APPENDIX C: GROUNDWATER MODELING REPORT

MODELING REPORT (PROVIDED BY LBG) DATED JULY 28, 2015

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TECHNICAL MEMORANDUM

DATE: July 28, 2015

TO: Mark Rosso, JEO Consulting Group

FROM: **John Oswald,** Martha Silks, PG

Subject: York, Nebraska Well Head Protection Plan – Groundwater Modeling Report

This report documents the Wellhead Protection Areas (WHPAs) delineation for the drinking water supply wells operated by the City of York, Nebraska (City). Leggette, Brashears & Graham, Inc. (LBG) was contracted by JEO, Inc. (JEO) to complete the WHPA delineation using MODFLOW (a numerical groundwater flow model) and the particle tracking module, MODPATH. Findings in this letter are based on information from the City, JEO, LBG, and the Upper Big Blue Natural Resources District (UBBNRD).

LBG completed the following tasks as part of this study:

- Obtained and evaluated available hydrogeologic information and updated the data elements;
- Refined the existing groundwater flow model with updated water levels and well pumping data, previous studies, and other delineation criteria;
- Applied the numerical groundwater flow model, MODFLOW, to delineate the WHPA of the City wells;
- Used a range of possible values for several model parameters to complete an uncertainty analysis; and,
- Used the results of the uncertainty analysis to create a composite capture zone for defining the WHPAs for the City's wells.

The City is located in the southeastern portion of Nebraska, in York County (shown on Figure 1). The geologic units of interest in the vicinity of the City and surrounding area consist of quaternary aged sediments. Groundwater flow is generally from northwest to southeast.

The particle-tracking package, MODPATH, was used in conjunction with the calibrated flow model to create the 50-year time of travel pathlines necessary for delineating the WHPAs for the City wells. A number of other model runs were also completed to examine the capture zones for the City Wells under a range of conditions that may be present. The capture zones for all of these possible scenarios were then concatenated to create composite capture zones for each well.

The composite capture zones were then used to delineate the final WHPAs. A combined pumping rate from all wells of approximately 964 million gallons per year (MGY) was applied based on the maximum pumping rate from each of the City's wells over the past five years.

Data Elements

Precipitation: Recharge was considered in all areas of the model. The amount of infiltration due to precipitation was determined through estimation and calibration.

Geology: The geology in and around York is well defined by existing models. The geology defined in the 2009 model developed for the City was used in this model. There are six layers of interest in the area of the City. The Uppermost layer is a mostly dry low conductivity layer. The second layer is an unconfined sand and gravel aquifer. The third is a low conductivity confining layer that overlies the confined aquifer that is the primary aquifer for the City. Another confining layer and a deeper, lower conductivity aquifer overlie Cretaceous bedrock. The bedrock is much lower permeability material than the overlying material and is not considered in this study.

Water Resources: Local rivers and streams may influence the delineation of the groundwater wellhead protection areas. Portions of Beaver and Lincoln Creeks were included in the model.

Water Quantity Data Elements

Levels in lakes and streams can have an impact on an aquifer that is unconfined if there is a geologic connection between the two. From the review of regional water levels, it appears that there may be some influence from Beaver Creek east and Lincoln Creek north of the City, but the rest of the rivers and streams in the area are intermittent do not significantly impact groundwater flow.

Surface Water Quantity: Surface water bodies had very little influence the delineation of the wellhead protection areas, and only portions of Lincoln and Beaver Creeks were included in the model.

Groundwater Quantity: Table 1 lists the City wells and their associated pumping rates over the last five years. Figure 2 shows the registered wells that were identified within the model domain from the Nebraska Department of Natural Resources registered groundwater wells database. These were included in the model.

Overland Drainage: Surface runoff is directed toward local surface water features and not considered in the model.

Delineation Criteria

The following discussion presents a summary of the five criteria for delineating the WHPA.

Time of Travel: Travel times of 10-, 20- and 50-years were used when simulating groundwater movement with pathlines.

Aquifer Transmissivity: In this setting, there are three hydrostratigraphic units that are of interest, the upper, unconfined aquifer and upper and lower confined aquifers. The City Wells are primarily completed in the upper and lower confined aquifers. Analysis of pumping data indicated the hydraulic conductivity of the upper confined sand and gravel aquifer could be as high as 400 feet per day (ft/d)] and as low as 100 ft/d with the conductivity of the lower confined aquifer being between 10 and 30 ft/d.

The conductivity values for this study are in the general range of values used for other studies in the area. The ranges of conductivities used in the model are described in Table 2. The modeled capture zones for this analysis were plotted together and the resulting outline forms the "composite" capture zone used in the WHPA delineation.

Daily Volume of Water Pumped: The daily volume selected for each well used in the WHPA delineation was chosen using the greatest annual volume of water pumped from each well over the previous five years and dividing that annual total by 365 days. The rates used in the delineation and from the previous five years are summarized in Table 1. Additionally, the total volume illustrated in Table 1 is conservative because the 964 MGY total pumping rate is approximately 50 percent higher than the highest total pumping for any individual year (627.5 MGY in 2012).

Hydrogeologic Boundaries: Hydrogeologic boundaries that could affect the delineation are surface water features, geological boundaries, high capacity wells, and overland drainage.

Groundwater Flow Field: In York County, groundwater is encountered in Quaternary and bedrock aquifers, with the regional flow direction being generally from west northwest to east southeast toward the Missouri River.

Table 1 - City Well and Model Pumping Rates

Well Name	Total Annual Withdrawal (million gallons/year[MGY])					Maximum Withdrawal 2010 - 2014 (MGY)	Withdrawal used in Current WHP Plan (m3/d)
	2010	2011	2012	2013	2014		
62-1	**0.05**	0.00	0.00	0.00	0.00	0.05	16.8
68-1	**18.0**	5.6	2.2	1.5	3.7	18.0	6,594.6
73-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76-1	5.5	10.3	32.6	3.7	**51.3**	51.3	18,780.9
77-1	22.9	15.5	19.0	**23.9**	13.0	23.9	8,741.5
77-3	111.9	58.4	85.2	**113.4**	83.2	113.4	41,512.8
77-4	**105.6**	84.2	81.4	61.5	50.7	105.6	38,646.7
82-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
82-2	8.7	14.4	**83.9**	29.9	26.2	83.9	30,717.6
88-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
97-1	57.5	17.2	14.4	**108.4**	31.9	108.4	39,670.0
97-1A	9.6	4.4	4.4	**31.3**	11.0	31.3	11,467.1
97-2	41.8	19.1	23.9	**60.1**	27.2	60.1	21,999.2
2004-1	101.6	32.0	**106.4**	14.4	67.7	106.4	38,937.6
2009-1	6.5	37.2	**39.6**	0.0	11.7	39.6	14,495.1
2009-2	0.0	**51.9**	23.7	0.0	19.5	51.9	19,008.9
2009-3	0.0	**32.8**	12.8	0.0	17.1	32.8	12,001.1
2009-4	0.0	**32.0**	15.8	0.5	17.7	32.0	11,712.4
2009-5	0.0	**35.4**	12.1	0.0	6.5	35.4	12,957.5
2009-6	0.0	34.6	**70.2**	0.0	10.3	70.2	25,689.2
Annual Total	489.7	485.0	**627.5**	448.7	448.6	964.3	352,949.2

Notes:
Modeled use is the maximum annual pumping volume 2010 through 2014.
MGY: Million gallons per year

Model Setup

The model for this study is based on earlier models for the same area (QSSI, 2009; Landon and Turco, 2007). The QSSI model was used as the foundation for this model and detailed information on its construction and calibration can be found in QSSI, 2009. The updated WHPA presented in this study was modeled using a MODFLOW model. All of the modeling for this project was done using GMS (Aquaveo, 2015), a pre- and post-processor for MODFLOW.

The model domain, shown on Figure 2, is the same as the original 2009 QSSI model with the addition of grid refinements in the areas of the City Wells. The domain was divided into a threedimensional, non-uniform grid that has 302 rows, 373 columns, and six layers. Finer grid spacing was applied in the model using telescopic mesh refinement in the area of the site where the City wells are located (Figure 3). This grid spacing provides better definition in the area of the flow field where simulating the influence of pumping from the wells was critical. The base of the model is variable at an elevation of approximately 1,170 to 1,300 feet above mean sea level (ft-amsl) with the top of the model extending from approximately 1,550 to over 1,700 ft-amsl. The layering corresponds to the original layering from the previous modeling studies area (QSSI, 2009; Landon and Turco, 2007). Pumping rates for wells within model domain were updated to use the average pumping rate over the past 5 years for registered non-City Wells and the maximum over the past 5 years for each of the City Wells.

Model Input Parameters: Discretization (process of dividing a geometry into finite elements to prepare for analysis) of aquifer properties in MODFLOW involves assigning initial values to each cell in the model domain. Hydraulic properties input for this model included horizontal components for hydraulic conductivity and effective porosity (required for MODPATH to calculate linear flow velocity).

The boundary conditions for the model are described in detail in QSSI, 2009. Constant head boundaries, based on measured heads in the area were used to define the eastern and western boundaries of the model. The northern and southern boundaries are no-flow bounds along flow lines. Portions of Beaver and Lincoln Creeks were included in the model using the MODFLOW river package. This allows water to enter and exit the model. They were defined using the elevations of the rivers from high resolution digital elevation model (DEM) data from the United States Geologic Survey (USGS).

Within the model domain, precipitation was added at the rate of 7.1 in/yr which corresponds to approximately 25% of annual precipitation. The recharge value includes both direct recharge from precipitation and return flow from irrigation. The City Wells were added with the pumping rates discussed earlier as well as the irrigation wells. The irrigation well pumping rates were defined using the 5-year average withdrawal rate based on information from UBBNRD

A representative value of 0.25 was chosen for the effective porosity; that is consistent with the range of values for the aquifer materials.

Calibration and Uncertainty

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 generally completed by running several steady-state simulations and comparing calculated heads to the measured head data a known calibration points within the model domain.

The groundwater flow field and hydraulic heads in the area of the City for the calibrated model are shown on Figure 2. The 10-, 20- and 50- year pathlines, predicted using the calibrated model, are shown on Figure 4.

The calibration plot, showing measured versus simulated hydraulic head values, for the model is shown in Figure 5. It can be seen in the plot that head values and measured values compare quite favorably and have a normalized root mean squared error of approximately five percent.

All modeling requires simplifying assumptions be made in order to create a groundwater flow model. Obviously there are significant differences in the conductivity, thickness, recharge and other characteristics throughout the model domain. The information and ability to account for these differences simply doesn't exist. The modeled aquifer is an attempt to best replicate the average conditions and replicate the general flow field. Due to the amount of uncertainty associated with the physical characteristics of highly heterogeneous setting of aquifers and confining layers, an uncertainty analysis was completed as part of the modeling effort. To adequately address the uncertainty associated with the parameters, thirteen models were completed to simulate 50-year capture zones; should conditions different from the calibrated model exist. The values used for each of these models are summarized in Table 2.

Table 2 - Values Used in the Uncertainty Analysis

Model Run	Conductivity					Recharge
	Layer 2 (Kh)	Layer 4 (Kh)	Layer 6 (Kh)	Layer 3 (Kv)	Layer 5 (Kv)	
	ft/d	ft/d	ft/d	ft/d	ft/d	in/yr
Base Model	310	160	19	0.005	0.005	7.1
Uncert-1	135	160	19	0.005	0.005	7.1
Uncert-2	400	160	19	0.005	0.005	7.1
Uncert-3	310	80	19	0.005	0.005	7.1
Uncert-4	310	240	19	0.005	0.005	7.1
Uncert-5	310	160	10	0.005	0.005	7.1
Uncert-6	310	160	30	0.005	0.005	7.1
Uncert-7	310	160	19	0.006	0.005	7.1
Uncert-8	310	160	19	0.001	0.005	7.1
Uncert-9	310	160	19	0.005	0.006	7.1
Uncert-10	310	160	19	0.005	0.001	7.1
Uncert-11	310	160	19	0.005	0.005	4.5
Uncert-12	310	160	19	0.005	0.005	11.2

Notes:
Kh – Horizontal Hydraulic Conductivity.
Kv – Vertical Hydraulic Conductivity

WHPA Delineation

After the uncertainty analysis was completed, the capture zones delineated for each of the models were merged. This concatenation created a final composite WHPA capture zone, shown on Figure 6 which can be used for delineating the Drinking Water Supply Management Area (DWSMA). While it is quite likely that none of the individual capture zones represents the true configuration, it is likely that the true capture zone is contained within the composite zone shown on Figure 6.

Sincerely,
LEGGETTE, BRASHEARS & GRAHAM, INC.

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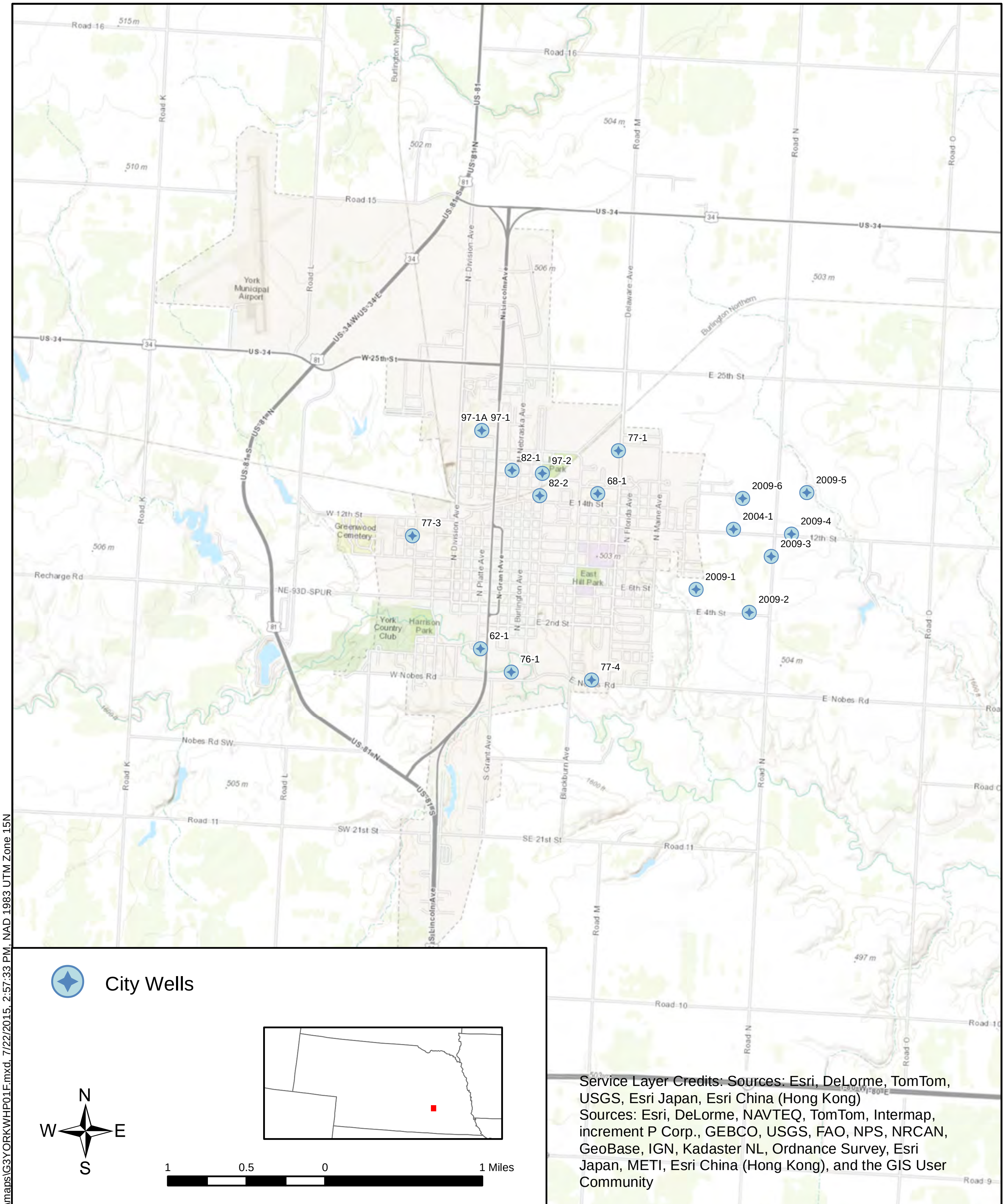
Associate

Reviewed by:

J. Kevin Powers
Senior Vice President



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YORK

YORK, NEBRASKA

LOCATION OF CITY WELLS

FILE: G3YORKWHP01F.MXD	DATE: 7/22/2015	FIGURE: 1

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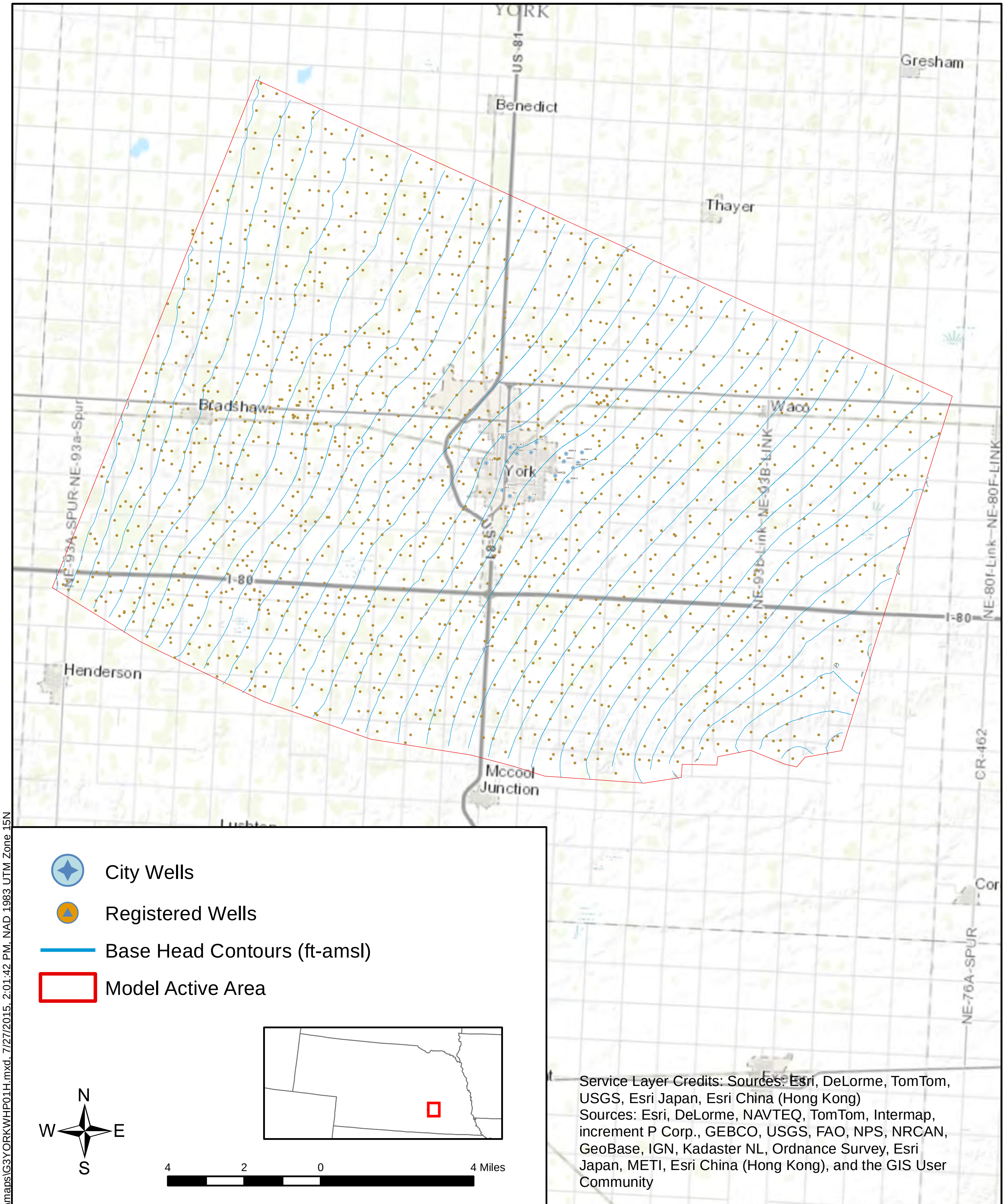

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YORK

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MODEL ACTIVE AREA, REGISTERED WELLS, AND
MODELED GROUNDWATER HEAD CONTOURS

FILE: G3YORKWHP01H.MXD | DATE: 7/24/2015 | FIGURE: 2

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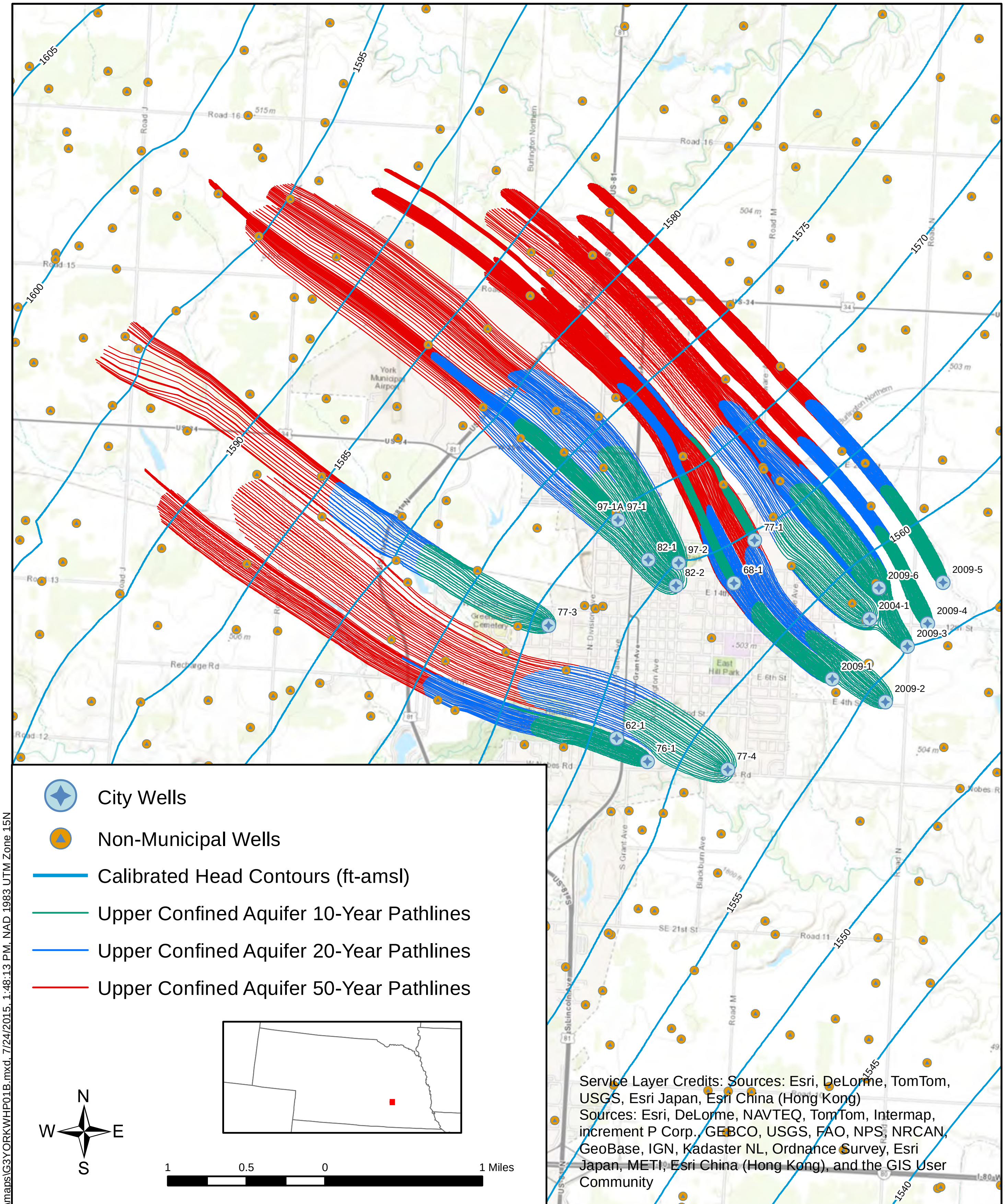
REFINED GRID IN AREA SURROUNDING CITY WELLS

FILE: G3YORKWHP01I.MXD | DATE: 7/24/2015 | FIGURE: 3



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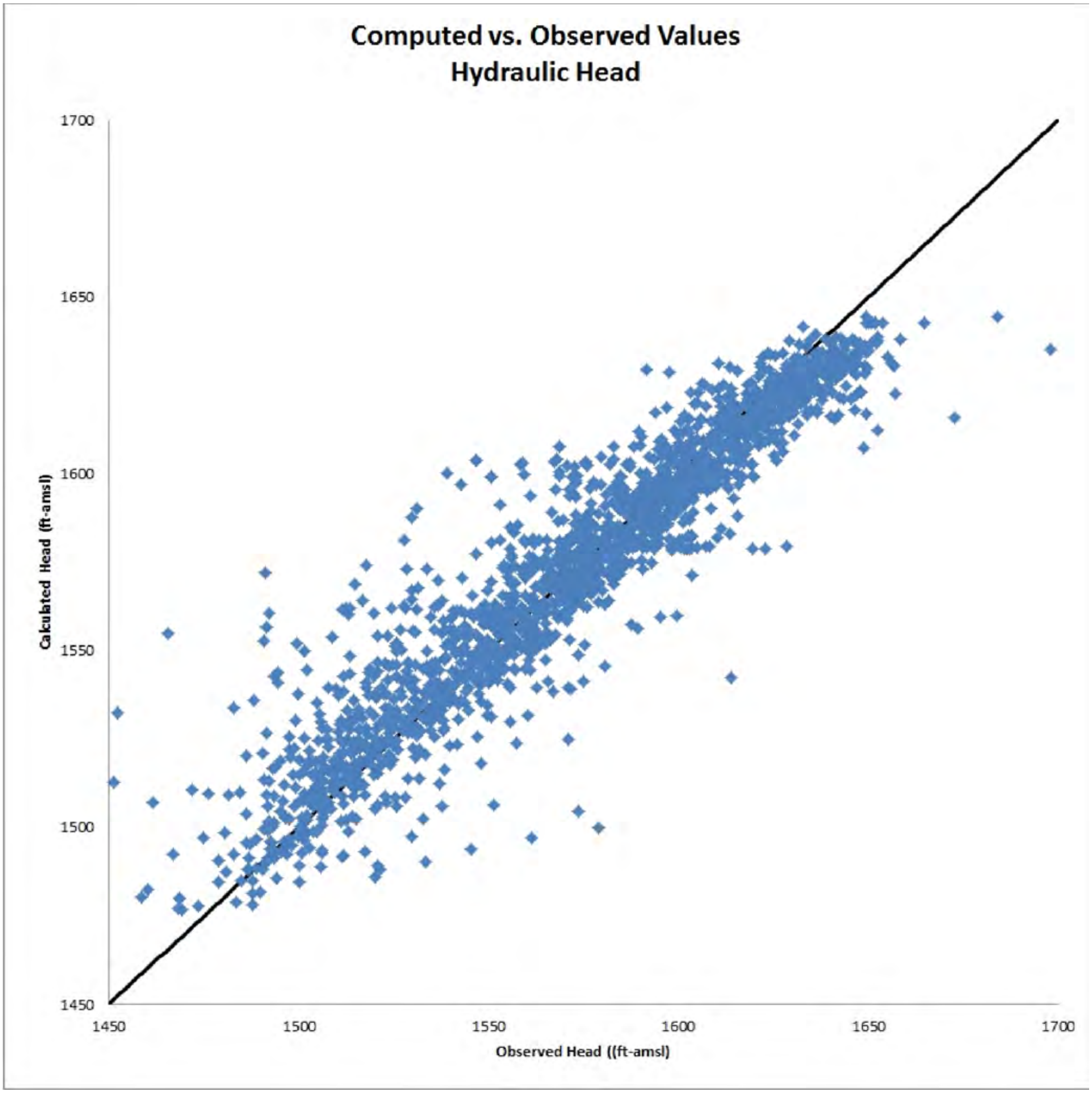
YORK, NEBRASKA

10-, 20-, and 50-YEAR FLOW PATHLINES FOR CALIBRATED MODEL.

FILE: G3YORKWHP01B.MXD	DATE: 7/22/2015	FIGURE: 4



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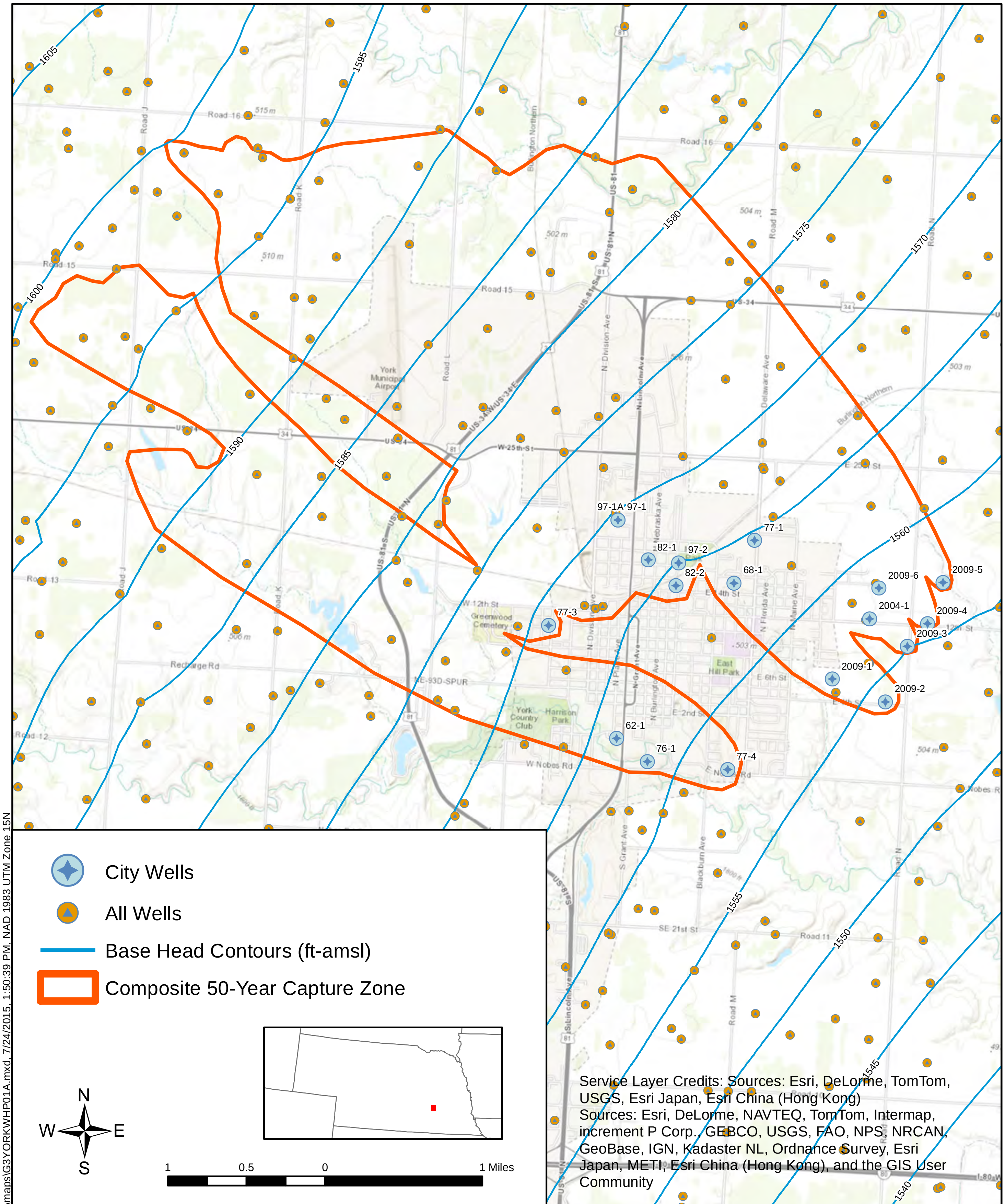
MODEL CALIBRATION

FILE: G3YORKWHP01C.MXD	DATE: 7/24/2015	FIGURE: 5



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YORK

YORK, NEBRASKA

50-YEAR COMPOSITE CAPTURE ZONES WITH CITY WELLS AND IRRIGATION WELLS PUMPING

FILE: G3YORKWHP01A.MXD | DATE: 7/24/2015 | FIGURE: 6