APPENDIX L

TECHNICAL MEMORANDUM
SIMULATION OF EW-3 PUMPING TEST

CONESTOGA-ROVERS
& ASSOCIATES

651 Colby Drive, Waterloo, Ontario, Canada N2V 1C2
Telephone: (519) 884-0510 Fax: (519) 884-0525
www.CRAworld.com

TECHNICAL MEMORANDUM

TO:	Brian Sandberg, Sarah Illi	REF. NO.:	002012
FROM:	Beiyan Zhang/Mark Kuhl/ev/1 MAK	DATE:	February 16, 2007
C.C.:	Nicholas Fitzpatrick		
RE:	**Simulation of EW-3 Pumping Test** **North Oaks, Minnesota**		

INTRODUCTION

This memorandum was prepared as an appendix to CRA's "Groundwater and Residential Well Evaluation Report (February 2006 - January 2007)" (Report) for North Oaks, Minnesota. This memorandum presents the development and results of a groundwater flow model constructed to assist in the analysis of a 24-hour constant rate pumping test conducted as part of a groundwater investigation conducted in the Ski Lane Ravine (Site).

The pumping test consisted of pumping a single basal St. Peter Sandstone aquifer extraction well, EW-3, at a constant rate of approximately 20 gpm, for a period of 24 hours. During the pumping test, groundwater drawdown response was measured in two basal St. Peter Sandstone aquifer monitoring wells, MW-19B and MW-20B. The observed drawdown response at both locations showed a strong hydraulic response to pumping during the early period of the pumping test, and a stabilized drawdown for the remainder of the pumping test. This type of hydraulic response suggests that a recharge boundary was established. Specifically, it was inferred that groundwater was drawn up to the pumping well from the more permeable underlying bedrock formation (i.e., Prairie du Chien aquifer). Therefore, a simplified numerical model was developed to assist in understanding the hydraulic relationship between the pumped formation and the underlying formation.

BACKGROUND

A detailed presentation of the EW-3 24-hour constant rate pumping test, Site geology, and Site hydrogeology is provided in the Report. An overview of key aspects of the Site geology and hydrogeology is presented below, in order to provide sufficient understanding of the basis underlying the model development.

Two hydrogeologic units are represented in the model:

1. The basal St. Peter Sandstone, which is approximately 37-feet thick at the extraction well (EW-3), and is bounded above by a competent shale unit; and

2. The upper portion of the Prairie du Chien Group, which is a dolomitic limestone.

A downward hydraulic gradient of 0.06ft/ft is observed between the basal St. Peter Sandstone aquifer and the upper portion of the Prairie du Chien aquifer.

SIMULATION PROGRAM

The three-dimensional finite-difference groundwater flow model MODFLOW (Harbaugh and MacDonald, 1996a and 1996b, MacDonald and Harbaugh, 1988), developed by the United State Geological Survey (USGS), was selected to simulate groundwater flow for this analysis. MODFLOW has been extensively verified and is readily accepted by many regulatory agencies throughout North America and Europe.

MODEL DEVELOPMENT

A simplified two-layer "box" model was developed, where layer 1 represents the basal St. Peter Sandstone (constant thickness of 37 ft), and layer 2 represents the upper 75 ft of the Prairie du Chien . The model grid is presented on Figure 1. The lateral extents of the model were selected such that the model domain boundaries are sufficiently distant from the Site as to not unduly influence simulated groundwater flow conditions. The model dimensions are approximately 26,000 ft along the north-south direction, and 30,000 ft along the east-west direction. The model domain is divided into 491 columns and 273 rows. The size of individual grid elements is variable, ranging from 10 ft in the vicinity of the EW-3, and gradually increasing to a spacing of 1,000 ft at the boundary of the model domain. The smaller grid cell spacing is applied in the vicinity of the pumping well to provide increased resolution of groundwater flow conditions at that location.

Constant head boundary conditions were specified along the east and west boundaries of the model, and no-flow boundary conditions were specified along the north and south boundaries of the model. The elevations of the constant head boundaries for layer 1 were specified to provide approximately the observed hydraulic head at the monitoring wells and to correspond to the average approximate regional gradient of 0.002 ft/foot. The elevations of the constant head boundaries in layer 2 were set 4 ft below those in layer 1, to represent the observed downward gradient. Figure 2 presents the simulated groundwater elevation contours for model layer 1.

The simulation of the pumping test at EW-3 was conducted via a transient simulation. Pumping at EW-3 was represented using a specified discharge boundary.

The assignment of initial values of hydraulic conductivity (1.85 ft/day) and specific storage (8.85×10^{-7} ft^{-1}) for the basal St. Peter Sandstone (layer 1) was based on the estimates derived from analysis of the pumping test data. For the upper portion of the Prairie du Chien (layer 2), the estimated transmissivity of 7,000 ft^2/day was provided (Norvitch and others, 1973). In the North Oaks area the Prairie du Chien has an average thickness of 120 ft, which yields a hydraulic conductivity of 58 ft/day for the Prairie du Chien aquifer. A literature value of 1×10^{-6} ft^{-1} was applied for the specific storage in the Prairie du Chien limestone (layer 2). These hydraulic property values were subsequently adjusted in order to match the observed drawdown curves at the two monitoring wells.

Recharge was applied at the top of the model domain to represent vertical leakage through the overlying shale unit. Specifically, a leakage rate of 0.0869 inch/year was applied to model layer 1, based on the observed vertical (downward) hydraulic gradient of 0.07 ft/foot across the shale and an assumed hydraulic conductivity 10^{-7} cm/s for the shale unit.

The model input parameters were adjusted on a trial-and-error basis in order to obtain a reasonable match to the observed drawdown curves at monitoring well locations MW-19B and MW-20B. Figures 3 and 4 present the comparisons of observed and simulated drawdown curves for MW-19B and MW-20B. In general, the curves match the early time groundwater drawdown response and show stabilized drawdown at the end of the test.

The finalized parameters that were used in the model are listed in Table 1. The adjusted horizontal hydraulic conductivities and specific storages are 2.22 ft/day and 8.54×10^{-7} ft^{-1} for the basal St. Peter Sandstone (model layer 1), and 70 ft/day and 1×10^{-6} ft^{-1} for the upper portion of the Prairie du Chien (model layer 2). The adjusted ratio between the horizontal and the vertical hydraulic conductivities is 300 for both units. Therefore, the corresponding vertical hydraulic conductivities are 0.0073 and 0.2333 ft/d for Layer 1 and Layer 2, respectively. Note that these adjusted parameter values represent estimated values that provide a reasonable match to the observed drawdown responses at the two monitoring wells. Actual hydraulic properties may be different than those simulated here, and may vary spatially.

SIMULATED CAPTURE ZONE

The box model was applied to simulate groundwater extraction at EW-3. A pumping rate of 10 gpm at EW-3 was simulated using the particle tracking code MODPATH (Pollock, 1994) in order to determine the extent of the capture zone. Figure 5 presents the simulated steady-state capture zone within the basal St. Peter Sandstone aquifer. The simulated capture zone generated by this model represents an approximation that is based on simplified subsurface conditions. The groundwater model indicates that the actual capture zone obtained by pumping EW-3 is sensitive to horizontal to vertical anisotropy and would need to be verified by a field monitoring program.

REFERENCES

Harbaugh, A.W. and M.G. McDonald, 1996a. *User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, United States Geological Survey Open-File Report 96-485,* Reston, Virginia.

Harbaugh, A.W. and M.G. McDonald, 1996b. *Programmer's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, United States Geological Survey Open-File Report 96-486,* Reston, Virginia.

McDonald, M.G. and A.W. Harbaugh, 1988. *A modular Three–Dimensional Finite-Difference Ground-Water Flow Model, United States Geological Survey Open-File Report 83-875.*

Norvitch, R.F., T.G. Ross, and A. Brietkrietz, 1973, *Water Resources Outlook for the Minneapolis - St. Metropolitan Area, Minnesota*. U. S. Geological Survey and Metropolitan Council of the Twin Cities Area, 219 pgs.

Pollock, D.W., 1994. *User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle tracking post-processing package for MODFLOW, the U. S. Geological Survey finite-difference ground-water flow model, U.S. Geological Survey Open-File Report 94-464,* Reston, Virginia.

TABLE 1

PARAMETER VALUES USED IN MODEL SIMULATIONS
EW-3 PUMPING TEST
NORTH OAKS, MN

	Horizontal Hydraulic Conductivity (ft/d)	*Kh/Kv*	*Specific Storage (ft^{-1})*	*Recharge (Leakage from the Unit above) (inch/year)*
Layer 1	2.22	300	8.54E-07	0.00869
Layer 2	70.0	300	1.00E-06	-

Note:

Layer 1 represents the basal St. Peter Sandstone and was assigned a thickness of 37 ft.
Layer 2 represents the upper 75 ft of Prairie du Chien dolomitic limestone.

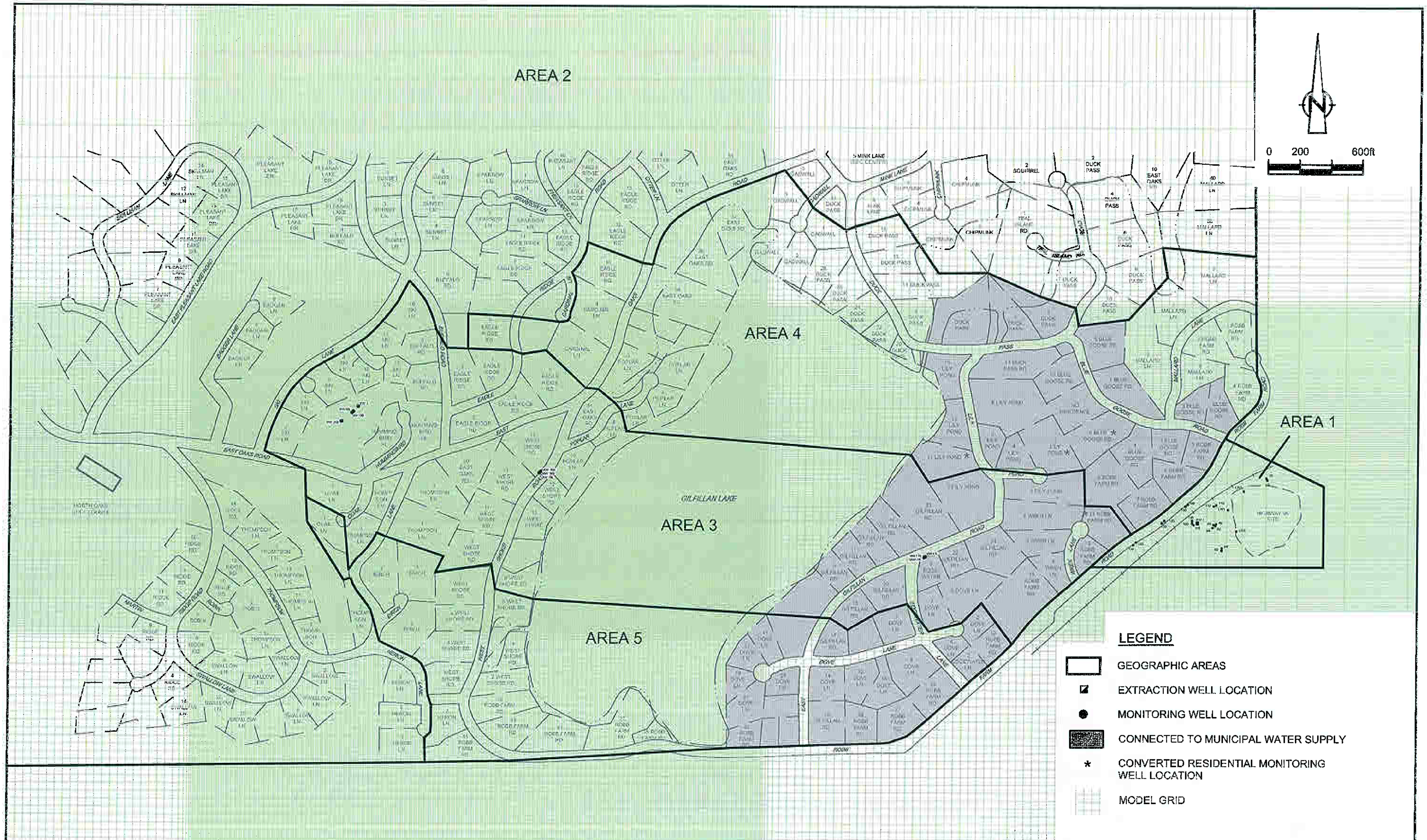

figure 1

MODEL GRID

North Oaks, Minnesota

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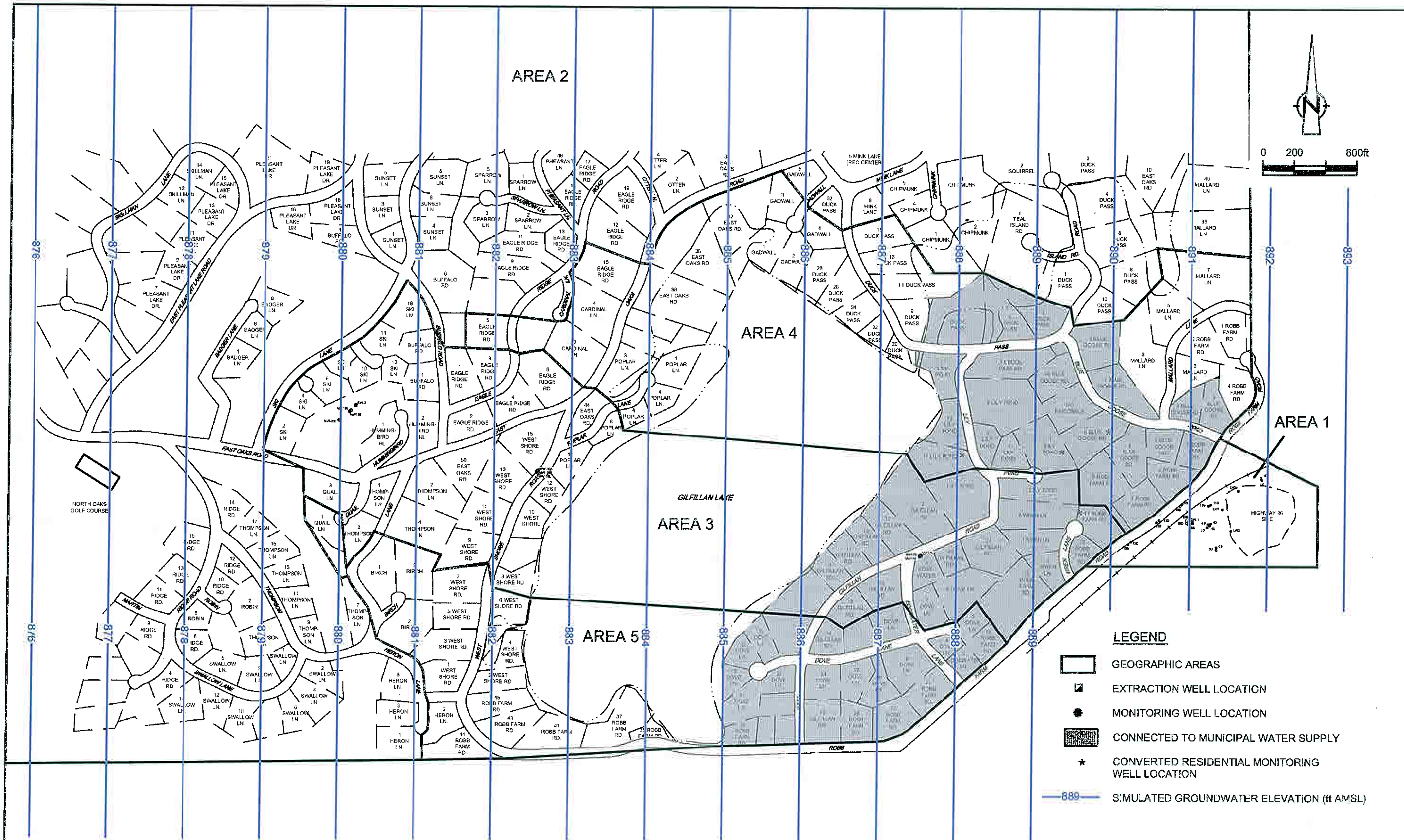

figure 2

SIMULATED GROUNDWATER ELEVATION CONTOURS
North Oaks, Minnestoa

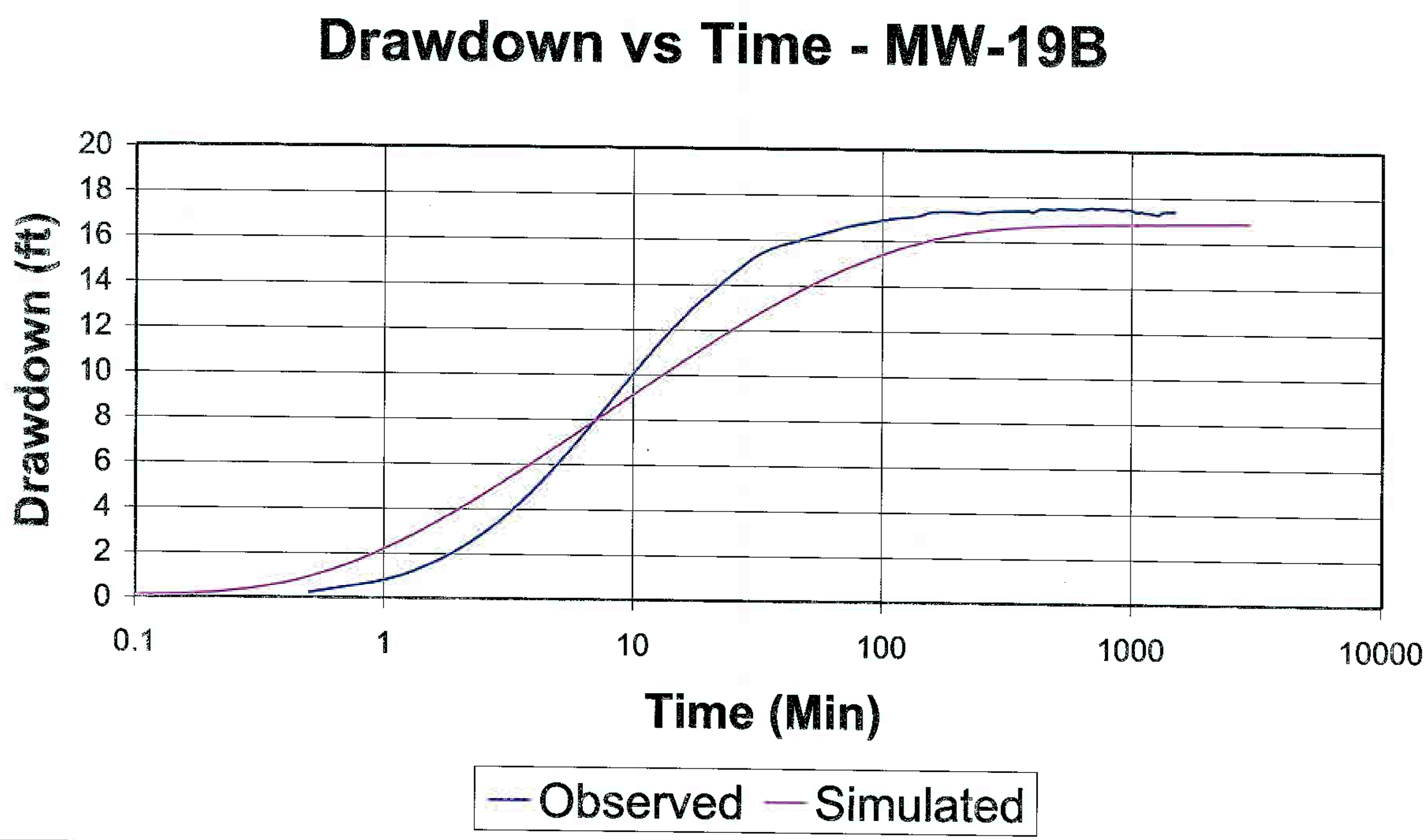

figure 3

OBSERVED AND SIMULATED DRAWDOWN VS TIME AT MW-19B
EW3 PUMPING TEST
North Oaks, Minnesota

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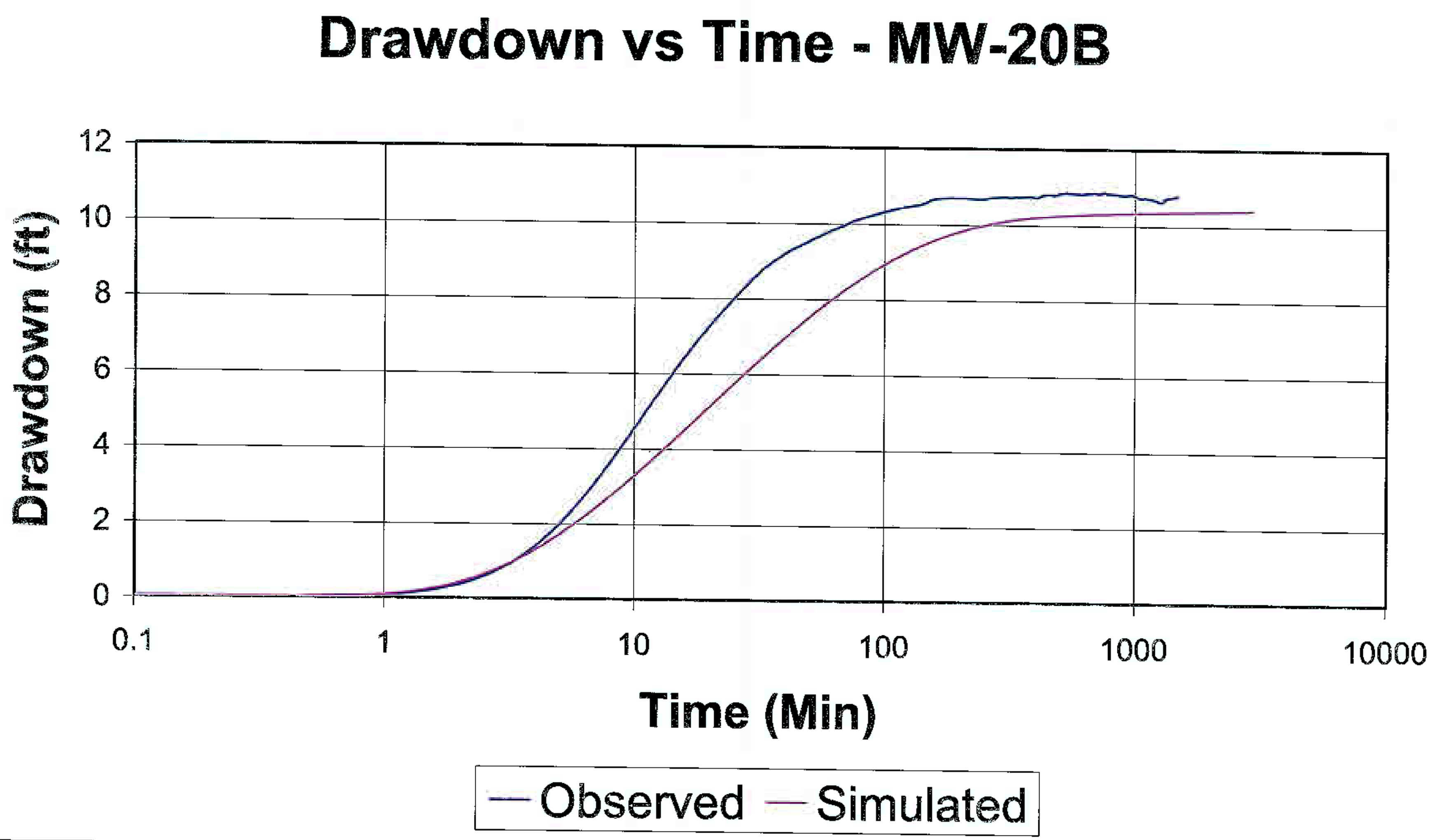

figure 4

OBSERVED AND SIMULATED DRAWDOWN VS TIME AT MW-20B
EW3 PUMPING TEST
North Oaks, Minnesota

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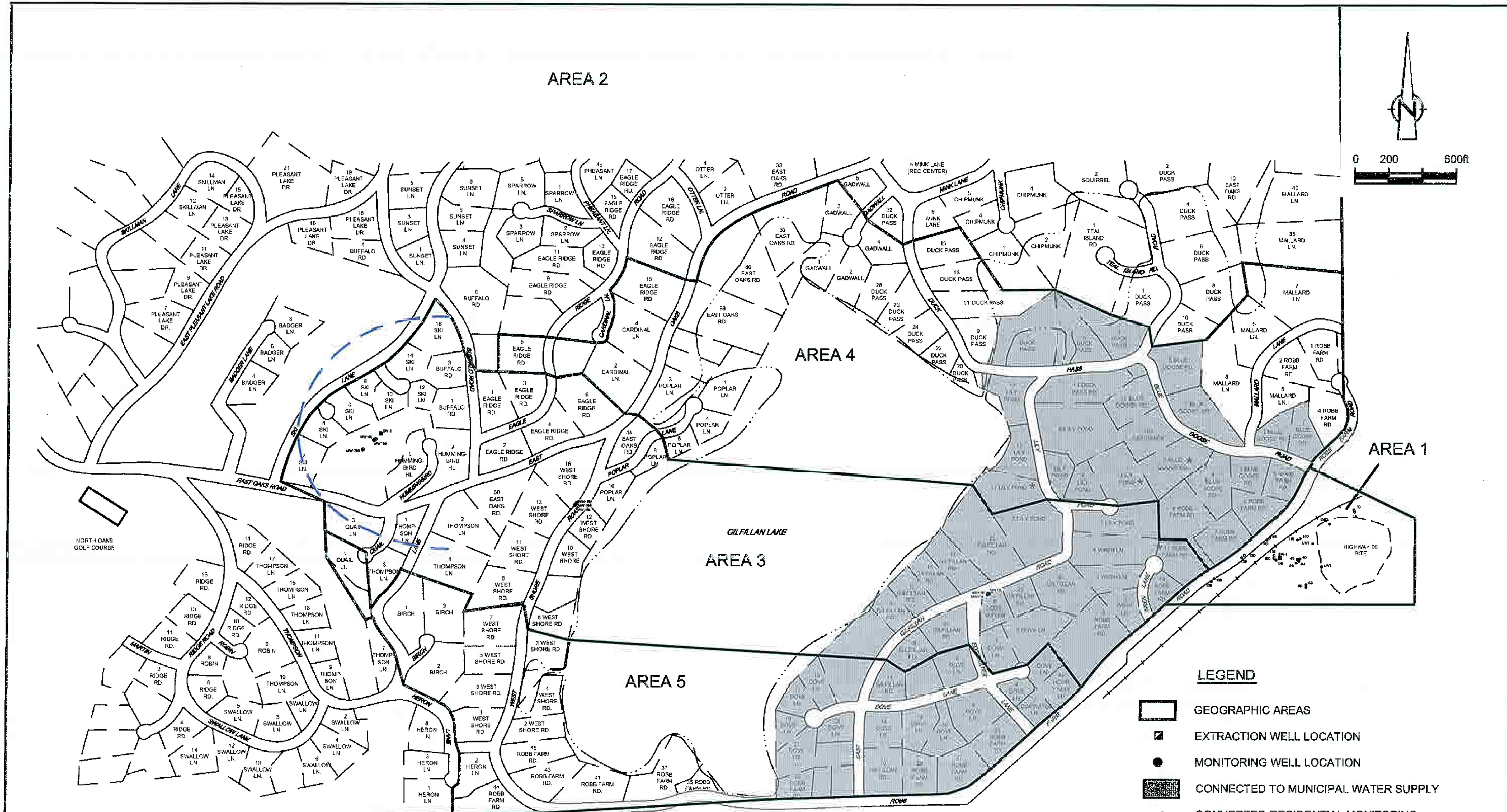

figure 5

ESTIMATED EXTENT OF GROUNDWATER CAPTURE - 10 GPM
BASAL ST. PETER SANDSTONE AQUIFER
North Oaks, Minnesota

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