363\Figure 2	Nov., 2001

<b>WIDSETH SMITH NOLTING</b>	ENGINEERS	ALEXANDRIA
	ARCHITECTS	BEMIDJI
	LAND SURVEYORS	BRAINERD
ENVIRONMENTAL SERVICES	CROOKSTON	
	GRAND FORKS	
	WWW.WSMN.COM	

















# **APPENDIX III**

## **Well Vulnerability Assessment Worksheets**

## Vulnerability Assessment Worksheet

Well Name/No. Crookston Well #1

Public Water Supplier ID No. 1600002

Minnesota Unique Well No. 147243

<b>1. DNR vulnerability rating - assign the following point values:</b>	
Very High	Vulnerable
High	Vulnerable
Moderate      Geologic sensitivity is L-7 but tritium result increases rating to moderate.	25 points
Low ("L" score of 1 to 3)	20 points
Low ("L" score of 4 to 7)	15 points
Very Low ("L" score of 8 to 11)	10 points
Very Low ("L" score of 12 or greater)	0 points
<b>TOTAL POINTS</b>	<b>25</b>

<b>2. Casing integrity - assign the following point values:</b>	
Each breach of the casing.	20 points
Each casing string not grouted or extending to the land surface.	10 points
Each category for which information requested is unknown.	5 points
Each string of properly installed casing.	0 points
<b>TOTAL POINTS</b>	<b>0</b>

<b>3. Casing depth - assign the following point values:</b>	
<50 feet	20 points
50 to 200 feet      140 feet	10 points
201 to 500 feet	5 points
>500 feet	0 points
<b>TOTAL POINTS</b>	<b>10</b>

<b>4. Pumping rate - assign the following point values:</b>	
>1000 gallons/minute	20 points
501 to 1000 gallons/minute	10 points
50 to 500 gallons/minute      200 gpm	5 points
<50 gallons/minute	0 points
<b>TOTAL POINTS</b>	<b>5</b>

<b>5. Isolation distance from contamination sources:</b>	
For wells <50 feet deep, assign 10 points to each source located within 100 feet of the well.	
For wells >50 feet deep, assign 10 points to each source located within 50 feet of the well.	
<b>TOTAL POINTS</b>	<b>0</b>

<b>6. Chemical and isotopic information:</b>	
<b>Volatile Organic Compounds Detection</b>	Vulnerable
<b>Synthetic Organic Compounds Detection</b>	Vulnerable
<b>Nitrate-Nitrogen Results</b>	Vulnerable
>10 parts/million	Vulnerable
>3 but ≤ 10 parts/million	30 points
1 to 3 parts/million	10 points
<1 parts/million	0 points
<b>Tritium Results</b>	
>1 TU                                      3.3 TU (4-11-2005)	Vulnerable
<1 TU	0 points
<b><sup>14</sup>Carbon Results</b>	
For wells in which the <sup>14</sup> carbon content of water indicates an age approximation of at least several centuries, subtract 20 points from the score.	
<b>TOTAL POINTS</b>	

<b>7. Grand total score:</b>	
1. DNR Vulnerability Rating	25
2. Casing Integrity	0
3. Casing Depth	10
4. Pumping Rate	5
5. Isolation Distance from Contaminant Sources	0
6. Chemical and Isotopic Information	Vulnerable
<b>GRAND TOTAL</b>	<b>This well is vulnerable due to Tritium detection.</b> 40

- ▶ If the score is 45 or more, the well is considered vulnerable.
- ▶ If the score is between 5 and 40, priority for phasing into the state's WHP program is referenced to population served.
- ▶ If the score is 0 or less, the well is considered not vulnerable.

## Vulnerability Assessment Worksheet

Well Name/No. Crookston Well #2

Public Water Supplier ID No. 1600002

Minnesota Unique Well No. 191552

<b>1. DNR vulnerability rating - assign the following point values:</b>	
Very High	Vulnerable
High                    Geologic sensitivity is moderate but tritium result increases rating to high.	Vulnerable
Moderate	25 points
Low ("L" score of 1 to 3)	20 points
Low ("L" score of 4 to 7)	15 points
Very Low ("L" score of 8 to 11)	10 points
Very Low ("L" score of 12 or greater)	0 points
<b>TOTAL POINTS</b>	<b>Vulnerable</b>

<b>2. Casing integrity - assign the following point values:</b>	
Each breach of the casing.	20 points
Each casing string not grouted or extending to the land surface.	10 points
Each category for which information requested is unknown.	5 points
Each string of properly installed casing.	0 points
<b>TOTAL POINTS</b>	<b>0</b>

<b>3. Casing depth - assign the following point values:</b>	
<50 feet                    41 feet	20 points
50 to 200 feet	10 points
201 to 500 feet	5 points
>500 feet	0 points
<b>TOTAL POINTS</b>	<b>20</b>

<b>4. Pumping rate - assign the following point values:</b>	
>1000 gallons/minute	20 points
501 to 1000 gallons/minute	10 points
50 to 500 gallons/minute                    175 gpm, per Pat Kelly (3/21/06)	5 points
<50 gallons/minute	0 points
<b>TOTAL POINTS</b>	<b>5</b>



## Vulnerability Assessment Worksheet

Well Name/No. Crookston Well #3

Public Water Supplier ID No. 1600002

Minnesota Unique Well No. 191553

<b>1. DNR vulnerability rating - assign the following point values:</b>	
Very High	Vulnerable
High                      Geologic sensitivity is moderate but tritium result increases rating to high.	Vulnerable
Moderate	25 points
Low ("L" score of 1 to 3)	20 points
Low ("L" score of 4 to 7)	15 points
Very Low ("L" score of 8 to 11)	10 points
Very Low ("L" score of 12 or greater)	0 points
<b>TOTAL POINTS</b>	<b>Vulnerable</b>

<b>2. Casing integrity - assign the following point values:</b>	
Each breach of the casing.	20 points
Each casing string not grouted or extending to the land surface.	10 points
Each category for which information requested is unknown.	5 points
Each string of properly installed casing.	0 points
<b>TOTAL POINTS</b>	<b>0</b>

<b>3. Casing depth - assign the following point values:</b>	
<50 feet                      50 feet (per MDH)	20 points
50 to 200 feet	10 points
201 to 500 feet	5 points
>500 feet	0 points
<b>TOTAL POINTS</b>	<b>20</b>

<b>4. Pumping rate - assign the following point values:</b>	
>1000 gallons/minute	20 points
501 to 1000 gallons/minute	10 points
50 to 500 gallons/minute                      450-500 gpm, per Pat Kelly (3/21/06)	5 points
<50 gallons/minute	0 points
<b>TOTAL POINTS</b>	<b>5</b>

<b>5. Isolation distance from contamination sources:</b>	
For wells <50 feet deep, assign 10 points to each source located within 100 feet of the well.	
For wells >50 feet deep, assign 10 points to each source located within 50 feet of the well.	
<b>TOTAL POINTS</b>	<b>0</b>

<b>6. Chemical and isotopic information:</b>	
<b>Volatile Organic Compounds Detection</b>	Vulnerable
<b>Synthetic Organic Compounds Detection</b>	Vulnerable
<b>Nitrate-Nitrogen Results</b>	Vulnerable
>10 parts/million	Vulnerable
>3 but ≤ 10 parts/million	30 points
1 to 3 parts/million	10 points
<1 parts/million	0 points
<b>Tritium Results</b>	
>1 TU                                      14.3 TU (4-11-2005)	Vulnerable
<1 TU	0 points
<b><sup>14</sup>Carbon Results</b>	
For wells in which the <sup>14</sup> carbon content of water indicates an age approximation of at least several centuries, subtract 20 points from the score.	
<b>TOTAL POINTS</b>	

<b>7. Grand total score:</b>	
1. DNR Vulnerability Rating	Vulnerable
2. Casing Integrity	0
3. Casing Depth	20
4. Pumping Rate	5
5. Isolation Distance from Contaminant Sources	0
6. Chemical and Isotopic Information	Vulnerable
<b>GRAND TOTAL</b>	<b>This well is vulnerable due to Tritium detection.</b> 25

- ▶ If the score is 45 or more, the well is considered vulnerable.
- ▶ If the score is between 5 and 40, priority for phasing into the state's WHP program is referenced to population served.
- ▶ If the score is 0 or less, the well is considered not vulnerable.

## Vulnerability Assessment Worksheet

Well Name/No. Crookston Well #4

Public Water Supplier ID No. 1600002

Minnesota Unique Well No. 191554

<b>1. DNR vulnerability rating - assign the following point values:</b>	
Very High	Vulnerable
High	Vulnerable
Moderate      Geologic sensitivity is L-7 but tritium result increases rating to moderate.	25 points
Low ("L" score of 1 to 3)	20 points
Low ("L" score of 4 to 7)	15 points
Very Low ("L" score of 8 to 11)	10 points
Very Low ("L" score of 12 or greater)	0 points
<b>TOTAL POINTS</b>	<b>25</b>

<b>2. Casing integrity - assign the following point values:</b>	
Each breach of the casing.	20 points
Each casing string not grouted or extending to the land surface.	10 points
Each category for which information requested is unknown.	5 points
Each string of properly installed casing.	0 points
<b>TOTAL POINTS</b>	<b>0</b>

<b>3. Casing depth - assign the following point values:</b>	
<50 feet	20 points
50 to 200 feet      127 feet	10 points
201 to 500 feet	5 points
>500 feet	0 points
<b>TOTAL POINTS</b>	<b>10</b>

<b>4. Pumping rate - assign the following point values:</b>	
>1000 gallons/minute	20 points
501 to 1000 gallons/minute	10 points
50 to 500 gallons/minute      350 gpm	5 points
<50 gallons/minute	0 points
<b>TOTAL POINTS</b>	<b>5</b>

<b>5. Isolation distance from contamination sources:</b>	
For wells <50 feet deep, assign 10 points to each source located within 100 feet of the well.	
For wells >50 feet deep, assign 10 points to each source located within 50 feet of the well.	
<b>TOTAL POINTS</b>	<b>0</b>

<b>6. Chemical and isotopic information:</b>	
<b>Volatile Organic Compounds Detection</b>	Vulnerable
<b>Synthetic Organic Compounds Detection</b>	Vulnerable
<b>Nitrate-Nitrogen Results</b>	Vulnerable
>10 parts/million	Vulnerable
>3 but ≤ 10 parts/million	30 points
1 to 3 parts/million	10 points
<1 parts/million	0 points
<b>Tritium Results</b>	
>1 TU                                      1.9 TU (9-10-1991)	Vulnerable
<1 TU	0 points
<b><sup>14</sup>Carbon Results</b>	
For wells in which the <sup>14</sup> carbon content of water indicates an age approximation of at least several centuries, subtract 20 points from the score.	
<b>TOTAL POINTS</b>	

<b>7. Grand total score:</b>	
1. DNR Vulnerability Rating	25
2. Casing Integrity	0
3. Casing Depth	10
4. Pumping Rate	5
5. Isolation Distance from Contaminant Sources	0
6. Chemical and Isotopic Information	Vulnerable
<b>GRAND TOTAL</b>	<b>This well is vulnerable due to Tritium detection.</b> 40

- ▶ If the score is 45 or more, the well is considered vulnerable.
- ▶ If the score is between 5 and 40, priority for phasing into the state's WHP program is referenced to population served.
- ▶ If the score is 0 or less, the well is considered not vulnerable.

## Vulnerability Assessment Worksheet

Well Name/No. Crookston Well #5

Public Water Supplier ID No. 1600002

Minnesota Unique Well No. 685465

<b>1. DNR vulnerability rating - assign the following point values:</b>	
Very High	Vulnerable
High	Vulnerable
Moderate      Geologic sensitivity is L-6 but tritium results in nearby wells increases rating to moderate.	25 points
Low ("L" score of 1 to 3)	20 points
Low ("L" score of 4 to 7)	15 points
Very Low ("L" score of 8 to 11)	10 points
Very Low ("L" score of 12 or greater)	0 points
<b>TOTAL POINTS</b>	<b>25</b>

<b>2. Casing integrity - assign the following point values:</b>	
Each breach of the casing.	20 points
Each casing string not grouted or extending to the land surface.	10 points
Each category for which information requested is unknown.	5 points
Each string of properly installed casing.	0 points
<b>TOTAL POINTS</b>	<b>0</b>

<b>3. Casing depth - assign the following point values:</b>	
<50 feet	20 points
50 to 200 feet      93 feet	10 points
201 to 500 feet	5 points
>500 feet	0 points
<b>TOTAL POINTS</b>	<b>10</b>

<b>4. Pumping rate - assign the following point values:</b>	
>1000 gallons/minute	20 points
501 to 1000 gallons/minute      1000 gpm	10 points
50 to 500 gallons/minute	5 points
<50 gallons/minute	0 points
<b>TOTAL POINTS</b>	<b>10</b>

<b>5. Isolation distance from contamination sources:</b>	
For wells <50 feet deep, assign 10 points to each source located within 100 feet of the well.	
For wells >50 feet deep, assign 10 points to each source located within 50 feet of the well.	
<b>TOTAL POINTS</b>	<b>0</b>

<b>6. Chemical and isotopic information:</b>	
<b>Volatile Organic Compounds Detection</b>	Vulnerable
<b>Synthetic Organic Compounds Detection</b>	Vulnerable
<b>Nitrate-Nitrogen Results</b>	Vulnerable
>10 parts/million	Vulnerable
>3 but ≤ 10 parts/million	30 points
1 to 3 parts/million	10 points
<1 parts/million	0 points
<b>Tritium Results</b>	
>1 TU	Vulnerable
<1 TU	0 points
<b><sup>14</sup>Carbon Results</b>	
For wells in which the <sup>14</sup> carbon content of water indicates an age approximation of at least several centuries, subtract 20 points from the score.	
<b>TOTAL POINTS</b>	<b>0</b>

<b>7. Grand total score:</b>	
1. DNR Vulnerability Rating	25
2. Casing Integrity	0
3. Casing Depth	10
4. Pumping Rate	10
5. Isolation Distance from Contaminant Sources	0
6. Chemical and Isotopic Information	0
<b>GRAND TOTAL</b>	<b>45</b>
<b>This well is vulnerable due to vulnerability score.</b>	

- ▶ If the score is 45 or more, the well is considered vulnerable.
- ▶ If the score is between 5 and 40, priority for phasing into the state's WHP program is referenced to population served.
- ▶ If the score is 0 or less, the well is considered not vulnerable.

## Vulnerability Assessment Worksheet

Well Name/No. Crookston Well #6

Public Water Supplier ID No. 1600002

Minnesota Unique Well No. 685466

<b>1. DNR vulnerability rating - assign the following point values:</b>	
Very High	Vulnerable
High	Vulnerable
Moderate      Geologic sensitivity is L-2 but the tritium result increases rating to moderate.	25 points
Low ("L" score of 1 to 3)	20 points
Low ("L" score of 4 to 7)	15 points
Very Low ("L" score of 8 to 11)	10 points
Very Low ("L" score of 12 or greater)	0 points
<b>TOTAL POINTS</b>	<b>25</b>

<b>2. Casing integrity - assign the following point values:</b>	
Each breach of the casing.	20 points
Each casing string not grouted or extending to the land surface.	10 points
Each category for which information requested is unknown.	5 points
Each string of properly installed casing.	0 points
<b>TOTAL POINTS</b>	<b>0</b>

<b>3. Casing depth - assign the following point values:</b>	
<50 feet	20 points
50 to 200 feet      88 feet	10 points
201 to 500 feet	5 points
>500 feet	0 points
<b>TOTAL POINTS</b>	<b>10</b>

<b>4. Pumping rate - assign the following point values:</b>	
>1000 gallons/minute	20 points
501 to 1000 gallons/minute      1000 gpm	10 points
50 to 500 gallons/minute	5 points
<50 gallons/minute	0 points
<b>TOTAL POINTS</b>	<b>10</b>

