Evaluation of Potential Impacts Related to Proposed Uranium Mining in Goliad County, Texas

Prepared for Goliad County Groundwater Conservation District
Goliad, Texas

June 25, 2007

T. Neil Blandford, PG (No. 1034)

STATE OF TEXAS
T. NEIL BLANDFORD
GEOLOGY
License Number 1034
LICENSED
PROFESSIONAL GEOSCIENTIST

Muthu Kuchanur, PhD

Daniel B. Stephens & Associates, Inc.

6020 Academy NE, Suite 100 • Albuquerque, New Mexico 87109

Table of Contents

Section **Page**

List of Figures

Figure

List of Tables

Table

List of Appendices

Appendix

Evaluation of Potential Impacts Related to Proposed Uranium Mining in Goliad County, Texas

1. Introduction

Daniel B. Stephens & Associates, Inc. (DBS&A) has prepared this report to present the methodology and results of numerical groundwater flow and solute transport modeling conducted to evaluate possible effects of proposed in-situ leach (ISL) uranium mining in north Goliad County, Texas. The approximate location of a local area that may be mined (Figure 1) was delineated based on the locations of potential ISL monitoring wells provided by the Goliad County Groundwater Conservation District (GCGCD). Figure 1 also shows the location of additional non-mining-related groundwater monitoring wells provided by GCGCD that exist in the vicinity of the proposed ISL mining area.

1.1 Objectives

The major objectives of the modeling study are to (1) evaluate the practicality of controlling injection fluid excursions from escaping downdip, (2) evaluate the practicality of controlling injection fluid excursions from escaping vertically into non-mined aquifer zones, and (3) determine the amount of bleed water required to control or eliminate such excursions.

1.2 Previous Studies

Several regional-scale studies have been carried out in the Central Gulf Coast Aquifer, including water availability studies by the Texas Water Development Board (TWDB) (Chowdhury et al., 2004), South Texas Groundwater Alliance (STGA) (Uddameri and Kuchanur, 2005), and others (e.g., Ryder, 1988; Ryder and Ardis, 1991; Hay, 1999). There have also been regional-scale studies conducted on uranium mineralization, including a thesis on the genetic stratigraphy of Goliad sands and its implications for the potential extent of uranium mineralization (Hoel, 1982) and a study on the uranium favorability of late Eocene through Pliocene rocks of the south Texas coastal plain (Quick et al., 1977). However, direct site-specific data on the potential mining area are not available from these regional-scale studies.

1.3 ISL Mining Operation Input Data

Three important variables in designing an ISL well field are well location, injection rate, and extraction rate. Because no information is available as yet from Uranium Energy Corporation (UEC) regarding these parameters, a literature review was conducted to identify the range of well spacings and injection/extraction rates used at other sites (Appendix A, Table A-1). The literature review gives a broad range of values for injection/recovery rates and well spacing. Values of these parameters for a specific site depend on many factors, including (1) local geology, geochemistry, and mineralogy of the ore, (2) the geometry and permeability of the ore body, (3) leach solution type and reaction chemistry, (4) physical design of injection/extraction wells, (5) treatment capacity, (6) permits/regulations and environmental concerns, and (7) capital and operating costs. A brief summary of data obtained from the literature is as follows:

- Well spacing ranges from 30 to 275 feet (most values in the literature are between 50 and 150 feet).

- The range of values for injection/extraction rates is 20 to 200 gallons per minute (gpm) (most literature values range from 20 to 150 gpm).

- The five-spot pattern in the literature typically includes one extraction well and four injection wells. In this study, as requested by GCGCD based on information provided by UEC, all the evaluations were carried out with one central injection well and four peripheral extraction wells.

- The operating life of an individual ISL well pattern is typically one to three years. Most of the uranium is recovered during the first six months of the operation.

2. Groundwater Flow Modeling

Recent regional-scale modeling efforts by TWDB and STGA were used to develop a finer-scale model of the proposed mining area. The STGA model developed by Texas A&M University Kingsville (TAMUK) has a grid size of 0.5 square mile, while the TWDB groundwater availability model (GAM) has a grid size of 1 square mile. However, the TAMUK model is a steady-state model and, as such, cannot be used to model transient effects of the proposed ISL mining operation. In order to use the TWDB GAM as the base model from which more detailed simulations could be derived, the calibration of the GAM near the mining area was verified using available well hydrographs. Four wells in the vicinity of the mining area (7913202, 7906703, 7907305 and 7915301) have water level data that could be readily obtained from the TWDB groundwater database. The simulated hydraulic head from the GAM shows a very good correspondence with the observed data for the wells near the proposed mining area (Appendix A). Based on the above considerations, the GAM was used as the base model to develop a more refined local-scale groundwater flow and solute transport model.

The telescopic mesh refinement (TMR) approach (Leake and Claar, 1999; ESI, 2004) was used to refine the GAM to develop a local groundwater flow model of the assumed mining area. TMR is the process of creating a more refined model (smaller grid cells) within a subregion of a larger-scale model. In the TMR approach, the larger-scale model (in this case the GAM) is run for the period of interest, and the simulation results are used to prescribe boundary conditions along the edge (or boundary) of the smaller model (in this case the ISL mining area model). TMR is often performed to obtain greater resolution when simulating contaminant transport or the effects of individual wells within a small portion of a larger groundwater flow model, both of which were conducted in this study.

It is important to note the limitations and assumptions inherent in local site-specific models developed from a regional-scale model like the GAM. The GAM has model grids of 1 square mile, which implies that the hydrogeologic properties within the 1 square mile area are homogeneous. Using the GAM as the base model for the TMR process implies that, although the grid spacing is reduced, the hydrogeologic properties within the 1 square mile area are still homogeneous. In reality, there are likely site-specific variations in hydrogeologic properties within the 1 square mile area that are not accounted for in the modeling. Local hydrogeologic complexities such as variations in hydraulic conductivity can be incorporated into the local model; however, in this case, there was insufficient information to do so.

A similar limitation applies to changes in vertical discretization. As explained in Section 2.2, model layer 1 in the GAM was divided into 5 model layers in the local model. In the GAM, the hydraulic conductivity applied in a given layer is assumed to be representative of the average permeability across the saturated thickness of that layer, and variations in lithology (i.e., the presence of interbedded lenses of sand and clay) are not explicitly accounted for. In reality, the hydraulic conductivity of the sand layers may be greater than that used in the model, and the hydraulic conductivity of the clay layers would be substantially less than that used in the model. Transport of leach solutions will occur preferentially along the sand lenses, potentially at a greater rate than that predicted in the model. Appropriate containment of leach solutions in the subsurface will therefore require knowledge of the distribution and hydraulic properties of the sand lenses.

2.1 Simulation Time Period

For the purposes of this project, the GAM was amended to include a predictive simulation period of 20 years (2007 through 2027). The historical transient model calibration period is from 1980 to 1999. For the predictive simulations, 1999 groundwater pumping conditions were applied for the entire period of 2000 through 2027. This approach is reasonable given the results of predictive simulations documented in Donnelly and Anaya (2005), which indicate no significant changes in simulated water levels near the study area under average recharge conditions from 1999 to 2060. It should be noted, however, that total estimated groundwater pumping in Goliad County has increased nearly 50 percent from 4,101 ac-ft/year in 1999 to 6,143 ac-ft/yr in 2006 (information provided by GCGCD). In addition, there are a number of domestic and irrigation wells within several thousand feet of the proposed mining area, and groundwater use associated with oil and gas drilling has increased significantly in recent years, starting at a point about 1.25 miles southeast of the proposed mining area. The distribution of local pumping and the location of individual non-mining wells are not accounted for explicitly in the GAM or in the local model developed for this analysis.

Although the anticipated duration of the mining operation is unknown at this time, experience at previous operations suggests that the duration of mining for a given region may be significantly less than 20 years (Section 1.3). Regardless, the 20-year time frame was selected to illustrate the nature of longer groundwater flow paths that can form in response to various injection and recovery ISL mining scenarios.

2.2 Model Discretization

The TMR process was applied using the GAM to obtain the local mining area model with a horizontal grid size of 20 feet by 20 feet. The total domain area of the local model is 1 mile by 1 mile, with the same grid orientation as that of the GAM, which is approximately parallel to the direction of regional groundwater flow. The GAM has three active model (vertical) layers in the proposed mining area to simulate groundwater flow within the Evangeline aquifer, the Burkeville aquitard, and the Jasper aquifer. The Evangeline Formation (composed predominantly of Goliad Sand) as represented in the GAM in the mining area is about 870 feet thick and is the target of proposed ISL, according to the GCGCD. Other information provided by GCGCD indicates that the thickness of Goliad Sand within and near the proposed area of mining may be closer to 500 feet, as the formation thins to the northwest across the county. The Evangeline Formation was discretized in the local model into five vertical layers (Figure 2) to account for the hydraulic effects of partial penetration of the injection/extraction wells in the proposed mining area. The estimated leakance between the Evangeline layers was taken from the TAMUK model.

2.3 Boundary Conditions

The boundary conditions on all four sides of the local model are time-varying prescribed hydraulic head boundaries (Figure 3). As explained above, these boundary conditions were obtained from the GAM using the TMR approach. Recharge as used in the GAM is applied as the top boundary condition, and the bottom boundary condition is a no-flow boundary, also the same as that used in the GAM.

2.4 Input Parameters

All the input parameters for the flow model (e.g., hydraulic conductivity, storage, and average recharge) are the same as those used in the GAM. The input parameters for the local groundwater flow model are provided in Table 1.

The U.S. Geological Survey (USGS) finite difference model code MODFLOW-96 (Harbaugh and McDonald, 1996) was used to simulate groundwater flow within the local model, consistent with the GAM.

2.5 Initial Conditions

The initial conditions for the local groundwater flow model for layer 1 are illustrated in Figure 3. The simulated hydraulic gradient (slope of the water table) is to the southeast at about 0.0009 foot per foot (ft/ft) (about 5 feet per mile). Under simulated ambient groundwater flow conditions, there is very little flow of groundwater between model layers in the Evangeline aquifer.

2.6 Determination of Groundwater Flow Paths

The simulated output of the MODFLOW simulations was coupled with MODPATH (Pollock, 1994), a USGS particle tracking code, to compute three-dimensional groundwater flow paths. Particles can be conceptualized as small volumes of water that are tracked as they move through the aquifer in accordance with the hydraulic gradient and aquifer hydraulic properties. Particle paths are computed by tracking particles from one model cell to the next based on the simulated groundwater flow velocity until the particle reaches a boundary, an internal sink/source, or satisfies some other termination criterion. In addition to computing particle paths, MODPATH keeps track of the travel time of particles as they move through the aquifer system. The particle paths computed by MODPATH were used to evaluate the particle capture by varying the injection/extraction rates within the ISL well field. A uniform effective porosity value of 0.2 was used in all model runs.

2.7 Simulation Approach for ISL Fluid Capture Evaluation

Three variables, well spacing, injection rate, and extraction rate, were used in various combinations to evaluate ISL well field performance. In this study, a five-spot pattern with a central injection well and four peripheral extraction wells was used. An alternative configuration with a central pumping well and exterior injection wells is also possible, but this configuration was not evaluated as part of this study. Well spacings are the distances between any two extraction wells. Three scenarios were simulated using well spacings of 100, 140, and 180 feet. The general procedure followed to evaluate the particle capture by the extraction wells is as follows:

1. Given a specific spacing between wells, assumed injection and extraction rates were applied in the model.

2. MODPATH was executed by releasing particles at the injection well, and the capture of these particles at the extraction wells was evaluated.

3. If all the particles were not captured, then steps 1 and 2 were repeated with different extraction rates until all the particles were captured.

Finally, in order to simplify the simulations and better illustrate basic principles, only one injection and extraction ISL well field was simulated. An actual mining operation would likely include multiple series of injection and extraction wells that would hydraulically affect one another to some extent.

3. Results and Analysis

The results from the 140-foot well spacing scenario are discussed in detail in this section; results of the other scenarios are provided in Appendix A. The injection and extraction wells in this scenario were assumed to penetrate the shallowest Evangeline model layer (layer 1) only (Figure 2). The three simulation steps outlined in Section 2.7 were conducted to determine the extraction well pumping rates necessary to capture all injection fluids in model layer 1. The injection rate was kept constant at 50 gpm and the extraction rate was varied until all the particles released at the injection well were captured by the extraction wells.

It was not possible using the model to achieve less than 1 percent bleed water with a constant well spacing of 140 feet. Therefore, the spacing between the downgradient extraction wells was decreased to 100 feet. With the reduced spacing at the downgradient wells, the target of less than 1 percent bleed water was met (the bleed water is the volume of water that must be extracted in addition to that injected in order to achieve complete capture of injected fluids).

This result highlights the fact that achieving capture of injected fluids is highly sensitive to well placement and spacing. The necessary sum of the extraction rates at the four peripheral capture wells was determined to be a minimum of 50.5 gpm for this scenario.

The pumping rates of the extraction wells and the simulated hydraulic head field for layer 1 as of 2027 are provided in Figure 4. The mound that forms around the injection well in the center of the five-spot pattern is evident, as are the cones of depression that form around the extraction wells.

Simulated groundwater flow paths in layer 1 are illustrated in Figure 5. Comparison of Figure 5 with Figure 4 illustrates that the groundwater flow pathlines are perpendicular to the simulated hydraulic head contours. The arrows marked on the pathlines in Figure 5 indicate the direction of groundwater flow, and the number by the arrow indicates the time, in years, that it takes for a particle of groundwater introduced to the aquifer at the injection well to reach the indicated location. Figure 5 shows that many of the particles travel from the injection well to the extraction wells within a time period of about 2 years or less. There are some simulated particle tracks, however, where it takes significantly longer in order for capture to be achieved. In fact, there are several groundwater flow pathlines illustrated in Figure 5 that are not captured within the 20-year simulation period. The longest flow paths are those that move out from the injection well at about the midpoint between two extraction wells. These particles pass through or near stagnation zones (zones of very low groundwater velocity), and therefore take significantly longer to be captured by the extraction wells. Typically, stagnation zones are formed downgradient of extraction wells and upgradient of injection wells. If the mining operation were stopped after several years, there would be injected fluids within the aquifer that would not be captured by a pumping well. These fluids could be contained within a several year period if additional extraction wells were installed between the capture wells simulated in this scenario.

Analysis of the groundwater flow budget indicates that there is net simulated downward leakage from model layer 1 to model layer 2 caused primarily by the ISL well field. This leakage is further confirmed by particles observed in layer 2, which were found to be particles released at the bottom of layer 1 at the injection well. The rate of injection at the central injection well is significantly higher than the extraction rates of the individual peripheral wells, implying that downward leakage near the injection well from layer 1 to layer 2 is greater than upward leakage from layer 2 to layer 1 near the extraction wells. The simulation results indicate that the net vertical migration of injection fluid from model layer 1 to model layer 2 is approximately 0.4 percent of the injection rate of 50 gpm, or about 0.2 gpm. This rate is equivalent to 288 gallons per day. Although this net rate of downward seepage is relatively small, it is approximately equivalent to the domestic use of a typical household.

Figure 6 illustrates the groundwater flow pathlines for the particles that migrated from layer 1 into layer 2. Note that once the particles migrate downward into layer 2, they are not captured by the extraction wells but rather migrate with the ambient direction of groundwater flow simulated for layer 2.

Similar model runs to those discussed above were carried out with well spacings of 100 and 180 feet (Figures A-6 and A-7). The simulations illustrate that there is an optimal combination for well spacing, injection rates, and extraction rates for given hydrogeologic conditions. Deviation from this optimal range of ISL design parameters causes an increase (in some cases quite significant) in the amount of bleed water required to capture injection fluids.

The results of the particle tracking simulations should be interpreted keeping in mind the following key assumptions:

- The particle tracking approach assumed that the velocity of the particles is the same as that of the groundwater, and does not consider the effects of dispersion, retardation, chemical reactions, and changes in viscosity and density of the injection or extracted fluid.

- The groundwater flow model and particle tracking simulations represent average conditions within the assumed ISL well field, and do not account for complex subsurface phenomena that can occur such as gas, chemical or mechanical clogging of pore space within the aquifer, or variable operational schedules of the injection or extraction wells.

All the above factors could significantly affect capture efficiency.

4. Contaminant Transport Model

The groundwater flow model and the particle tracking simulations discussed above only estimate the migration of groundwater and dissolved solutes in accordance with the simulated average groundwater flow velocity; they do not account for dispersion, geochemical reactions, dilution, or retardation of solution fronts. Modeling all the physical processes in an ISL well field is possible, but is data intensive, expensive, and would require more detailed site-specific data. As a first step, a contaminant transport model was developed using MT3D (Zheng, 1990), which explicitly accounts for dispersion in addition to advective solute transport. Dispersion in porous media refers to the spreading of contaminants over a greater region than would be predicted solely from the average groundwater velocity vectors. Dispersion is caused by deviations of actual velocity from the average groundwater velocity on a microscale. The MT3D model is similar to the MODPATH model in that it uses the output from the groundwater flow model to determine groundwater flow velocity.

The actual concentrations of the injected fluids that will be applied in the proposed ISL mining operation are not available. Therefore, injected fluid was assumed to be of normalized unit concentration (concentration of 1.0 milligram per liter). All other groundwater inflows were assigned a solute concentration of zero. Additional required inputs for the transport model simulation are the longitudinal, transverse, and vertical dispersivities. Constant values of 20 and 2 feet for longitudinal and transverse dispersivities, respectively, were assumed for the MT3D transport model. Vertical dispersivity was assumed to be negligible.

The groundwater flow simulation used in the transport modeling is the same as that presented in Section 3. The concentration contours simulated for layers 1 and 2 are shown in Figures 7 and 8, respectively. In layer 1, the simulated normalized concentration contours exhibit a shape consistent with the simulated groundwater flow pathlines, although comparison of Figure 7 with Figure 5 illustrates the effects of dispersion, as significant solute concentration occurs in the aquifer at distances greater than the farthest groundwater flow pathline. The transport model also simulated the migration of injected fluids in model layer 2 (the layer below the injection and extraction wells). Concentrations as high as six-tenths of the injection concentration were simulated to occur near (but beneath) the injection well (0.6 contour in Figure 8), and solute concentrations of about one-tenth the injection concentration (0.1 contour in Figure 8) migrate about 220 feet downgradient of the central injection well. The contaminant transport modeling evaluates the migration of a conservative contaminant; hydrogeochemical reactions or other phenomena that may reduce the rate of solute migration are not considered in the model.

5. Summary and Conclusions

This study evaluated, through application of groundwater flow, particle tracking, and solute transport modeling, various issues related to capture of fluids that may be injected for ISL mining in north Goliad County, Texas. Simulation results indicate that capture of injected fluids within the mined zone with 1 percent bleed water is feasible, although the simulation results are very sensitive to well placement, selected injection and pumping rates, and hydraulic conductivity of the aquifer. In some cases, an increase of even 20 feet in the well spacing caused the simulated bleed water to increase by about 6 percent.

In addition, the nature of the hydraulic groundwater flow field that may develop due to mining leads to the formation of long, low-velocity travel paths in certain areas of the injection-capture system; impacted groundwater within or near these travel paths may not be extracted during the life of the mining operation if a specific approach is not designed and implemented to account for these aquifer regions. Most of the injected fluid is extracted at capture wells within a time frame of about 3 years or less for the scenarios evaluated. At the cessation of ISL mining, monitoring locations should be selected carefully in order to identify potential groundwater impacts in the vicinity of these longer, low-velocity pathways. In addition, groundwater monitoring should be continued for an extended period of time.

The simulation results also indicate that ISL fluids can, and likely would, migrate vertically between aquifer layers. The ISL scenario evaluated assumes that injection and pumping would occur in the uppermost layer of the Evangeline aquifer (Goliad Sand), which has a saturated thickness of approximately 105 feet in the model. ISL fluids migrate vertically downward in the vicinity of the injection well. Once these fluids enter the model layer below the mined layer, they are not recaptured by the pumping wells, but rather migrate with the ambient groundwater flow velocity of the deeper aquifer layer. Other, more complicated factors that could affect vertical migration of ISL fluids through the aquifer were not considered in the simulations. For example, the density of the fluid that results from the mixing of native groundwater and injected fluid can affect transport nature and extent.

Finally, the input parameters for the groundwater flow and solute transport modeling were assumed in part based on a literature survey and in part based on Evangeline aquifer properties used in the GAM and the TAMUK model. Complex hydrogeochemistry and other complicating factors that could alter the simulated travel times and zones of capture were not accounted for in the simulations. Consideration of such factors, and potentially other analyses, may be useful when site-specific mining plans and data become available from the operator. Regardless, the basic hydraulic principles of capture and solute migration summarized above and explained in the report are applicable.

References

Chowdhury, A.H., S. Wade, R.E. Mace, and C. Ridgeway. 2004. *A groundwater availability model of the Central Gulf Coast Aquifer System: Numerical simulations through 1999*. Texas Water Development Board, Austin, Texas. September 27, 2004.

Donnelly, A.C.A. and R. Anaya. 2005. GAM run 05-27. Requested by Goliad County Groundwater Conservation District, Texas Water Development Board. October 27, 2005.

Environmental Simulations, Inc. (ESI). 2004. *Guide to using Groundwater Vistas*. Reinholds, Pennsylvania.

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

Hay, R. 1999. *A numerical groundwater flow model of the Gulf Coast Aquifer along the South Texas Gulf Coast*. Texas A&M University-Corpus Christi, Corpus Christi, Texas.

Hoel, H.D. 1982. *Goliad Formation of the South Texas Gulf Coastal Plain: Regional genetic stratigraphy and uranium mineralization*. The University of Texas at Austin, Austin, Texas.

International Atomic Energy Agency (IAEA). 2001. *Manual of acid in-situ leach uranium mining technology*. Vienna, Austria.

Leake, S.A. and D.V. Claar. 1999. *Procedures and computer programs for telescopic mesh refinement using MODFLOW*. U.S. Geological Survey Open-File Report 99-238.

Pollock, D. 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.

Quick, J.V., N.G. Thomas, L.D. Brogdon, C.A. Jones, and T.S. Martin. 1977. *Uranium favorability of late Eocene through Pliocene rocks of South Texas Coastal Plain*. Bendix Field Engineering Corporation, Colorado.

Ryder, P.D. 1988. *Hydrogeology and pre-development flow in the Texas Gulf Coast aquifer systems*. U.S. Geological Survey.

Ryder, P.D. and A.F. Ardis. 1991. *Hydrology of the Texas Gulf Coast aquifer systems*. U.S. Geological Survey.

Uddameri, V. and M. Kuchanur. 2005. *A multi-county groundwater availability model for the Gulf Coast Aquifer in the Coastal Bend Region of South Texas*. Texas A&M University–Kingsville, Kingsville, Texas.

Zheng, C. 1990. *MT3D, A modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems.* Report to the U.S. Environmental Protection Agency.

Figures

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/GIS/MXDS/STUDY_AREA.MXD 706140

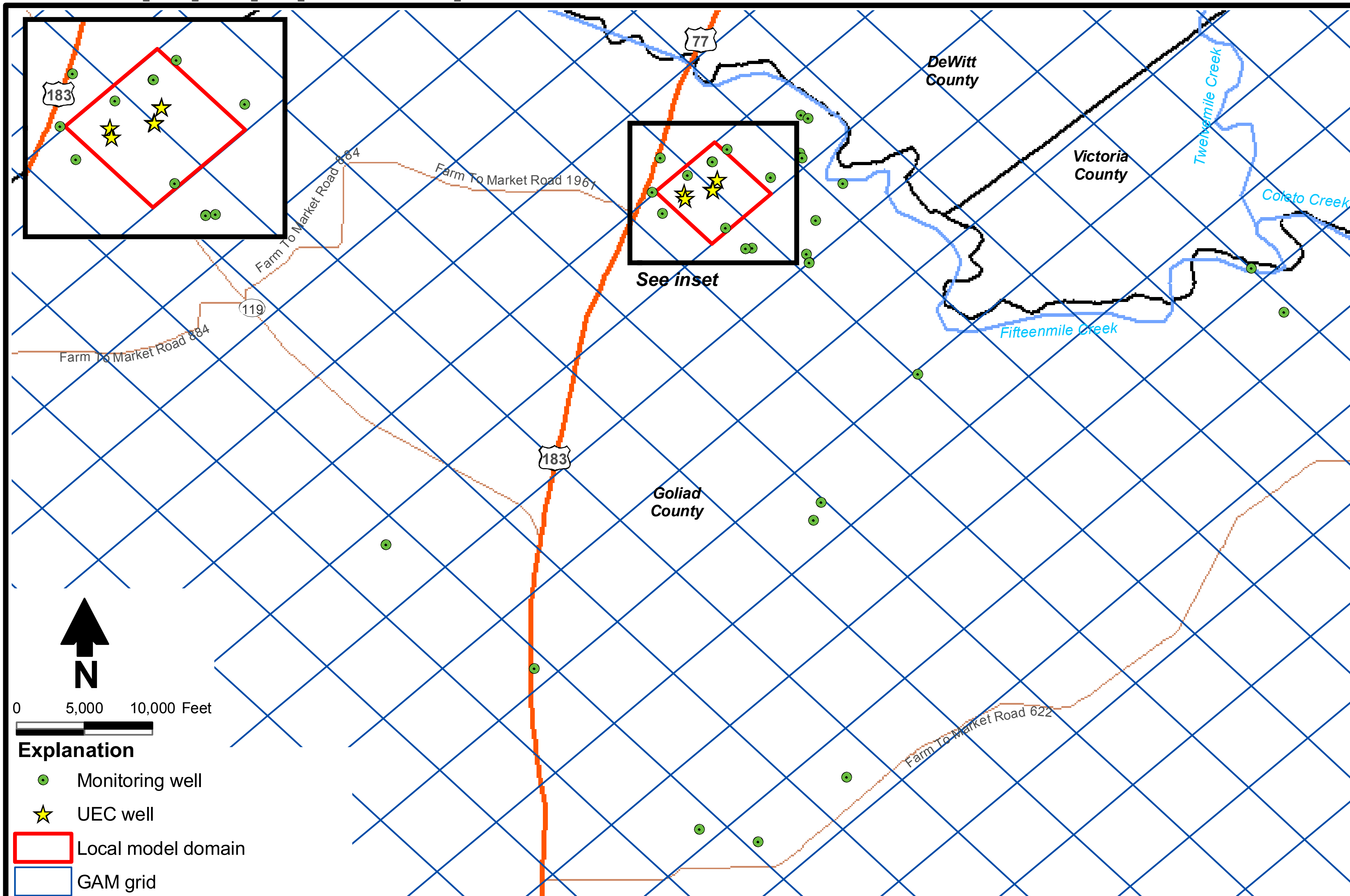


Figure 1

GOLIAD COUNTY URANIUM MINING IMPACTS

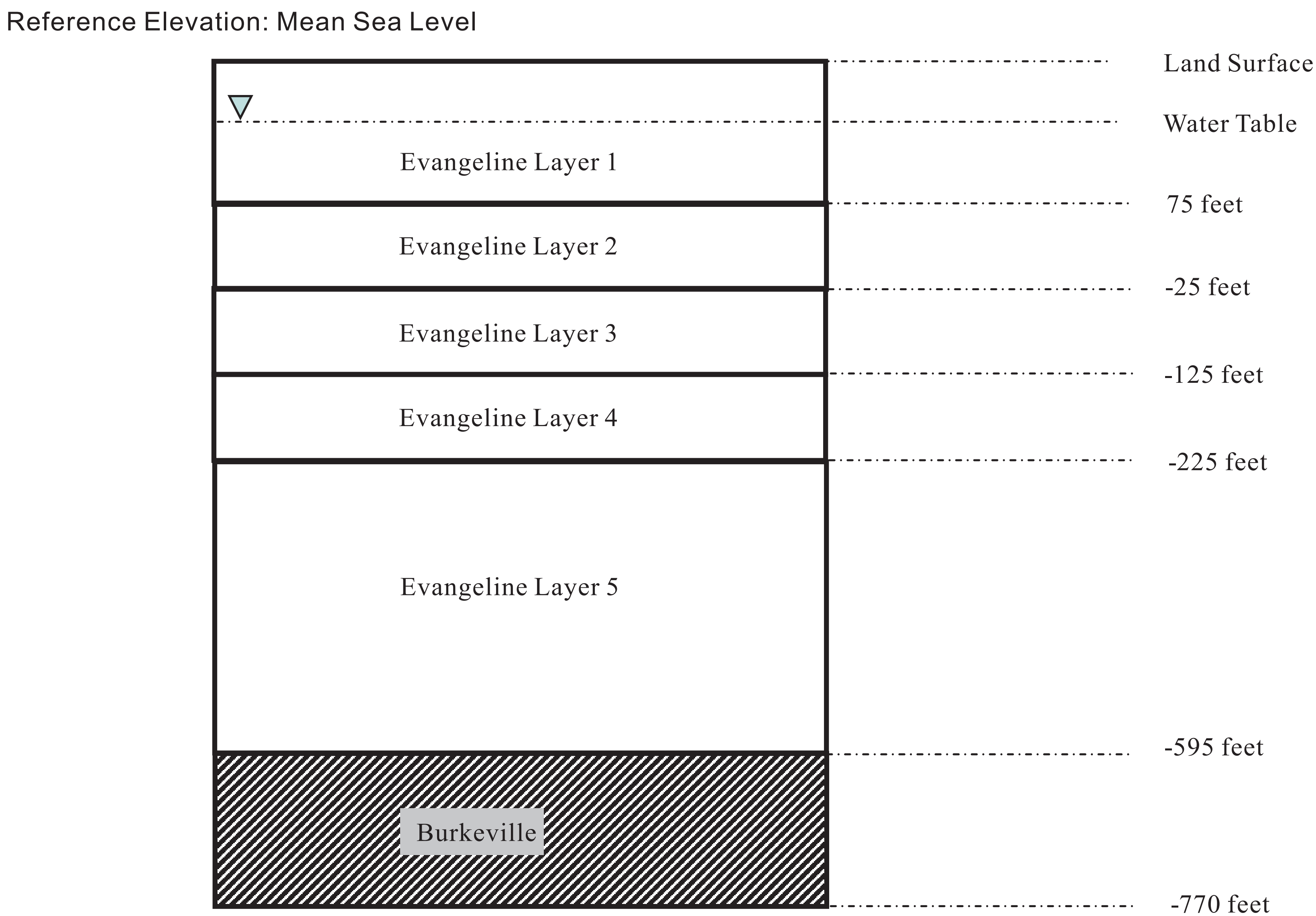
Study Area

Daniel B. Stephens & Associates, Inc.

04/16/2007

JN WR07.0040

S:\Projects\WR07.0040_Goliad_Uranium_Mining_Impacts\VR_Drawings\Figure2.cdr



GOLIAD COUNTY URANIUM MINING IMPACTS

Cross Section of the Local Model Layers in the Proposed Mining Area

Daniel B. Stephens & Associates, Inc.
4-26-07
JN WR07.0040

Figure 2

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/GIS/MXDS/WLE_2007.MXD 707140

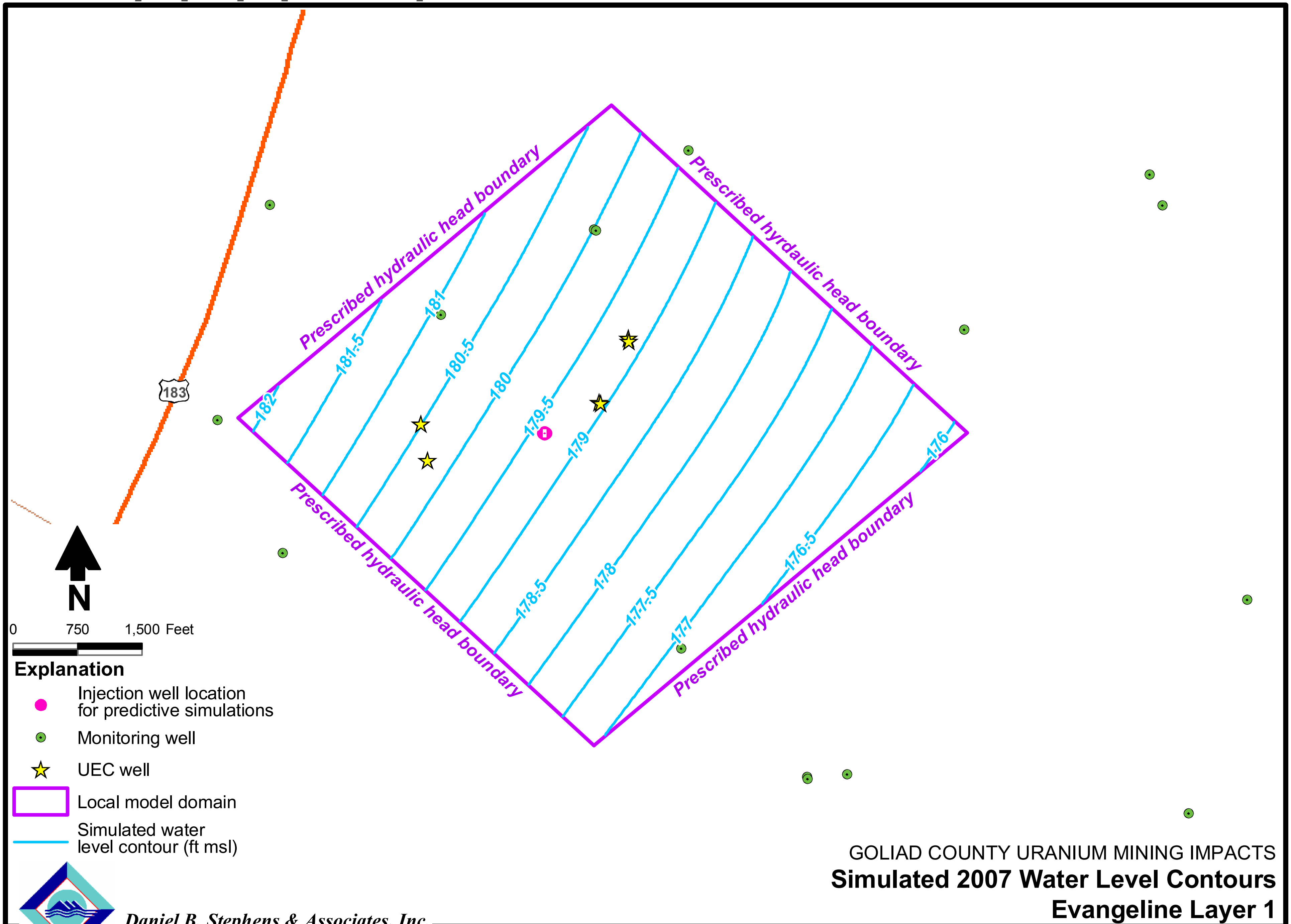
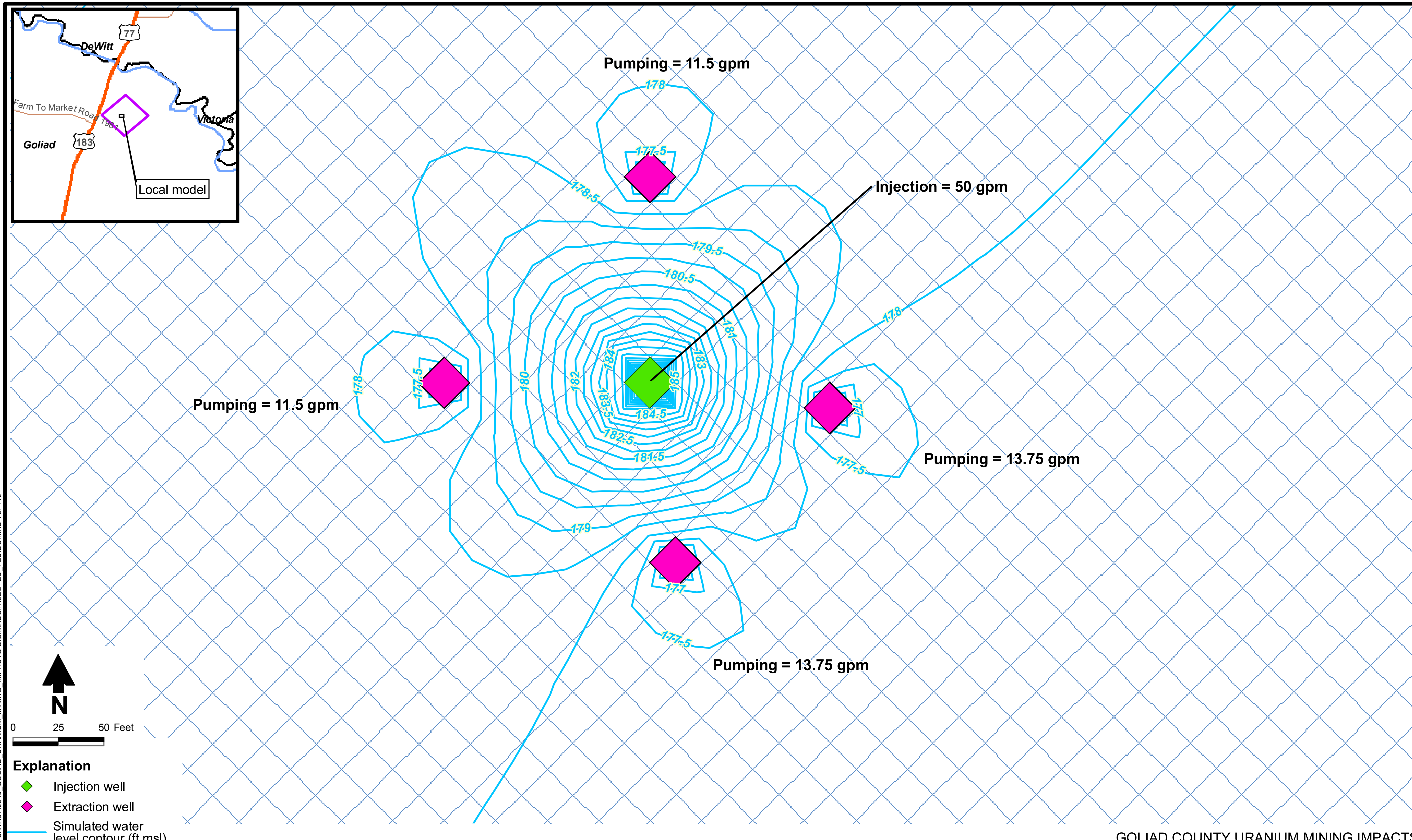


Figure 3

Daniel B. Stephens & Associates, Inc.

04/16/2007

JN WR07.0040



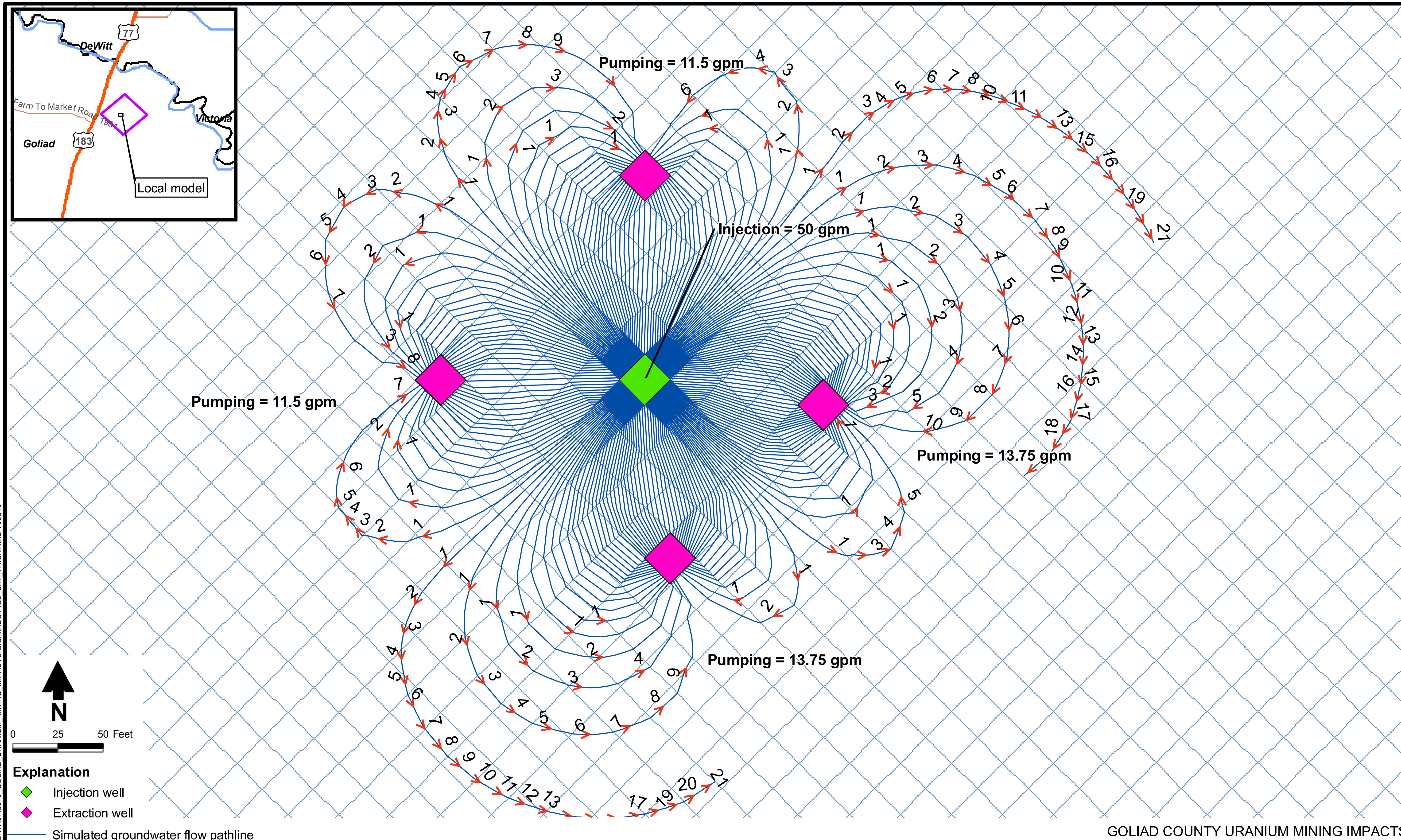
S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/GIS/MXDS/INJECTED_FLUIDS.MXD 707140

GOLIAD COUNTY URANIUM MINING IMPACTS

Simulated Hydraulic Head at 2027 and Well Pumping Rates
Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure 4



GOLIAD COUNTY URANIUM MINING IMPACTS

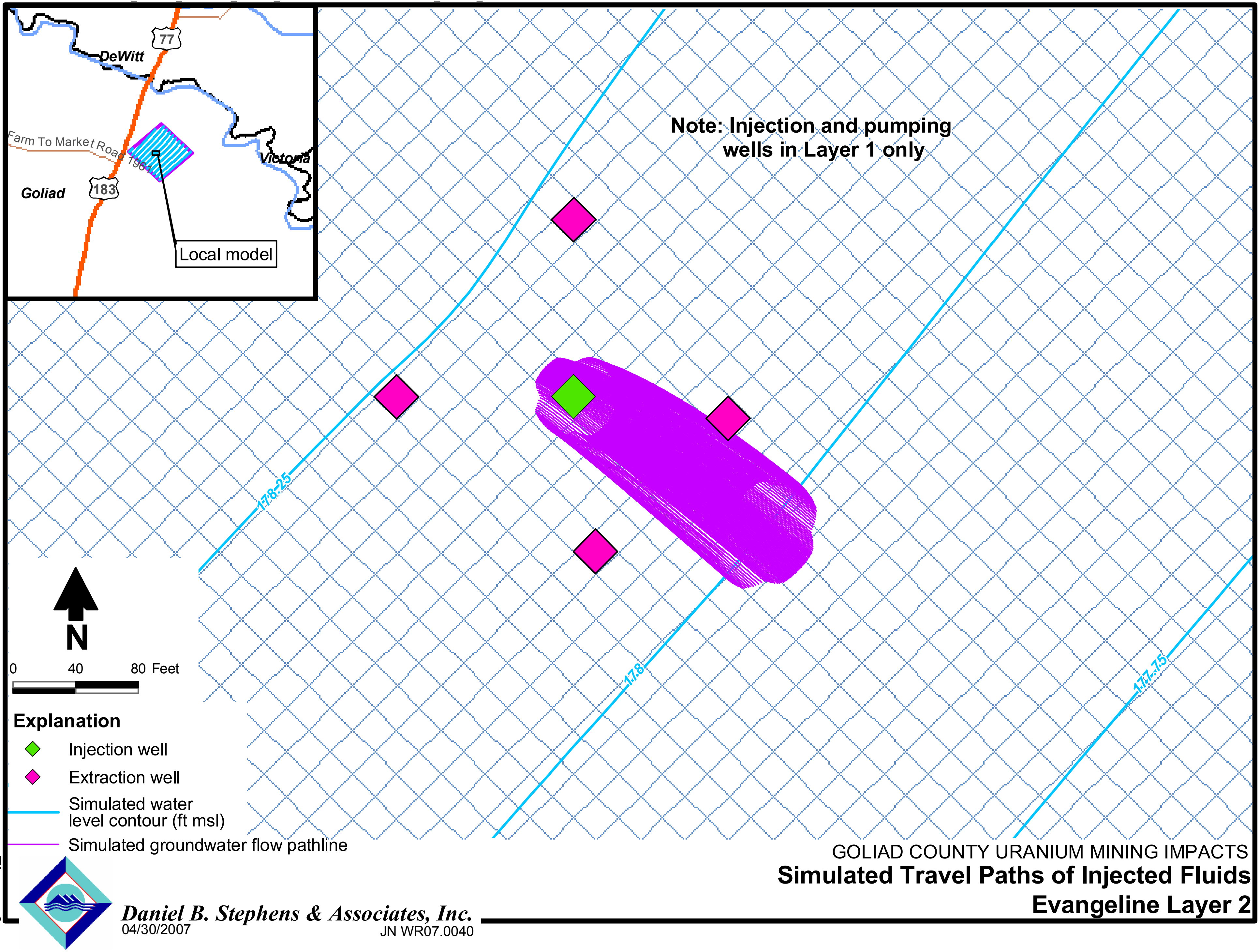
Simulated Travel Paths of Injected Fluids

Evangeline Layer 1

Figure 5

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

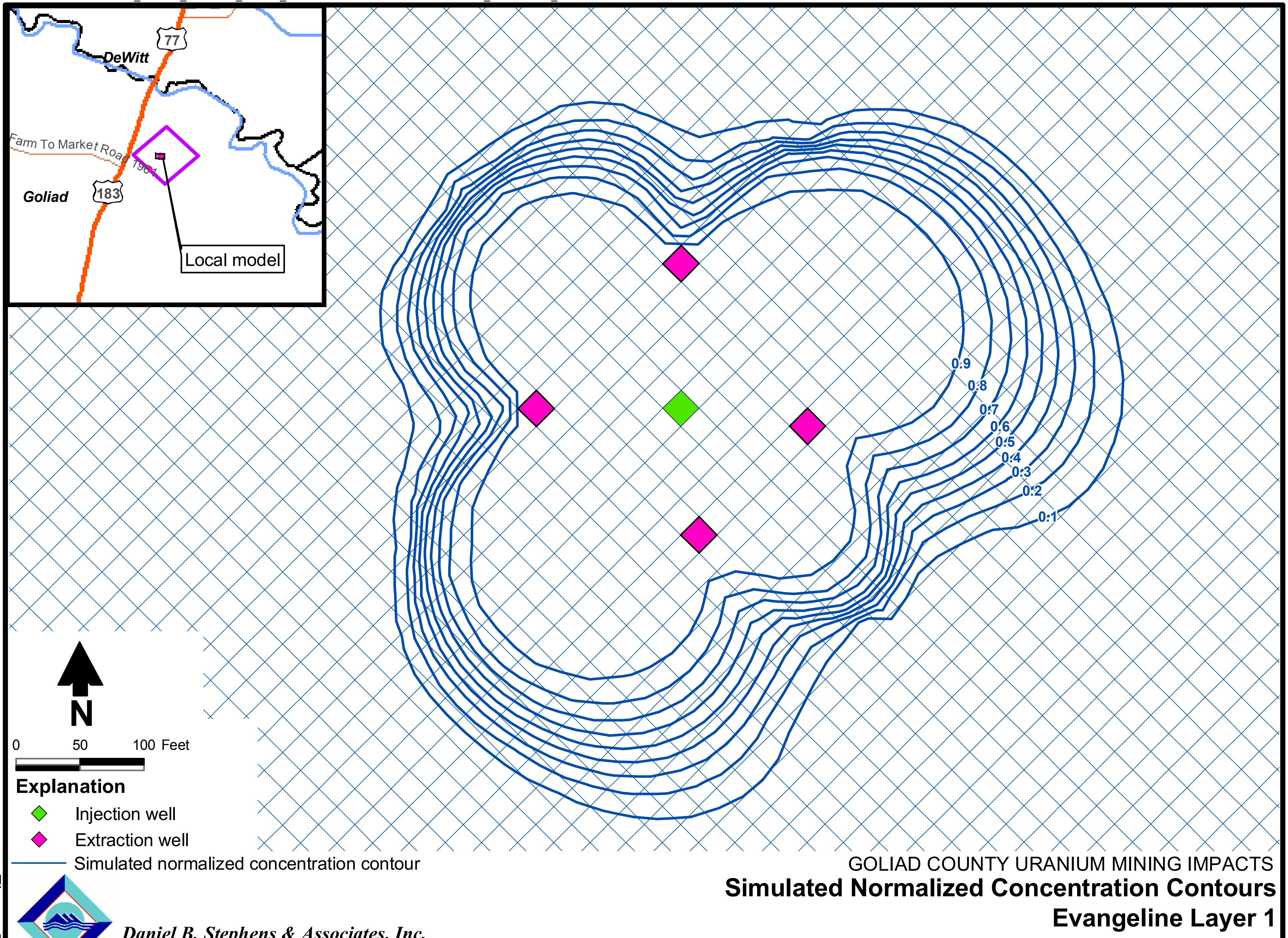
S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/GIS/MXDS/FIG5_SAT_THICK.MXD 700340



GOLIAD COUNTY URANIUM MINING IMPACTS
Simulated Travel Paths of Injected Fluids
Evangeline Layer 2

Figure 6

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/GIS/MXDS/CONCENTRATION_CONTOURS_EV1.MXD 700340

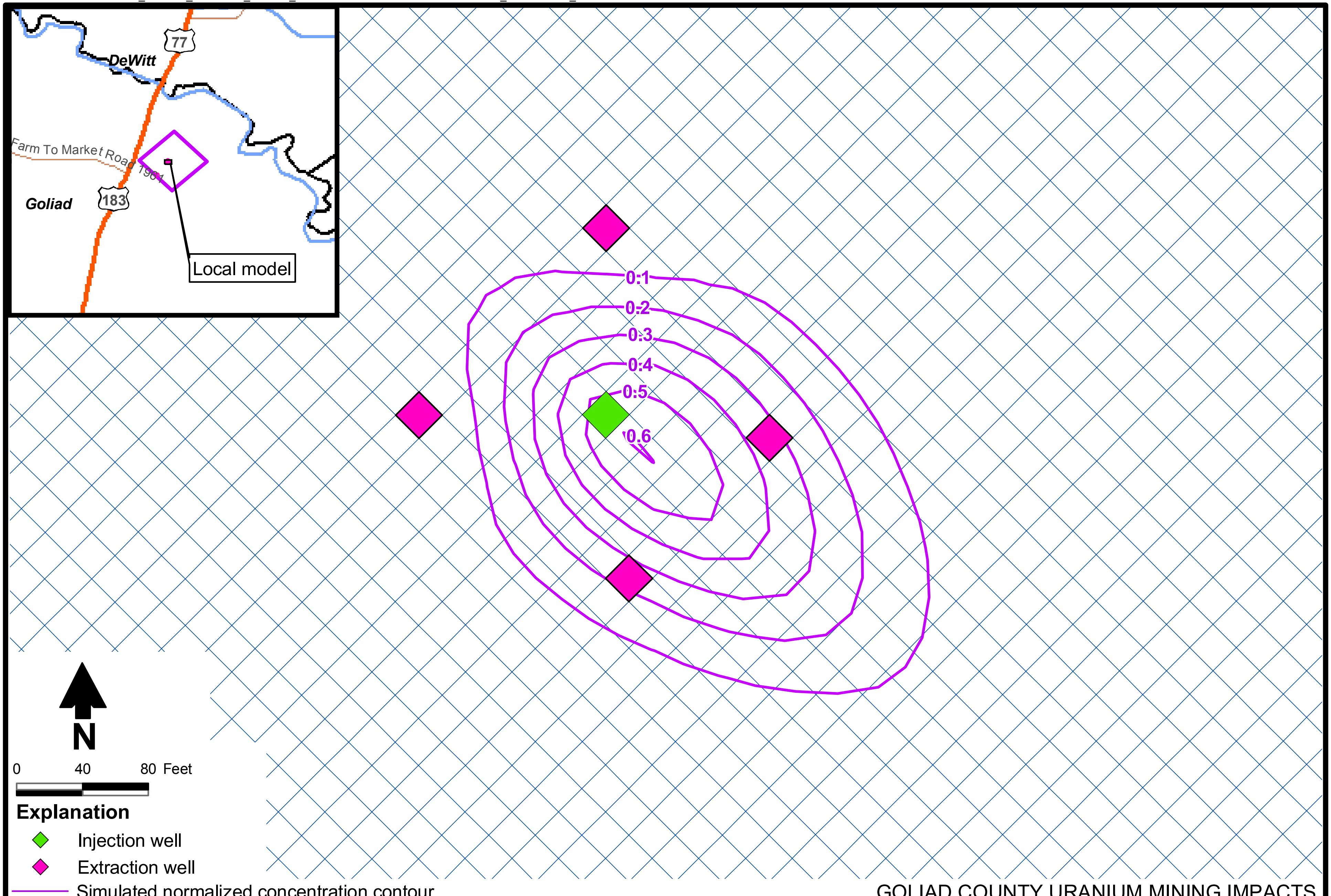


Daniel B. Stephens & Associates, Inc.
04/17/2007
JN WR07.0040

GOLIAD COUNTY URANIUM MINING IMPACTS
Simulated Normalized Concentration Contours
Evangeline Layer 1

Figure 7

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/GIS/MXDS/CONCENTRATION_CONTOURS_EV2.MXD 700340



GOLIAD COUNTY URANIUM MINING IMPACTS
Simulated Normalized Concentration Contours
Evangeline Layer 2

Figure 8

Daniel B. Stephens & Associates, Inc.
04/17/2007
JN WR07.0040

Table

Table 1. Input Parameters for the Local Groundwater Flow Model

S. No	Parameter	Value
1	Horizontal hydraulic conductivity – Evangeline Formation	3.5 ft/d
2	Specific yield – Evangeline Formation	0.01
3	Recharge	1.420 x 10^{-6} to 3.780 x 10^{-5} ft/d
4	Vertical hydraulic conductivity between Evangeline layers (from TAMUK model)	0.06 ft/d

ft/d = Feet per day

Appendix A

Supplemental Information and Modeling Results

Table A1. Summary of Literature Review on ISL Well Field Design Parameters

S. No	Injection Rate	Extraction Rate	Well Spacing/ Geometric Design	Source
1	100 gpm	---	100 ft x 100 ft / 5 spot pattern	Freeman and Stover, (1999), The Smith Ranch Project: A 1990s In Situ Uranium Mine, The Uranium Institute 24th Annual Symposium 8-10 September 1999: London
2	---	---	15 to 30 meters (approximately 50 to 100 ft)	Paul Kay (1998), Beyond the Three Mines - In Situ Uranium Leaching Proposals in South Australia, Science, Technology, Environment and Resources Group, Research Paper 12 1997-98
3	---	~ 2.5 to 3.8 L/sec (approximately 40 to 60 gpm)	15 meters (approximately 50 ft)/ 5 spot pattern - Nine mile lake site, Wyoming	G.Mudd (2001), Critical Review of Acid-insitu Mining: 1. USA and Australia, Environmental Geology, 41:390-403
4	---	2.5 L/sec (approximately 40 gpm)	12 meters (approximately 40 ft)/ 5 spot pattern - Reno Ranch site, Wyoming	
5	---	1.6 L/sec (approximately 25 gpm)	15 meters (approximately 50 ft)/ 7 spot pattern - - Reno Ranch site, Wyoming	
6	---	2.5 L/sec (approximately 40 gpm)	15 meters (approximately 50 ft)/ 7 spot pattern - Nine mile lake site, Wyoming	
7	---	50 gpm	Lost Creek, Wyoming	http://events.onlinebroadcasting.com/urenergy/011607/index.php
8	---	44 gpm	15 to 60 meters (approximately 50 to 165 ft) / Hexagonal Pattern	T. C. Pool and Wallis, C.S (2006), Technical report on the Akalda, Uranium Mine, Kazakhstan, Prepared for Urasia Energy LTD.
9	---	1.2 L/sec (approximately 20 gpm)	40 meters (approximately 130 ft)/ Hexagonal pattern	T. C. Pool and Wallis, C.S (2006), Technical report on the North Kharassan Uranium Project, Kazakhstan, Prepared for Urasia Energy LTD.

Table A1. Summary of Literature Review on ISL Well Field Design Parameters

S. No	Injection Rate	Extraction Rate	Well Spacing/ Geometric Design	Source
10	Ranges from a minimum of 0.0007 m^3/second (~10 gpm) to a maximum of 0.007 m^3/second (~110 gpm) with a typical average rate of 0.0014 m3/second (22 gpm)	Ranges from a minimum of 0.0014 m^3/second (~22 gpm), to a maximum of 0.014 (~220 gpm) and a typical average rate of 0.0028 m3/second. (44 gpm)	The maximum distance between the injection and recovery wells vary from 10 to 80 meters (the most prevalent from 30 to 50 m).	International Atomic Energy Agency (IAEA, 2001), Manual of Acid in-situ Leach Uranium Mining Technology, Vienna, Austria:294 pp

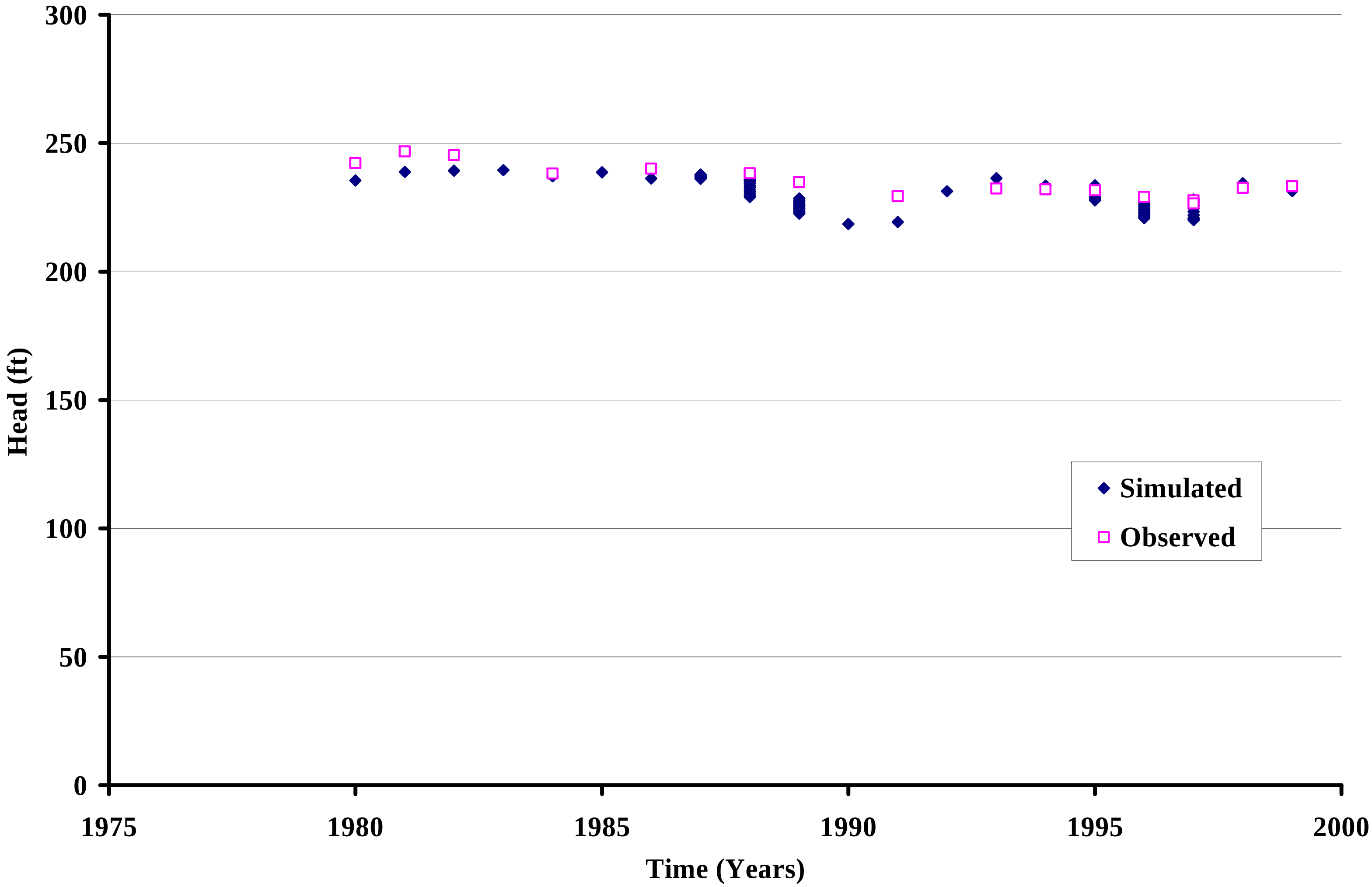
Grids shown are GAM grids of 1 square mile size

GOLIAD COUNTY URANIUM MINING IMPACTS

Location of Wells Used to Check the Calibration of GAM Near the Study Area

Daniel B. Stephens & Associates, Inc.

Figure A-1

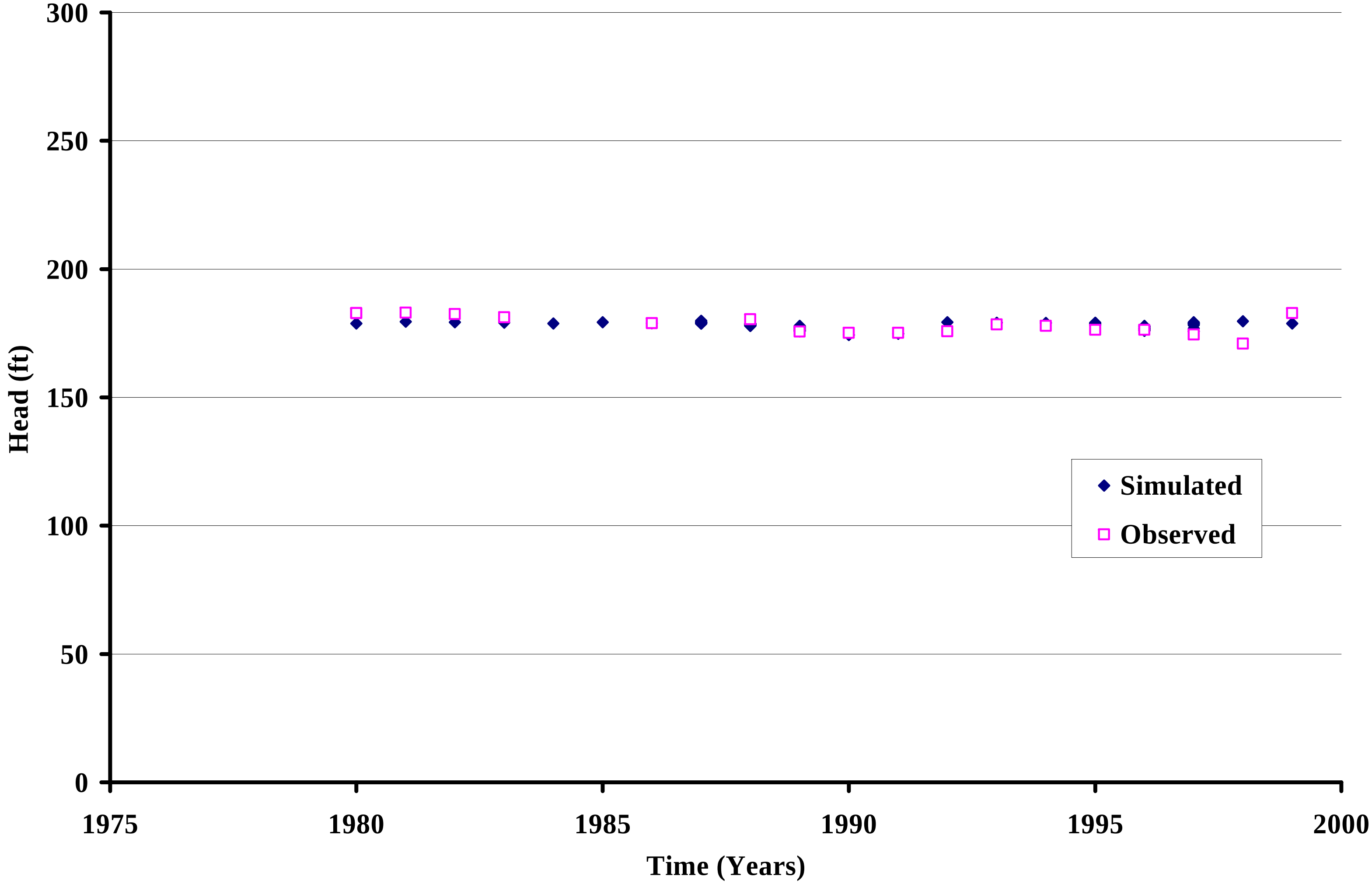


GOLIAD COUNTY URANIUM MINING IMPACTS

Observed and Simulated Hydrograph for Well No. 7913202

Daniel B. Stephens & Associates, Inc.

Figure A-2

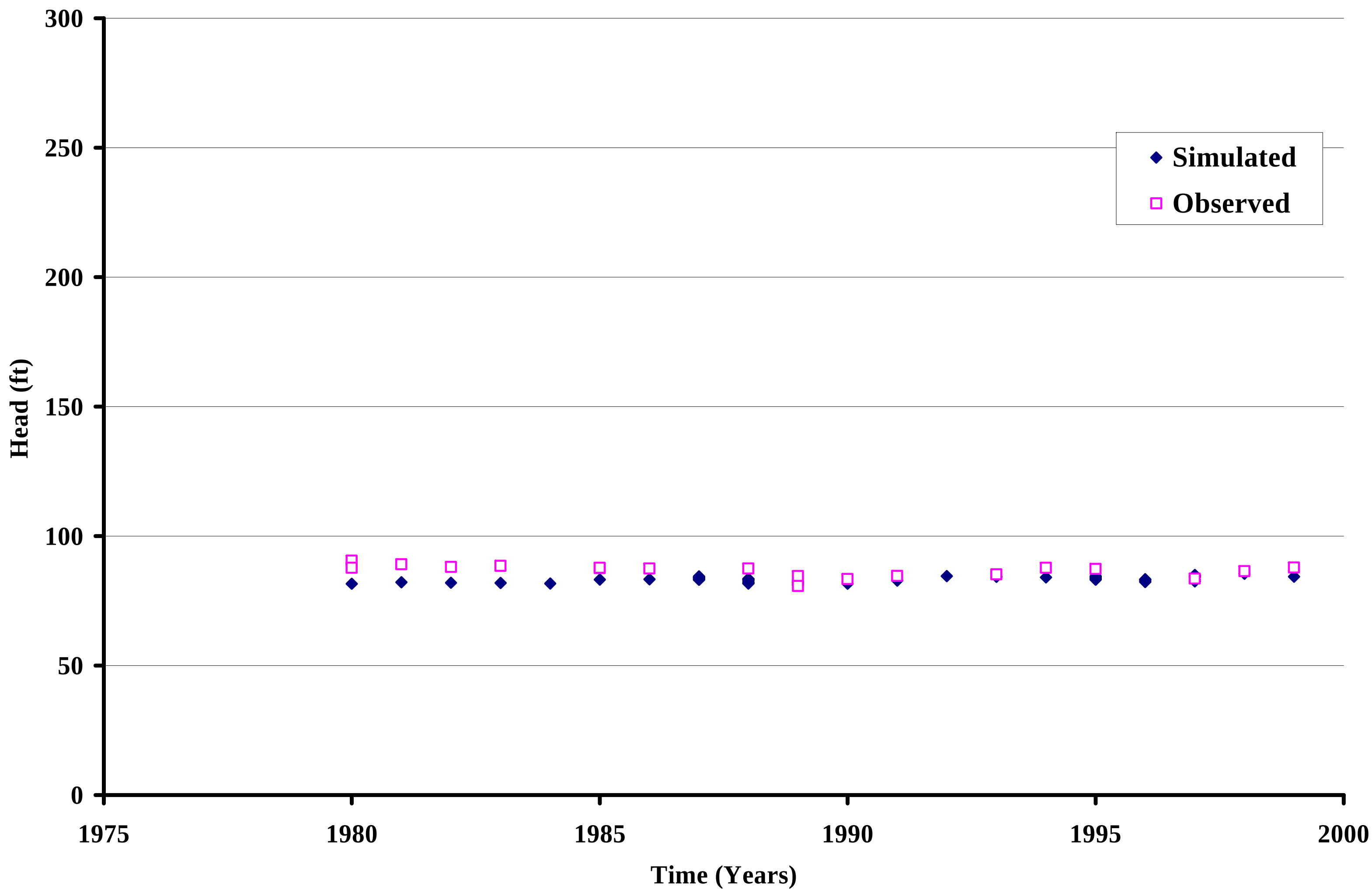


GOLIAD COUNTY URANIUM MINING IMPACTS

Observed and Simulated Hydrograph for Well No. 7906703

Daniel B. Stephens & Associates, Inc.

Figure A-3

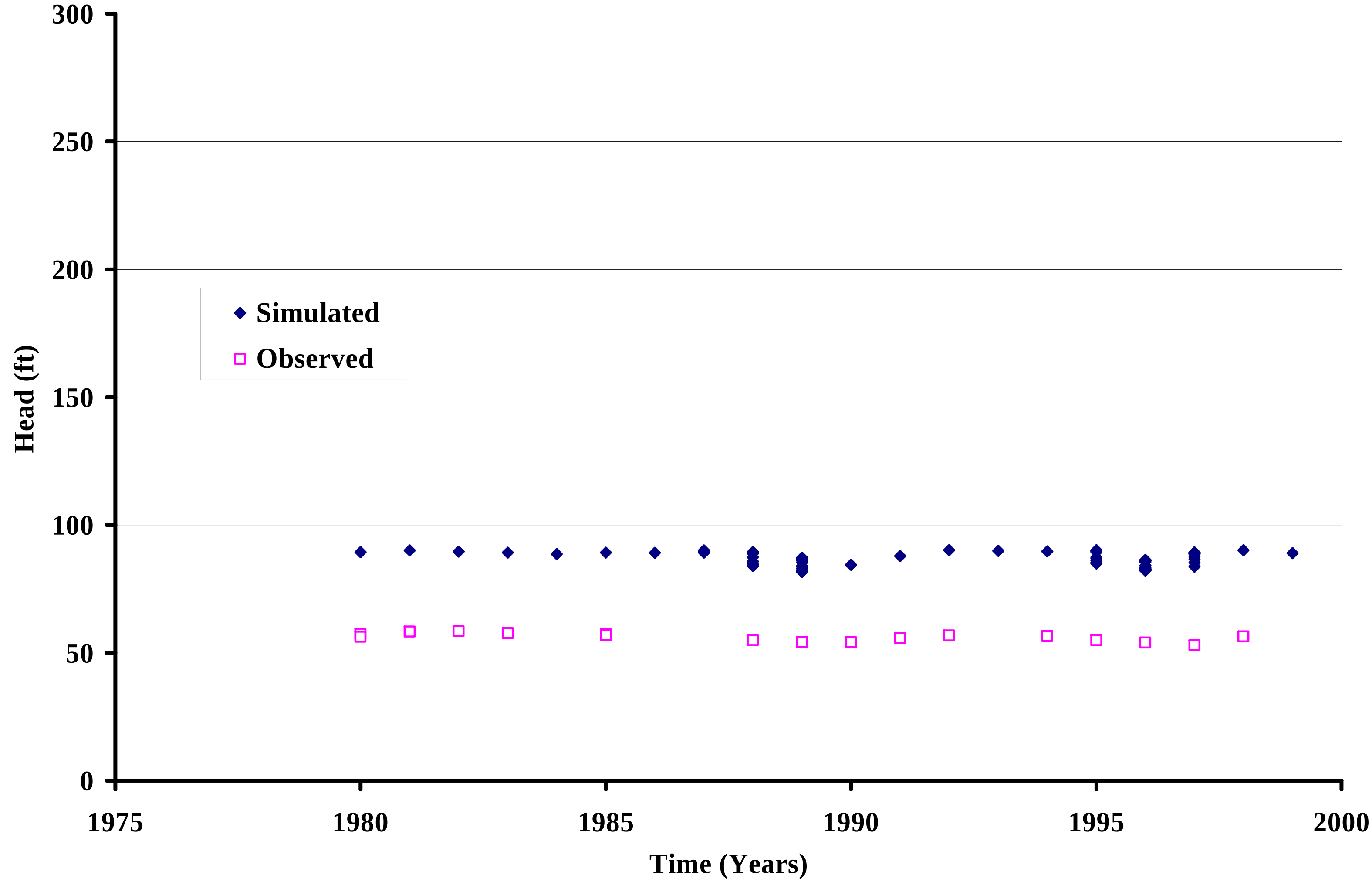


GOLIAD COUNTY URANIUM MINING IMPACTS

Observed and Simulated Hydrograph for Well No. 7907305

Daniel B. Stephens & Associates, Inc.

Figure A-4

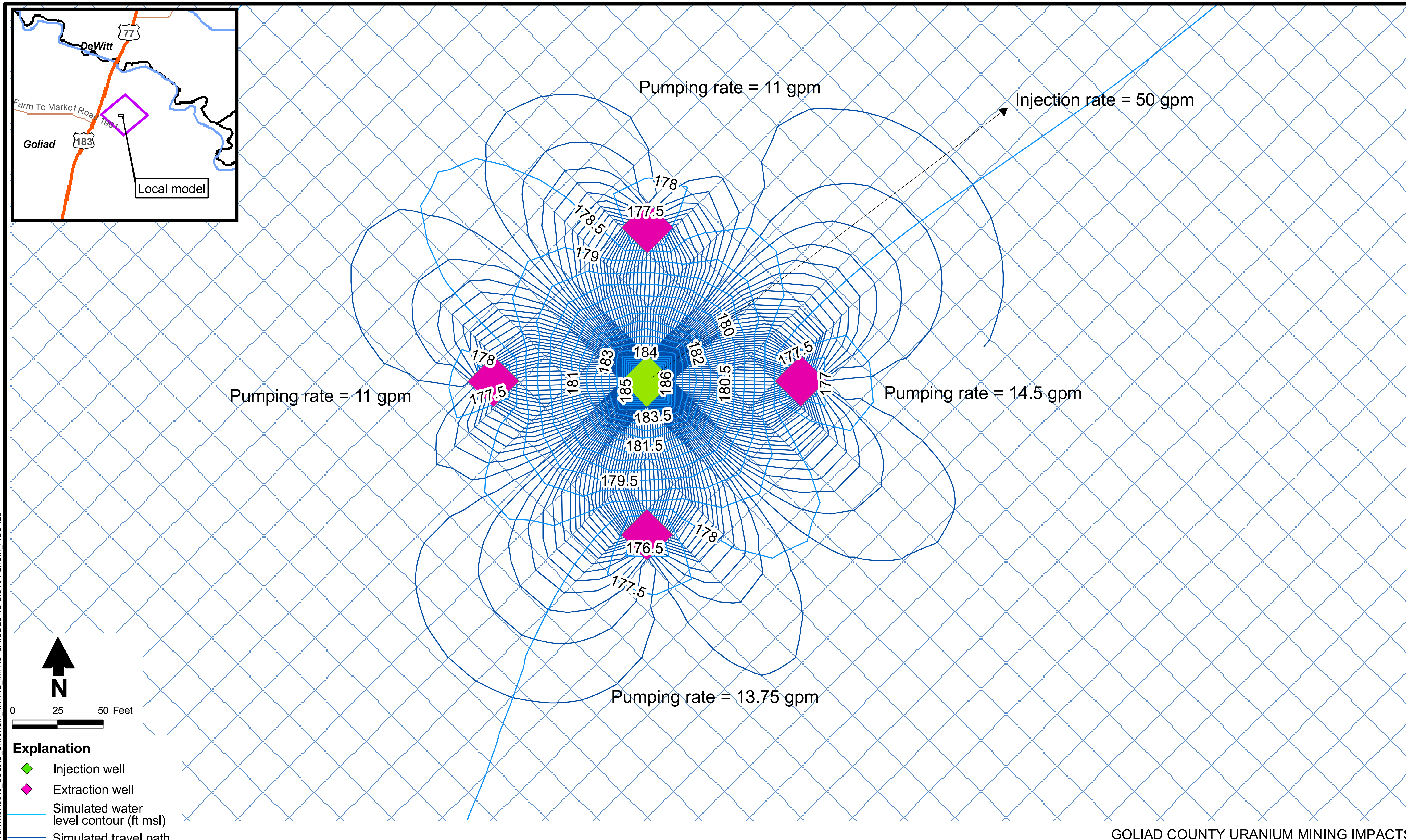


GOLIAD COUNTY URANIUM MINING IMPACTS

Observed and Simulated Hydrograph for Well No. 7915301

Daniel B. Stephens & Associates, Inc.

Figure A-5



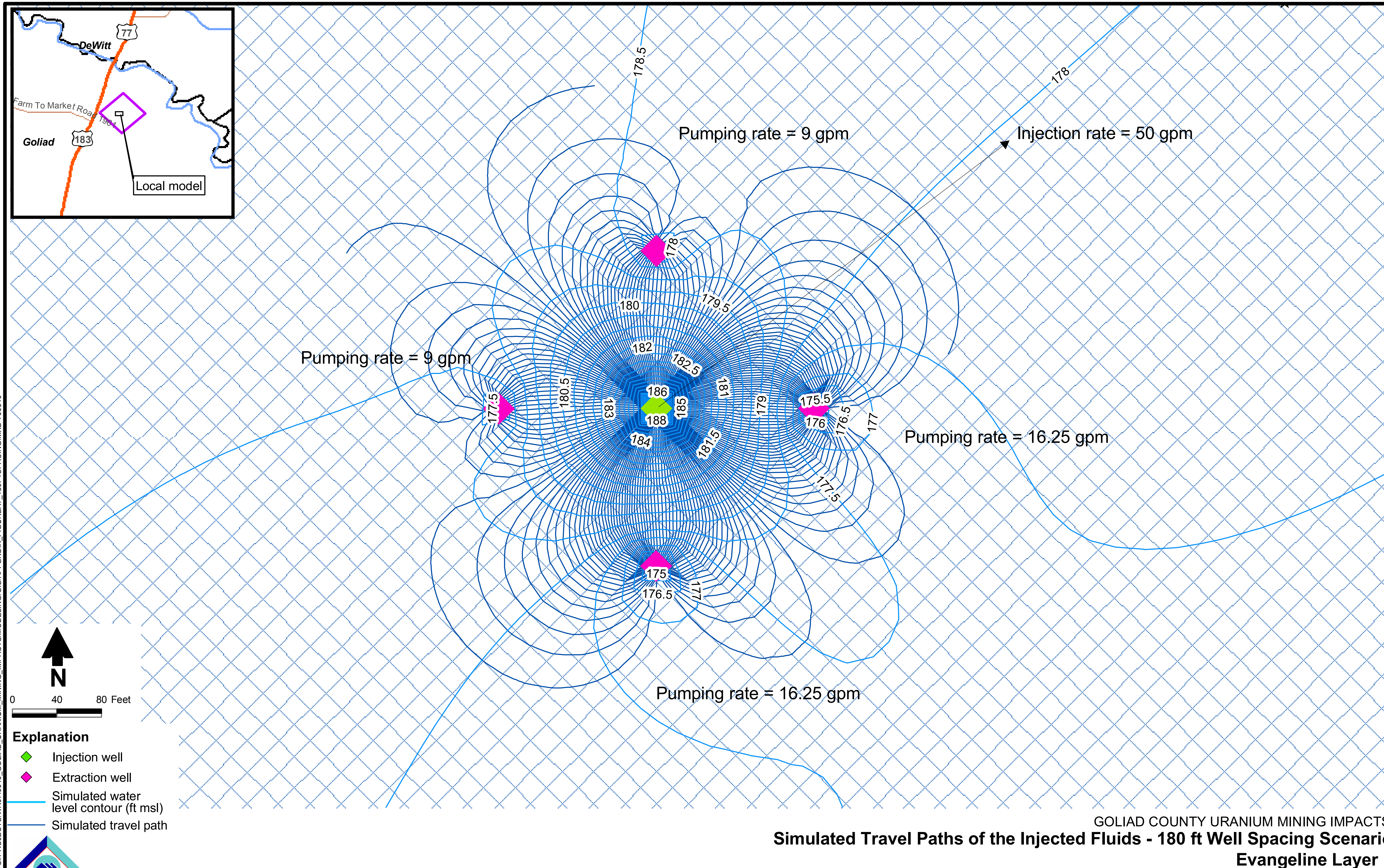
S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/APPENDIX_FIGURE6

GOLIAD COUNTY URANIUM MINING IMPACTS

Simulated Travel Paths of Injected Fluids - 100 ft Well Spacing Scenario
Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-6

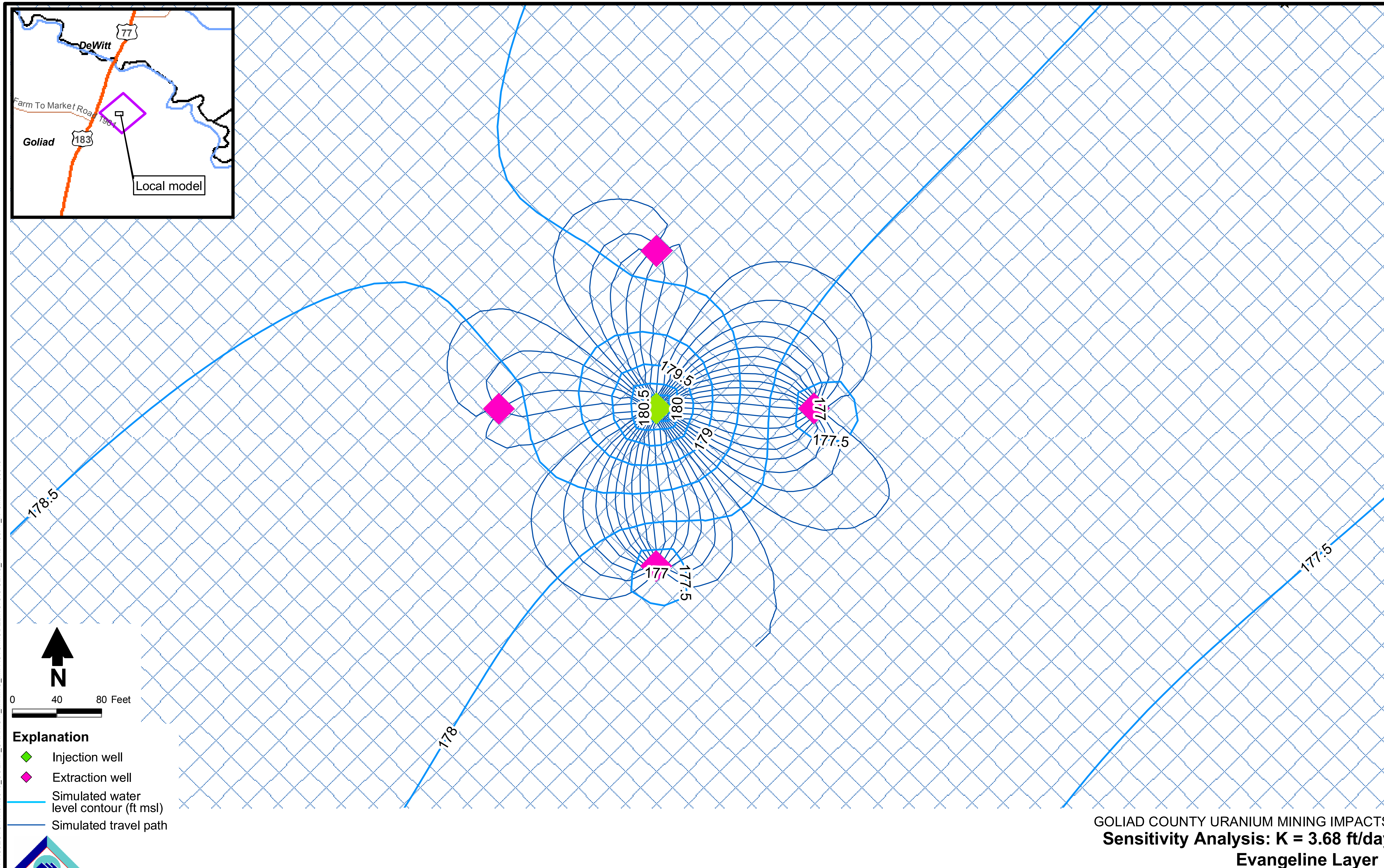


GOLIAD COUNTY URANIUM MINING IMPACTS

Simulated Travel Paths of the Injected Fluids - 180 ft Well Spacing Scenario
Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-7



GOLIAD COUNTY URANIUM MINING IMPACTS

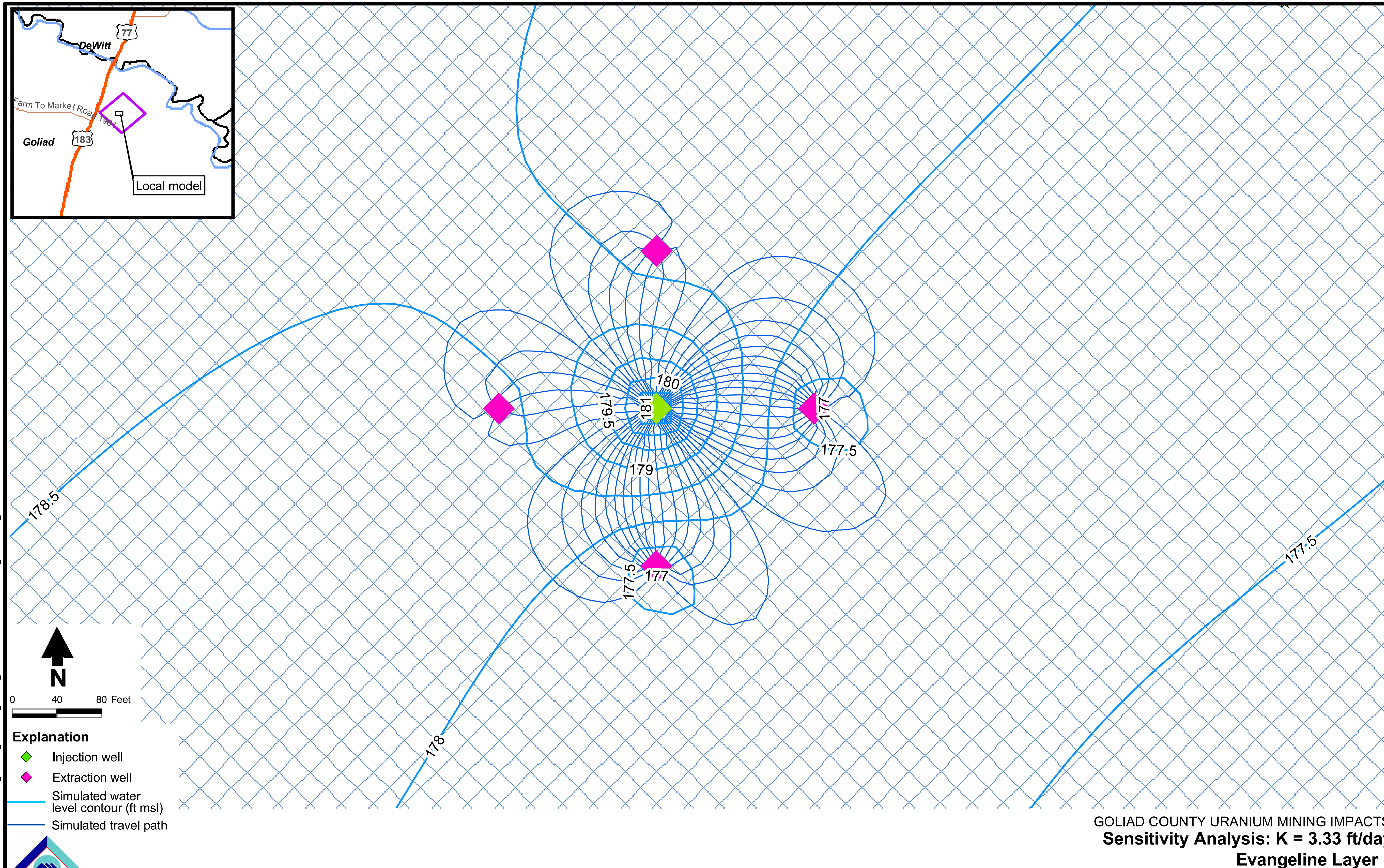
Sensitivity Analysis: K = 3.68 ft/day

Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-8

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K+5.MXD 700340

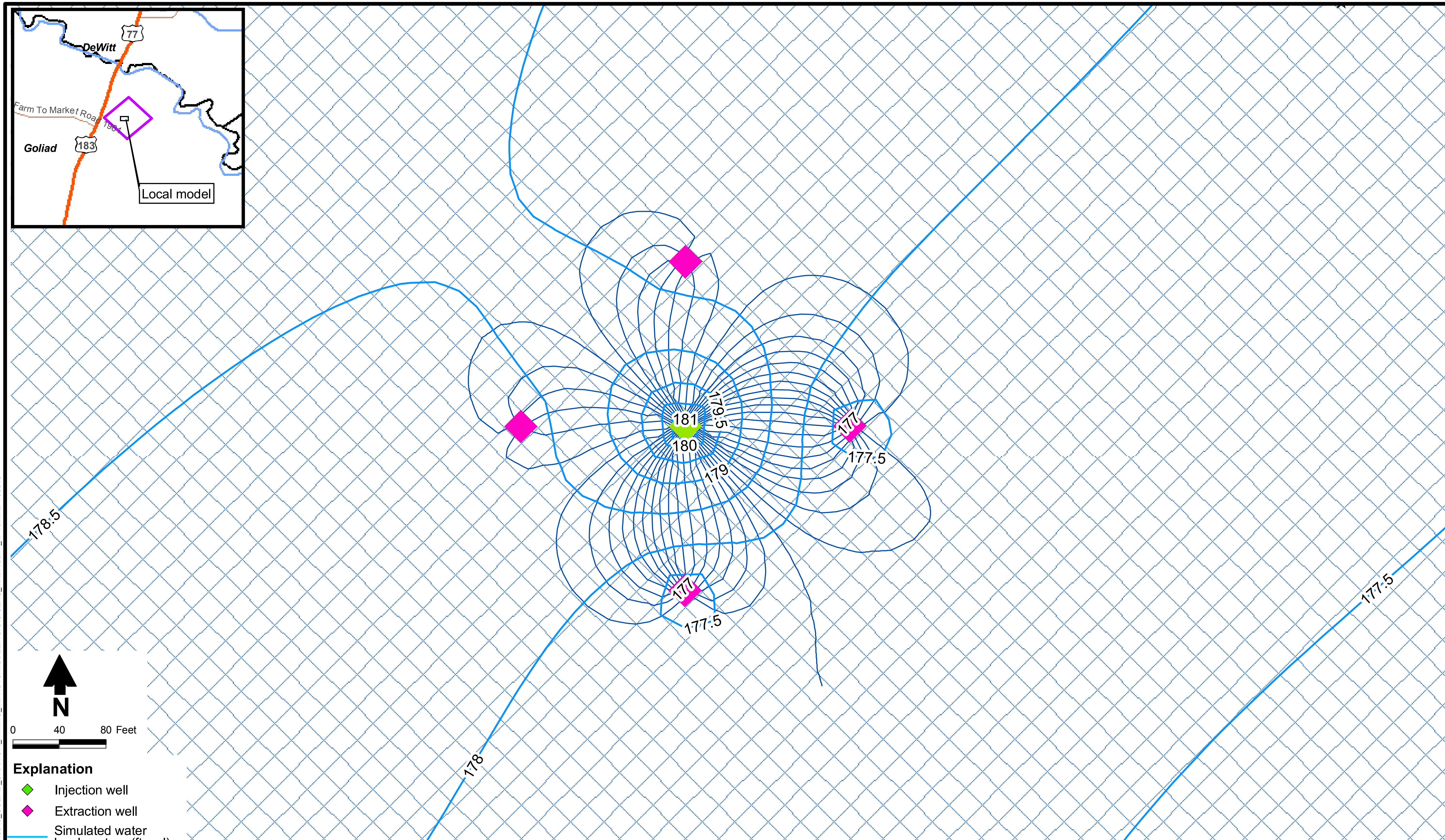


GOLIAD COUNTY URANIUM MINING IMPACTS
Sensitivity Analysis: K = 3.33 ft/day
Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-9

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K-5.MXD 700340



S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K+10.MXD 700340

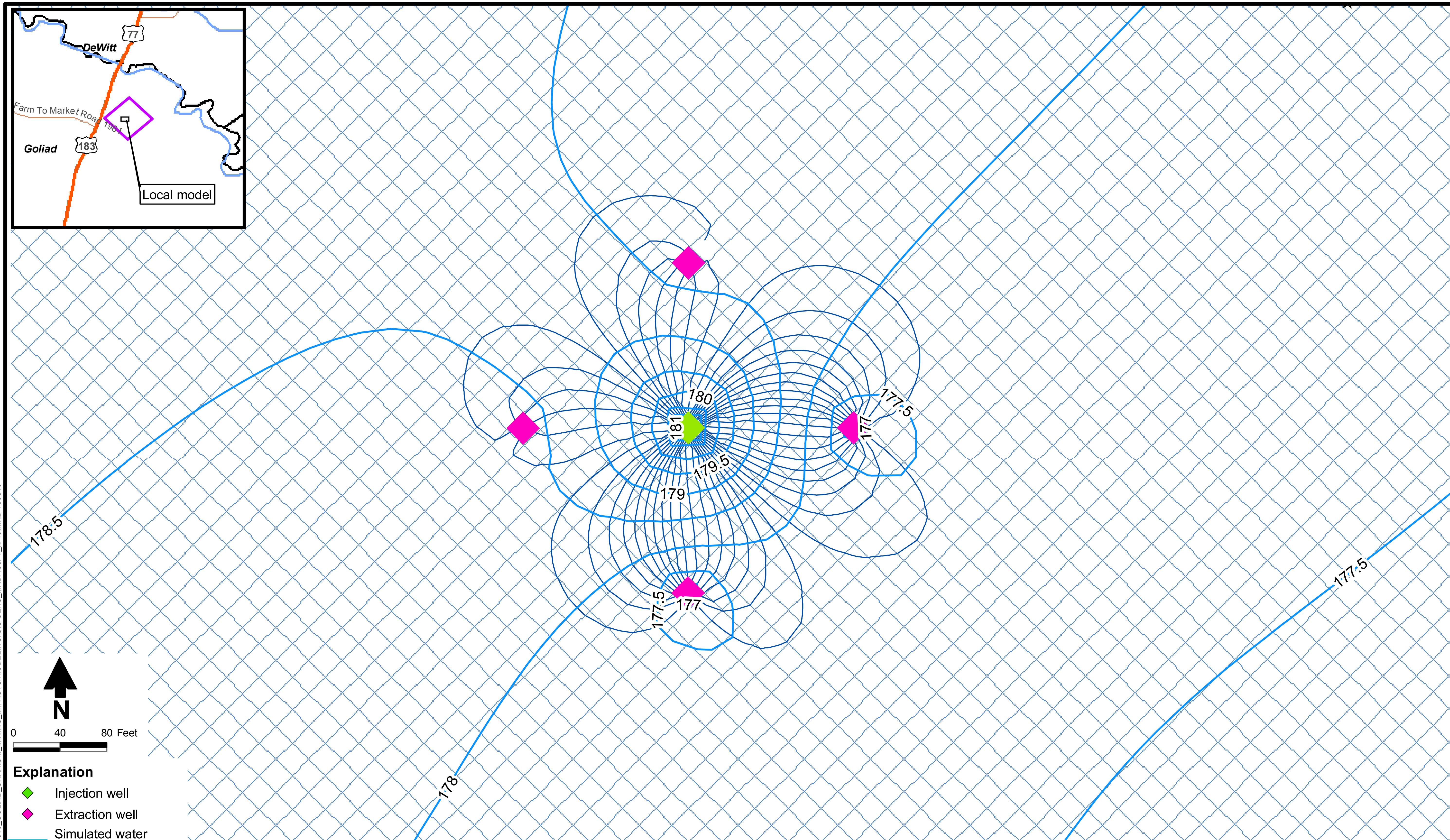
GOLIAD COUNTY URANIUM MINING IMPACTS

Sensitivity Analysis: K = 3.85 ft/day

Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-10



Explanation

- Injection well
- Extraction well
- Simulated water level contour (ft msl)
- Simulated travel path

GOLIAD COUNTY URANIUM MINING IMPACTS

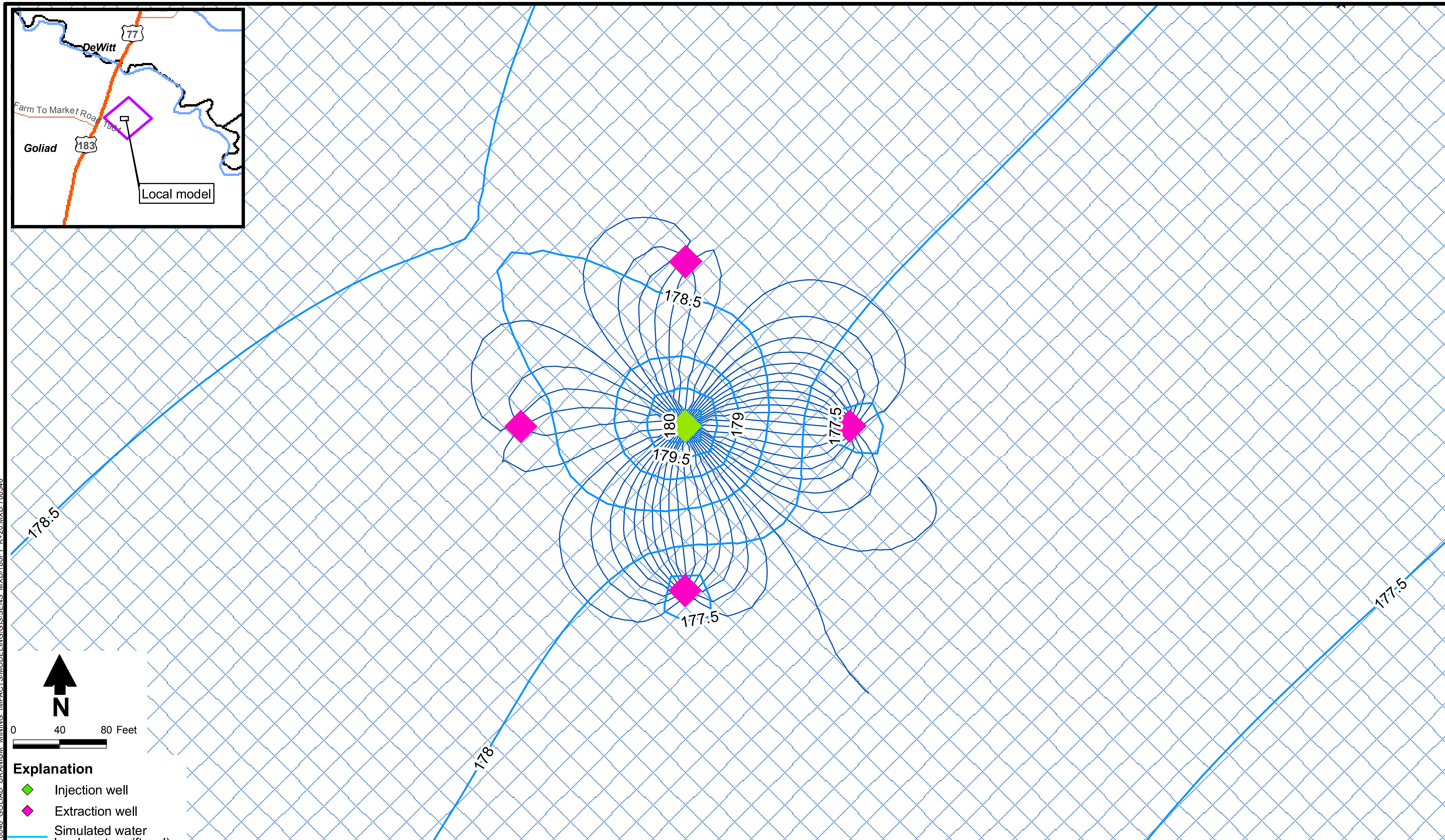
Sensitivity Analysis: K = 3.15 ft/day

Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-11

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K-10.MXD 700340



S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K+20.MXD 700340

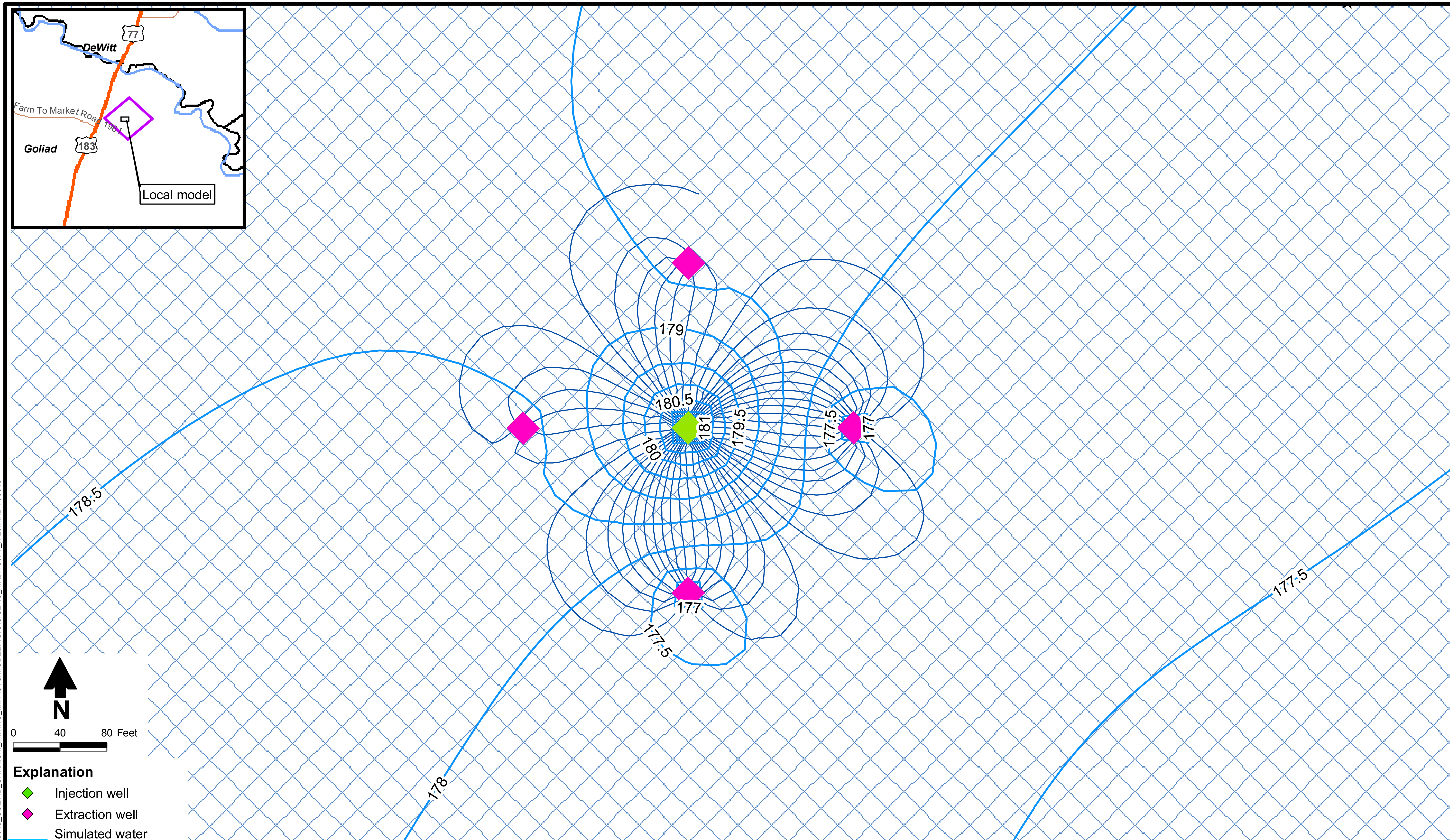
GOLIAD COUNTY URANIUM MINING IMPACTS

Sensitivity Analysis: K = 4.2 ft/day

Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-12



N

0 40 80 Feet

Explanation

- Injection well
- Extraction well
- Simulated water level contour (ft msl)
- Simulated travel path

GOLIAD COUNTY URANIUM MINING IMPACTS

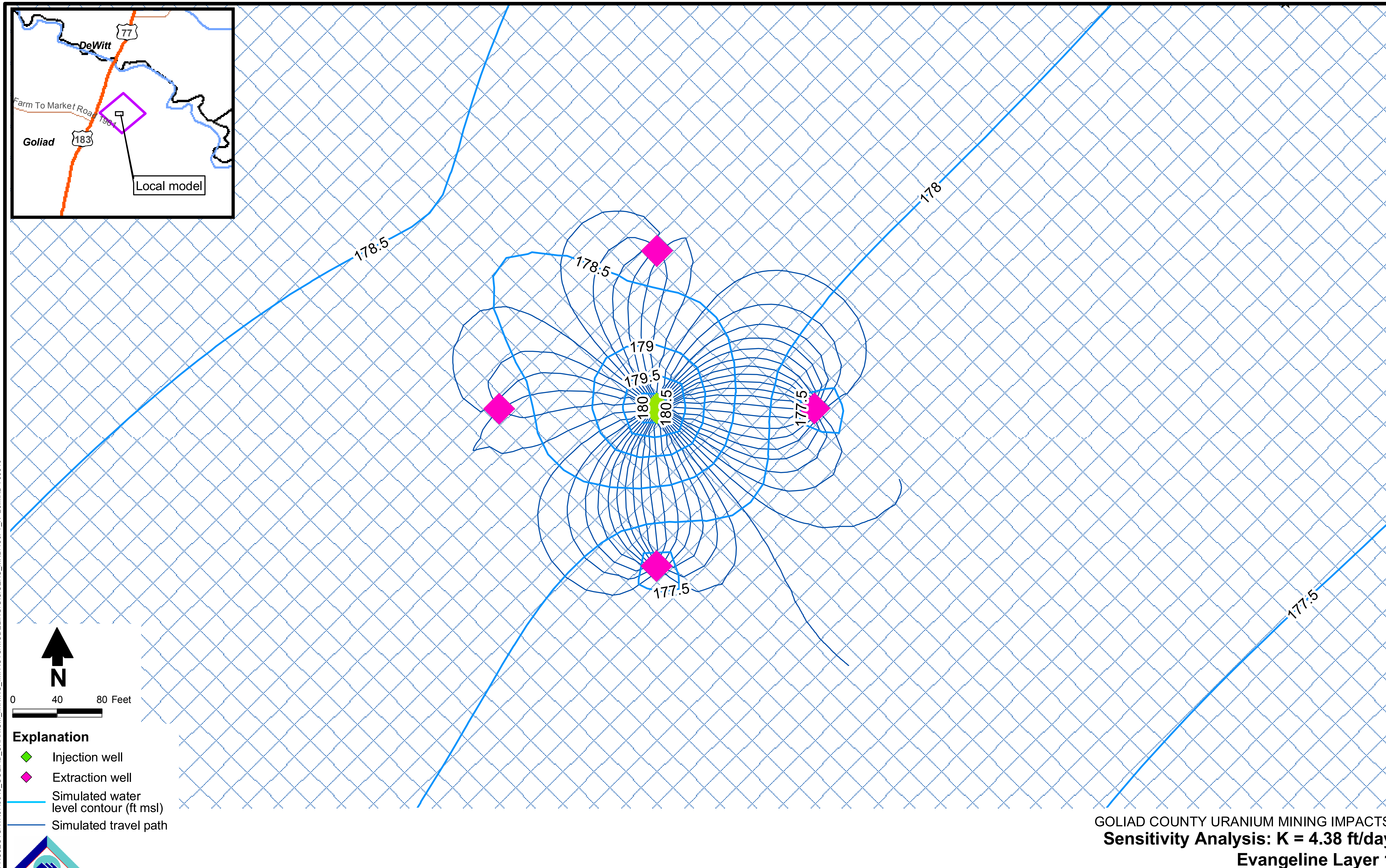
Sensitivity Analysis: K = 2.8 ft/day

Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-13

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K-20.MXD 700340



GOLIAD COUNTY URANIUM MINING IMPACTS

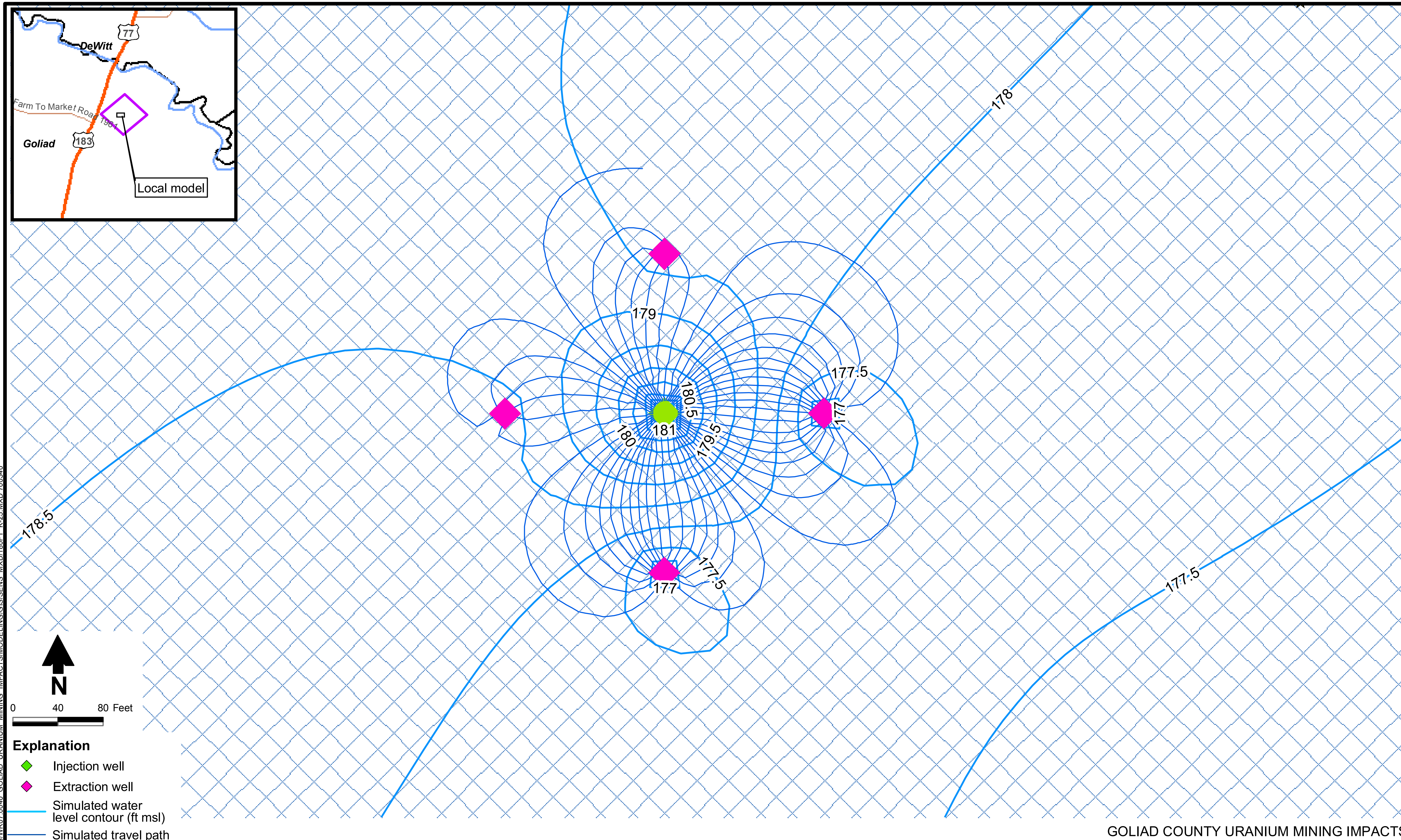
Sensitivity Analysis: K = 4.38 ft/day

Evangeline Layer 1

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

Figure A-14

S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K+25.MXD 700340



S:/PROJECTS/WR07.0040_GOLIAD_URANIUM_MINING_IMPACTS/MODELING/GIS/SENS_MXD/180FT_K-25.MXD 700340

Daniel B. Stephens & Associates, Inc.
04/17/2007 JN WR07.0040

GOLIAD COUNTY URANIUM MINING IMPACTS

Sensitivity Analysis: K = 2.63 ft/day

Evangeline Layer 1

Figure A-15