Hydrogeologic Evaluation and Groundwater Flow Model Report

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OLSSON ASSOCIATES

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EXECUTIVE SUMMARY

The City of Abilene relies on the alluvial aquifer of the Smoky Hill River for its water supply. Currently, the city has little excess capacity given existing infrastructure, giving rise to concerns over growth potential as well as uncertainty over future water supply conditions. This study provides a comprehensive assessment of the groundwater system in the vicinity of the City of Abilene based on all existing information. Generally speaking, the alluvial aquifer in the study area could provide a significantly greater water supply than is currently available to the city. However, for the area underlying the city's existing water supply infrastructure, state regulations impose significant restrictions on water supply expansion.

The first phase of this study focused on areas to the south, southeast, and east of the city where new water infrastructure development might be feasible for the city. Results indicate that water is likely both physically and legally available in three focus areas chosen by city staff. If the city wishes to further explore water supply development in any of these areas next steps would be: 1) develop some type of property right interest for the land overlying the aquifer in one or more of those areas, 2) make application to the state for an appropriation to pump groundwater, 3) initiate test drilling to confirm the aquifer conditions in those areas, and 4) analyze the results of any test drilling completed.

The second phase of this study involved the development of a groundwater model of the alluvial aquifer in the vicinity of the City of Abilene. This report demonstrates that the model comprises a good numerical representation of the hydrogeologic conditions for the area. Therefore, the groundwater model provides a very useful tool to evaluate past, current, and future aquifer conditions. Future conditions can be evaluated under a variety of water supply and water use scenarios for planning considerations.

Finally, the two phases are related as the groundwater model can be used to evaluate the impact of new water supply development on existing wells in the area, including the city's existing water supply wells.

1.0 INTRODUCTION

1.1 Purpose and Scope

This report provides the results of a hydrogeologic analysis completed for the City of Abilene that encompasses the study area shown in Figure 1. The goals of the analysis were:

1. Locating potential drilling sites for a new water supply well(s), and
2. Providing a tool to simulate the potential implications to the city's existing groundwater wells concerning new wells and/or future water supply and/or use scenarios.

The first phase of this project involved a comprehensive assessment of the groundwater resources for the area in Figure 1, with a more refined focus on certain areas that initially appeared to meet the study's first goal. The second phase of the project included developing a groundwater model using the groundwater modeling software developed by the U.S. Geological Survey called MODFLOW. The model can be used to answer questions that are related to the study's second goal.

The scope of the hydrogeologic analysis was defined by the physical features of the surface, groundwater system, and the availability of hydrogeologic data. Since the first goal of the study was to identify areas to site a new water supply well, the aquifer characteristics of the area within and immediately surrounding the city limits were evaluated in greater detail. To facilitate development of the groundwater model, the evaluation area was extended well beyond the city limits to include the areas from stream gages upstream of Abilene on the Solomon and Smoky Hill Rivers and downstream of Abilene on the Smoky Hill River. The stream gages are U.S. Geological Survey (USGS) gages for the Solomon River at Niles (06876900), Smoky Hill River at New Cambria (06870200), and Smoky Hill River at Enterprise (06877600). Figure 2 illustrates the entire study area including the stream gages that helped define the extent of the full study area and the area south and southeast of Abilene that was the focal area for siting a new water supply well.

This document was prepared for the City of Abilene by Olsson Associates in accordance with professional standards at the time of the services. All data, drawings, documents, or information contained in this report have been prepared exclusively for the City of Abilene and may not be relied upon by any other person or entity without the prior written consent of the city. Olsson relied on information provided by the City of Abilene and published documents/datasets as referenced throughout the report. No field investigations were completed as part of this project and unless otherwise expressly indicated, Olsson has made no independent investigation as to the validity, completeness, or accuracy of the information provided.

1.2 Data Sources

To assess the aquifer characteristics of the area around the City of Abilene, a combination of published reports, online databases, and information from the city on the current water supply wells were evaluated. The University of Kansas, State Geological Survey Bulletin 84 by B.F. Latta (1949) described the geology and groundwater aquifers in the Smoky Hill River Valley in Saline, Dickinson, and Geary Counties. The bulletin was used for a description of the regional hydrogeology. The Kansas Geological Survey (KGS) online database provided approximate well locations and drilling log information used to prepare geologic cross sections of the Smokey Hill River alluvial aquifer (KGS 2017). For well development and well spacing evaluations, the Kansas Department of Agriculture online database provided information on current surface and groundwater rights in the study area (KDA 2017). The Smoky Hill River Valley Ground-water Model

Open File Report 2008-20 (Wilson, 2008) described a groundwater model that was developed for the City of Salina and the Smoky Hill River basin just west of this study area (herein referred to as the Salina Model). The model report was used to help develop a conceptual model for the area. The Public Works Department for the City of Abilene provided well construction, test hole drilling, and water level information from their groundwater monitoring and water supply well network.

2.0 SITE CHARACTERIZATION

2.1 Topography and Land Use

The study area lies within the Great Plains physiographic province which is part of the Interior Plains (NPS 2017). The vast majority of the province is plateau-like with flat plains and little topographic relief. However, in this study area the Solomon and Smoky Hill River valleys cut through the upland plateau. Topographic relief in the study area ranges from a high of 1,400 feet above mean sea level (AMSL) near New Cambria to a low of 1,121 feet AMSL near Enterprise. Consequently, the Solomon and Smoky Hill Rivers flow west to east with minor tributaries that drain the uplands along primarily north/south drainages.

Land use in the study area is dominated by dryland farming. The urban areas from west to east include New Cambria, Solomon, Abilene, Detroit, and Enterprise. Abilene is the largest community with a population of 6,590 as reported by the US Census Bureau for 2014. The major roadways that cross the study area include Interstate 70 just north of Solomon and Abilene and highway 221, 15, and 43 that bisect Solomon, Abilene and Enterprise, respectively.

2.2 Hydrology

The Smoky Hill and Solomon Rivers are the primary surface water feature in the study area. The two gages that measure the river discharges on the western side of the study area are on the Solomon River near Niles and on the Smoky Hill River east of New Cambria. On the eastern side of the study area, the Smoky Hill River discharge is measured at Enterprise. Historic monthly discharge measurements are plotted in Figure 3. Monthly stream gain is shown in Figure 4. The smaller tributaries that flow into the Smoky Hill River across the study area from west to east include Coal, Buckeye, and Mud Creek on the north and Gypsum, Holland, and Turkey on the south.

2.3 Hydrogeology and Aquifer Delineation

The geology of the study area was described in a detailed US Geological Survey Bulletin 84 (Latta 1949) and was mapped by the KGS and illustrated in three published surficial geologic maps (KGS, 1959; KGS, 2011; and KGS, 2014). The following description is a summary from these four publications.

The bedrock formations of central Kansas dip to the west which is the opposite of the surface topography. Along the Solomon and Smoky Hill Rivers, the bedrock formations are overlain by relatively thick unconsolidated alluvial deposits. In contrast, in the uplands, the bedrock formations are primarily exposed or overlain by relatively thin alluvium. East of Abilene, the bedrock consists of alternating beds of Permian limestone and shale of the Wolfcampian Series. West of Abilene, the Permian Wellington Formation underlies the alluvial deposits and is composed primarily of shale with thin beds of gypsum and limestone. The bedrock formations in the study area are not a significant source of groundwater.

The Quaternary alluvial deposits within the river valleys are the primary aquifer for the study area (Figure 5). The alluvium ranges in thickness from a few feet to over 80 feet in thickness and is composed of

unconsolidated clay, silt, sand, and gravel. In general, the finer materials overlie the coarser sand and gravel deposits. Well yields in the alluvial aquifer range from a few gallons per minute (gpm) in small stock wells to 1,500 gpm in the large irrigation wells.

There is a 40-foot-thick sequence of dune sand that covers an area of approximately 20 square miles along the north side of the Smoky Hill River between Solomon and Abilene. Beneath the dune sand are terrace deposits formed by streams during the Pleistocene. These terrace deposits are up to 50-65 feet thick and thin to less than 1 foot thin to the north.

Sand Spring, located 2.5 miles west of Abilene is the only natural spring of importance in the Smoky Hill Valley. The spring discharges water from dissolution cracks between bedding plans in the Permian limestone. As described in Latta, 1949, water moves through the sand dunes and terrace deposits into fractures of the limestone where it discharges at rates up to 1,200 gpm during wet periods and less than 900 gpm during periods of low rainfall.

2.4 Areas for Potential Groundwater Development

To identify areas for new water supply wells for the City of Abilene, an evaluation of current groundwater development was completed. Well logs from wells within the Smoky Hill River alluvium were reviewed, and three detailed cross sections were developed for areas south and southeast of town to illustrate the vertical and lateral extent of coarse sand and gravel deposits (Figure 6). Within these cross sections (Figures 7 and 8), there is an area where sand and gravel deposits are up to 17 feet thick. Based on well yields from wells in the area and due to proximity to existing water infrastructure, this area would be well suited for water supply well development (Figure 9).

According to the Kansas Water Appropriation Act administered by the Kansas Department of Agriculture, the minimum spacing between groundwater wells is defined in Kansas Administrative Regulation (K.A.R.) 5-4-4. For alluvial aquifer wells, the minimum distance that a new well can be permitted from a domestic well is 660 feet. The minimum distance that a new well can be permitted from all other senior authorized non-domestic, non-temporary wells is 1,320 feet. Figure 10 illustrates the well spacing requirements from the existing network of senior authorized wells, according to the Water Information Management and Analysis System (WIMAS) database. Based on this map, the areas outside the spacing requirements of existing wells should be evaluated for test hole drilling and water quality testing. Should the city decide to propose a new water supply well that does not meet the well spacing requirements described above, a hydrologic analysis must be submitted to the chief engineer to show that the spacing can be decreased without impairing existing rights or prejudicially and unreasonably affecting the public interest.

The other requirement in siting a new groundwater well is what is referred to as Safe Yield (K.A.R. 5-3-10). The basic requirement of the Safe Yield regulations is to limit the amount of water authorized for withdrawal at any given point to no more than the average amount of water that the aquifer receives from recharge within a two mile radius. Long-term average recharge in the vicinity of the City of Abilene is approximately three inches per year. Figure 11 shows the amount of water authorized for withdrawal within a two mile radius of every 40 acre cell within the study area. Figure 12 shows the total amount of recharge that occurs within the same area for these same cells. The maximum possible amount given the three inch assumption for recharge and the two mile radius is approximately 2,000 acre-feet per year. The reason for the variability in Figure 12 is that as the alluvial aquifer pinches out, the area receiving recharge within that two mile circle is gradually reduced. Therefore, water availability is more limited near the edges of the aquifer than at the center line of the aquifer.

The difference between the recharge that is available for use and the authorized quantities of use are displayed in Figure 13. While it is clear that the Safe Yield rules would not allow additional well development directly to the west of town, there do appear to be areas to the south and east of town that may offer an allowable location to site a new well. Based on this, and other considerations such as proximity to existing water delivery infrastructure, the city selected three focus area that are displayed on Figure 14. A new version of the data displayed in Figure 13 was created for this area with a much finer degree of resolution (Figure 15). Based on these results there appears to be up to approximately 400 acre-feet per year of water available for appropriation at locations within all three of these focus areas.

3.0 GROUNDWATER MODEL DEVELOPMENT

3.1 Geology and Hydrogeology of Model Area

To facilitate the construction of the groundwater model a total of 928 boring logs of existing wells within the area of Quaternary deposits shown on Figure 5 were evaluated. Figure 16 shows the depth to bedrock across this area. The Quaternary deposits range from being very thin, typically along the edges of the river valleys to greater than 100 feet across large areas to the west of the City of Abilene on the north side of the Smoky Hill and Solomon Rivers. However, as discussed above, the Quaternary formation in this area consists of a wide range of materials, from clays and silts, to sands and gravels. Furthermore, some of these materials are unsaturated and not important to the flow of groundwater through this alluvial aquifer system. Therefore, for the purposes of model development, the portion of the formation made up of saturated sands and gravels was delineated from a slightly smaller subset of the wells used to generate Figure 16. Figure 17 shows the thickness of saturated sands and gravels, which ranges from essentially zero to over 25 feet. This map was generated using the water level that was documented in the well registration information for 826 wells across this area (Figure 18).

3.2 Model Design

The groundwater model was constructed using MODFLOW-USG, a software developed by the United States Geological Survey (USGS). MODFLOW-USG uses unstructured grids to simulate groundwater flow via an approximation of the finite-difference equation. An unstructured grid offers the ability to create higher spatial resolution around features of interest. This advantage of MODFLOW-USG allows features to be modelled more closely to their real-world locations and as such, provides a better estimation of temporal interactions between the aquifer and stream. In the case of the City of Abilene, features of interest include city wells and streams in the model area. Cell sizes in this model range from 330 ft. x 330 ft. to 1320 ft. x 1320 ft. in size. There are a total of 27,320 active model grid cells. Figure 19 shows the unstructured grid used by this model. Groundwater Vistas (version 7.14, Build 3) was used as a graphical interface platform to construct and view the model, modify inputs, and evaluate calibration.

The model uses three layers, all of which are simulated as unconfined. The elevations of the top of layer one is the land surface elevation obtained from a digital elevation model of the area (Figure 20). The base of layer one and two were determined from the aquifer delineation phase of this project (Figures 21 and 22). A third layer with a constant thickness of 20 ft. was inserted in the area of the Sand Springs wells to simulate the presence of the carbonate materials associated with Sand Springs (Figure 23).

Boundary conditions of the model were set at either no-flow or head dependent flow boundaries (Figure 24). The no-flow boundaries exist where the alluvial aquifer pinches out within the model grid, and the

head dependent flow boundaries were set up along the boundary of the model grid in locations where the alluvial aquifer was present. No-flow boundaries were created by simply making the adjacent cells inactive and the head-dependent flow boundaries were simulated using the General Head Boundary package in MODFLOW. The head elevations were set at five feet below the top elevation of layer one, and were deemed suitable for the purpose of this model.

Streams in the model area were simulated using the Stream Flow Routing (SFR) package in MODFLOW-USG. Locations of the streams were found using the National Hydrography Dataset, provided by the USGS. The elevations of these streams were specified using 1/9 arc second digital elevation models. The layout and numbering of stream reaches within the SFR package are shown in Figure 25. The data from the stream gages on the Solomon River near Niles and the Smoky Hill River near New Cambria were used to compute an average monthly flow into the model area on those rivers and these values are specified inflows to the stream network in the SFR package.

Wells in the model area were simulated in the model with the Well package in MODFLOW. Information on historic pumping for the wells in the model area were obtained from the WIMAS. Wells with use data available are shown by use type in Figure 26. Figure 27 shows the distribution of water use by the six water use categories. On average, municipal pumping accounts for approximately 58% of groundwater use in the model area, irrigation accounts for approximately 37% of the groundwater use in the model area, and industrial pumping accounts for less than 5% of the groundwater use in the model area. Stock wells, domestic wells, and recreation wells account for less than 0.5% of groundwater use in the model area. Given this extremely small contribution, these wells were ignored for the purpose of model construction.

The water use data that is available in WIMAS is the total water use for each year, and assumptions were required to distribute these data to monthly volumes. The monthly distribution of municipal, industrial, and irrigation pumping was done differently for each category to more accurately represent the actual pattern of those uses. Table 1 demonstrates the percentage of the annual total for each water use type for each month. The distribution of the municipal pumping was based on an assumption used for the Salina Model (Wilson, 2008), the distribution of the irrigation pumping was based on modeling experience, and the distribution of the industrial pumping was even throughout the year assuming that, on average, production rates would remain steady through a given year.

Table 1. Monthly distribution of groundwater pumping by water use type as a percent of the total annual use.

Type	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Municipal	6.3	6.3	6.3	10.3	10.3	10.3	10.3	10.3	10.3	6.3	6.3	6.3
Irrigation	0	0	0	0	0	20	40	40	0	0	0	0
Industrial	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3

Of particular importance to this model development is the water usage that was assumed for the city's production wells. Figure 28 and 29 show the monthly values used for the Sand Springs wells and the

River Alluvium wells, respectively. Figure 30 shows the total water withdrawal from all of the wells in the model by year.

The aquifer recharge was simulated using the MODFLOW Recharge package and was based on precipitation data collected by the National Oceanic and Atmospheric Administration at the Abilene weather station (Station number USC00140010). The process for translating precipitation to recharge was identical to that used for the Salina Model (Wilson, 2008). The data was summarized for six-month periods consisting of October to March (i.e., winter months) and April to September (i.e., summer months). There were relationships developed between total precipitation for each six month period and the resulting recharge that was used in the model simulation. Figures 31 and 32 document the recharge curves for the winter months and the summer months, respectively. For each time period there are curves for three terrains. The distribution of these terrains is shown in Figure 33. The annual distribution of recharge for the total model area is shown in Figure 34, and these values are compared to the annual total pumping in Figure 35. Outside of very dry years, total groundwater recharge is significantly greater than groundwater pumping.

Finally, the aquifer properties were specified within the Layer Property Flow (LPF) package of MODFLOW. Figure 36 shows the final hydraulic conductivity values for the model, which were developed through the calibration process described below.

3.3 Model Simulation and Calibration

Two transient simulations were conducted for the time period of January 1, 1990, through December 31, 2015. Monthly stress periods were used for a total of 312 stress periods in each simulation, with two time steps per stress period. This time period is appropriate for the purpose of this evaluation as it includes dry, average, and wet conditions. The purpose of the first transient simulation was solely to generate the starting heads for the final transient simulation. Initial heads in the model were set at the elevation of the top of layer one for the first transient simulation. Ending heads from this first simulation were used as initial heads for the second transient simulation. This modelling method improves calibration and gives the model more time steps to reach equilibrium.

The groundwater model simulations solve for changes in water levels due to changes in inputs to the model as well as changes to computed fluxes. This is done for defined periods of time known as stress periods. In this model the stress periods are monthly in length, so the model is computing water level surfaces and water fluxes that occur over an entire month in one step. In order for each of these solutions to be valid, the following equation should very nearly produce this equality:

Recharge (from Precipitation) + Lateral Flow into Aquifer = *Well Pumping* + Lateral Flow out of Aquifer + Discharge to Streamflow + Change in Aquifer Storage

The italicized terms in this equation are the inputs to the model. These are specified amounts that are fed directly into the model as described above. The underlined terms are those that are solved by the model. The lateral flow into and out of the aquifer is computed based on water levels near the boundaries and specifications in the GHB package in MODFLOW that was described above. The discharge to streamflow is computed based on water levels in the aquifer and the stage in the stream, as well as specification in the SFR package in MODFLOW. The change in aquifer storage represents spatially summed changes in water levels, which depends on the specified terms in the equation above as well as the aquifer properties that are specified in the LPF package of MODFLOW.

The process of calibrating the model involves comparing known information to information generated by the model. For this model there is information that can represent the discharge to streams and the change in aquifer storage terms in the equation above. Known information regarding streamflows in the model area is discussed in section 2.2. Figure 4 shows the increase in streamflow that occurs between the upstream edge of the groundwater model domain and the downstream edge of the groundwater model domain. These additions to streamflow come from two sources; overland runoff during storm events, and discharge to the stream from the aquifer. The latter source is typically referred to as baseflow and is the portion of the gain in streamflows that the model can simulate. Figure 37 shows the discharge from the aquifer to the Solomon and Smoky Hill Rivers and their tributaries that is simulated by the model. Negative values indicate a net loss of water from the stream to the aquifer.

In order to get a better comparison of the model simulated baseflow with the measured total flows, the data for both were first averaged by month and then these monthly averages were used to compute average annual monthly flows (Figure 38). The most applicable comparison between measured streamflows and modeled baseflow is during low flow conditions when the vast majority of streamflow is coming from baseflow. As can be seen in Figure 38, simulated baseflows compare well with measured streamflows during the years with the lowest average annual monthly streamflows.

The second comparison that can be made between known information and information generated by the model is water level data. There is a rich dataset available for this from measurements taken by city staff over the years that span this model simulation. These comparisons are typically presented both statistically and visually.

Table 2. Calibration statistics for observed vs. modeled water levels in the Abilene model area.

Statistic	Value
Residual Mean (ft)	-2.11
Residual Standard Deviation (ft)	10.02
Absolute Residual Mean (ft)	7.42
Residual Sum of Squares	9.35×10^{-5}
Root Mean Square Error (ft)	10.24
Minimum Residual (ft)	-24.91
Maximum Residual (ft)	39.87
Range of Observations (ft)	101.12
Scaled Residual Standard Deviation	0.099
Scaled Absolute Mean	0.073
Scaled RMS	0.101
Number of Observations	8911

The term residual is commonly used to represent the difference between the simulated and the observed water level. The two common statistics of this residual are the residual mean and the absolute residual mean. The absolute residual mean is an indication of the average error between observed and simulated water levels, and residual mean indicates whether and to what extent that error is biased. For this model, the residual mean is -2.11 feet and the absolute residual mean is 7.42 feet. These values are well within industry standards, indicating the model is able to adequately represent water level changes in the aquifer.

Appendix A contains a hydrograph for each of the wells used for model calibration. As can be seen, the pattern of water level changes is well represented in all wells and the absolute value is also well represented in most wells.

4.0 ACRONYMS AND ABBREVIATIONS

KGS	Kansas Geological Survey
AMSL	Above Mean Sea Level
gpm	gallons per minute
WIMAS	Water Information Management and Analysis System

5.0 REFERENCES

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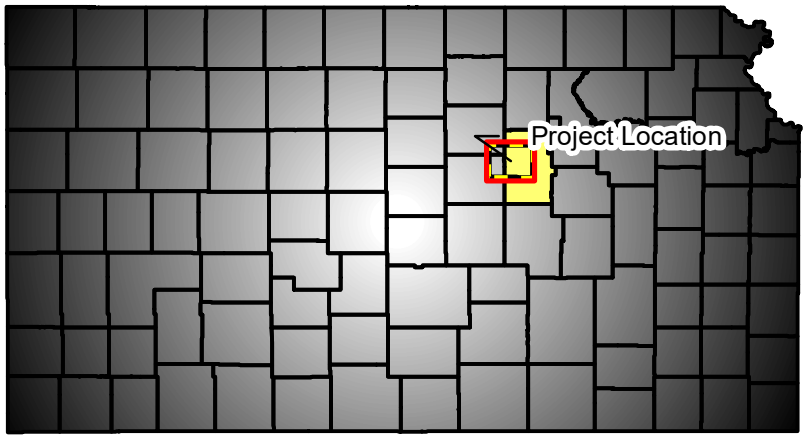

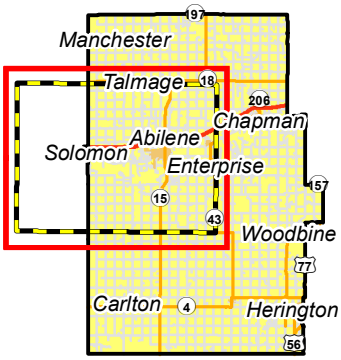

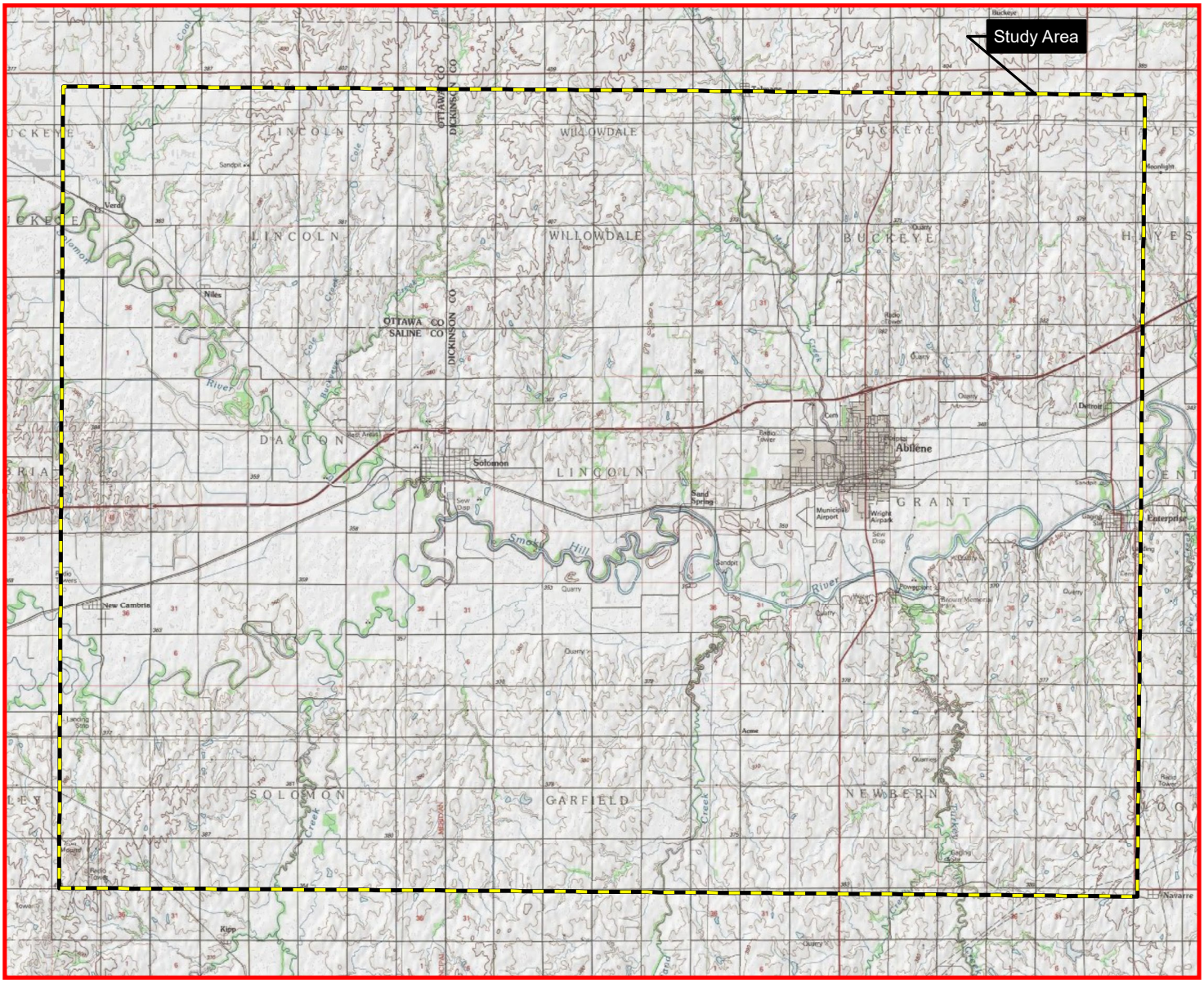

OLSSON ASSOCIATES

N

0 4,250 8,500 17,000

1 " = 16,321 '

Original Published Resolution

WGS 1984 ARC System Zone 11

ESRI USA Topographic Map

Project Location Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

1

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USCB TIGER Line shapefiles 2015

USCB TIGER Line shapefiles 2015

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0 3,100 6,200 12,400

1 " = 12,321 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Feet

ESRI World Imagery

Detailed Location Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

2

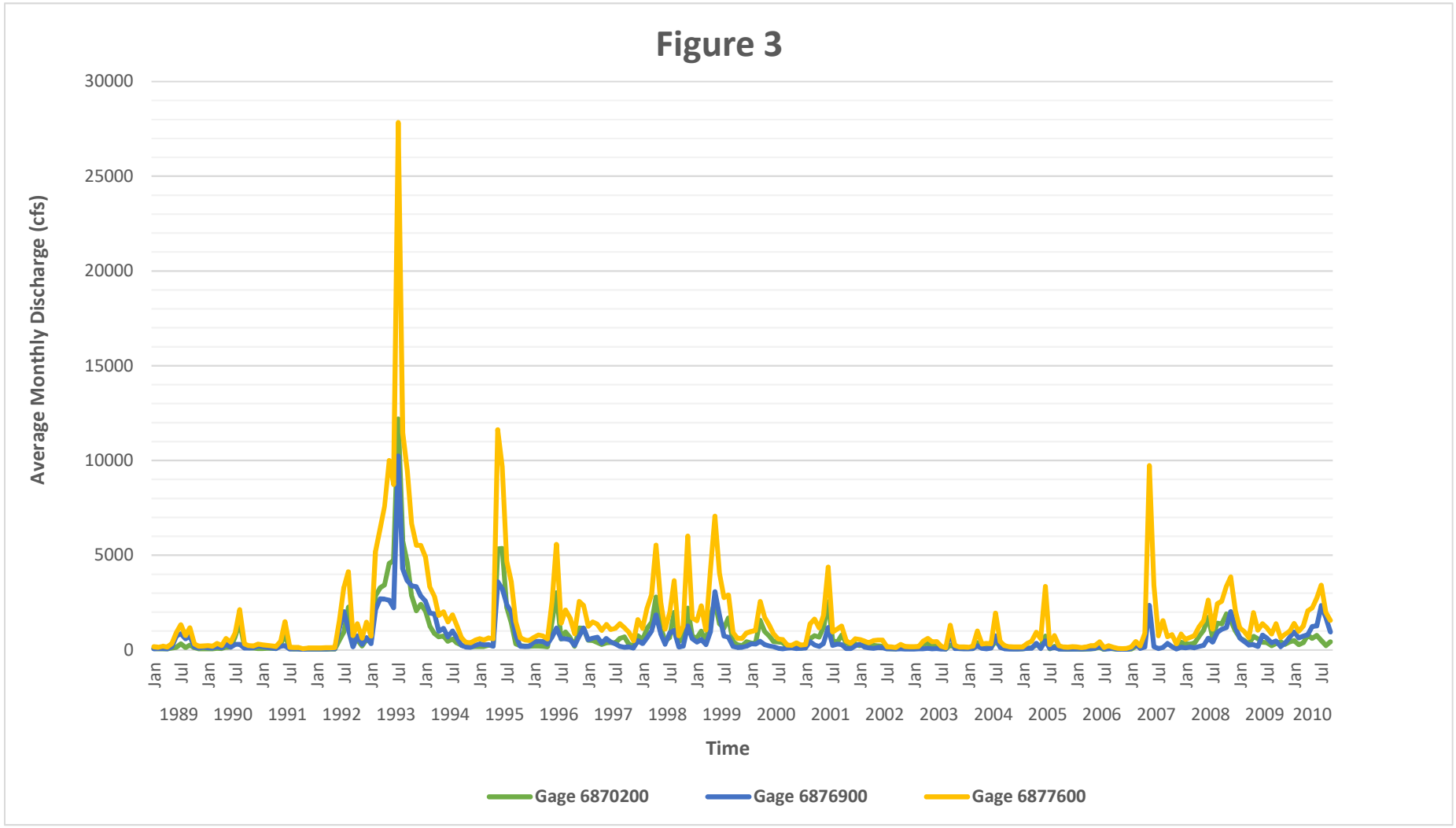


Figure 3. Historic monthly discharge measurements at United States Geological Survey streamgage locations within the Abilene model boundary.

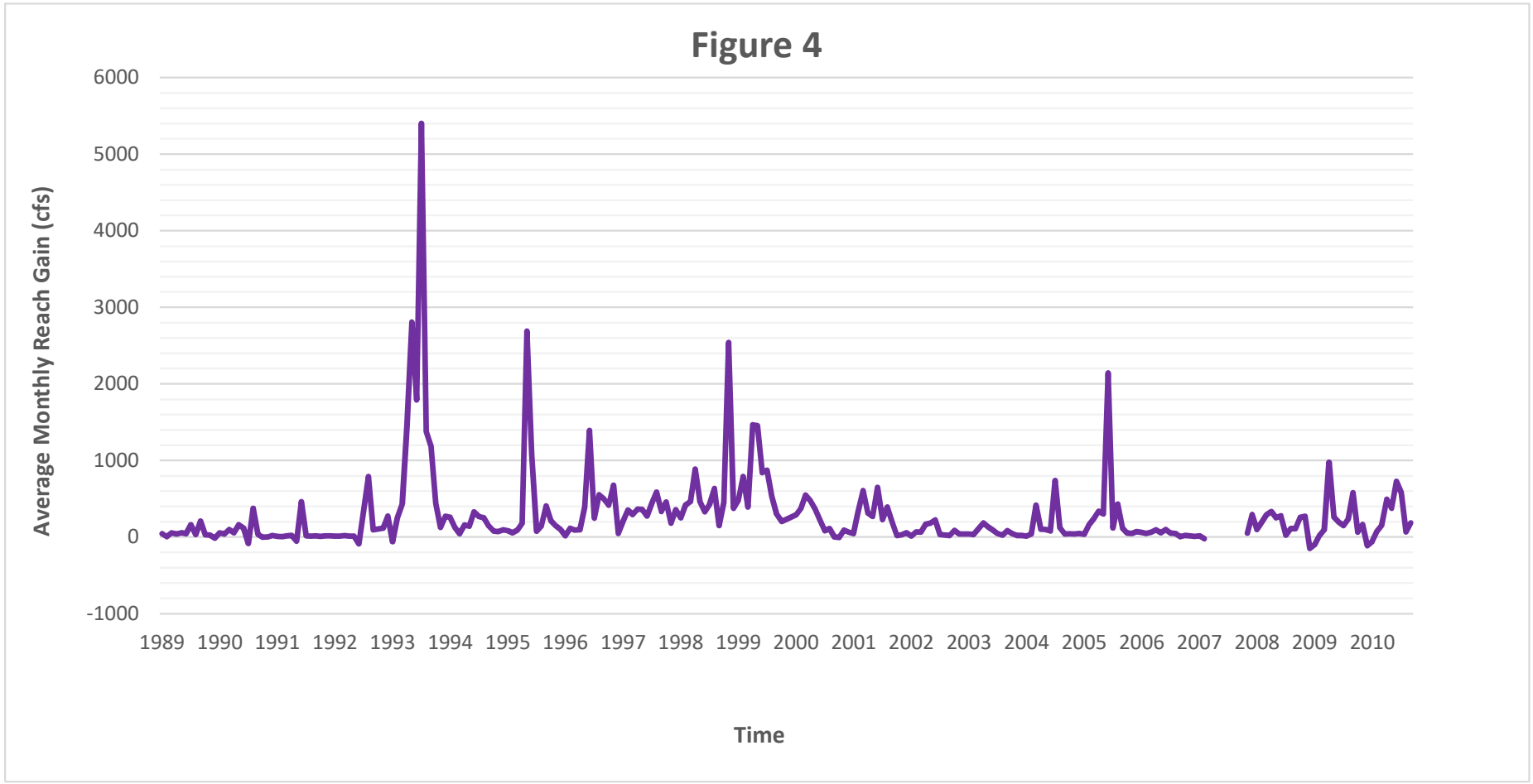
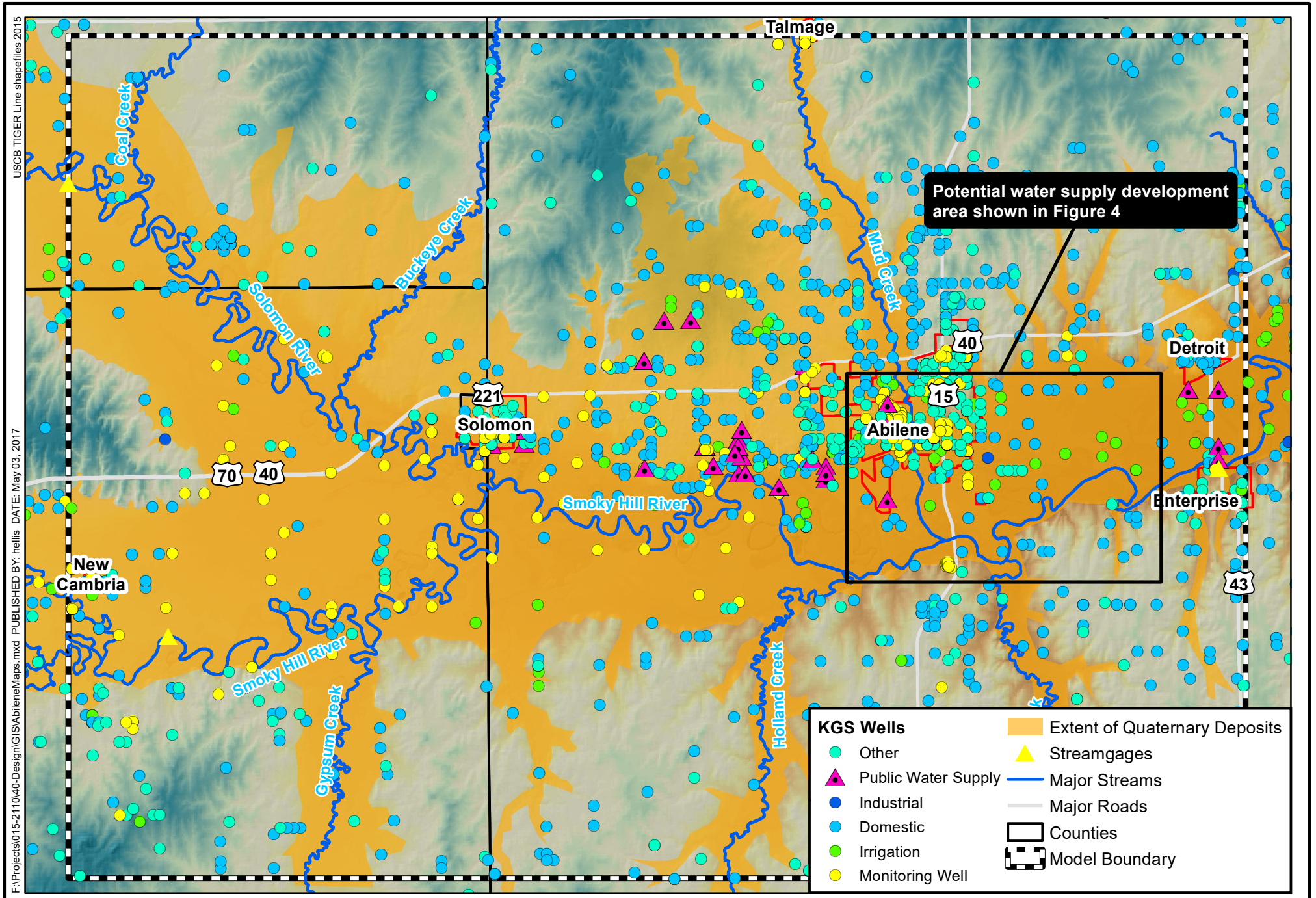


Figure 4. Average monthly reach gain for the Smoky Hill River within the Abilene model boundary developed from streamgage data.



USCB TIGER Line shapefiles 2015

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OLSSON ASSOCIATES

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1 " = 12,321 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Feet

ESRI World Imagery

NOTE: The well locations on this map were estimated from location information provided in the Kanas Geological Survey Kansas Water Wells database (kgs.ku.edu). The locations are estimated to the nearest quarter mile.

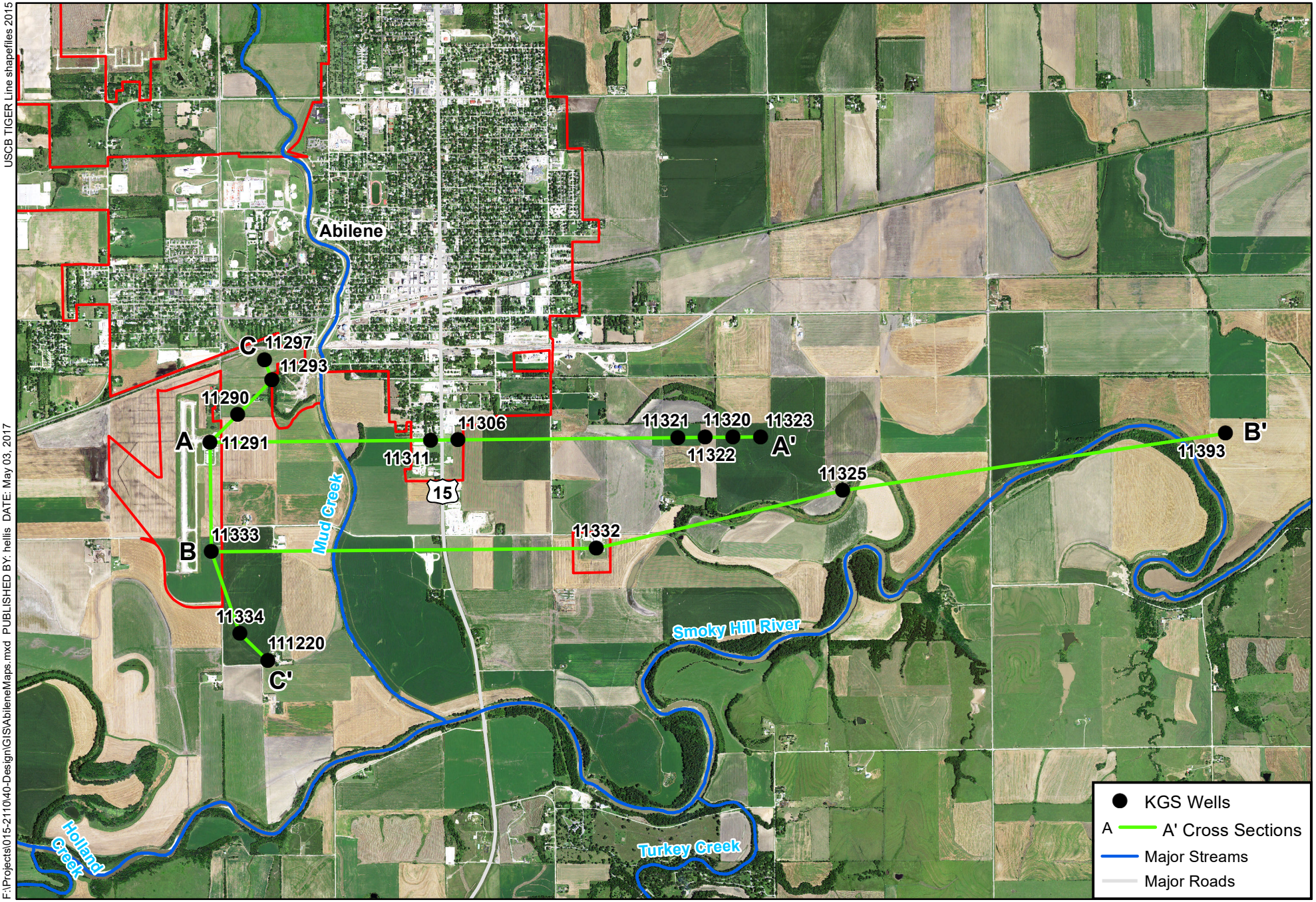
KGS Wells and Quaternary Deposits Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

5



F:\Projects\015-211040-Design\GIS\AbileneMaps.mxd PUBLISHED BY: hellis DATE: May 03, 2017

USCB TIGER Line shapefiles 2015

OLSSON ASSOCIATES

N

0 800 1,600 3,200

1 " = 3,094 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Feet

ESRI World Imagery

NOTE: The well locations on this map were estimated from location information provided in the Kanas Geological Survey Kansas Water Wells database (kgs.ku.edu). The locations are estimated to the nearest quarter mile.

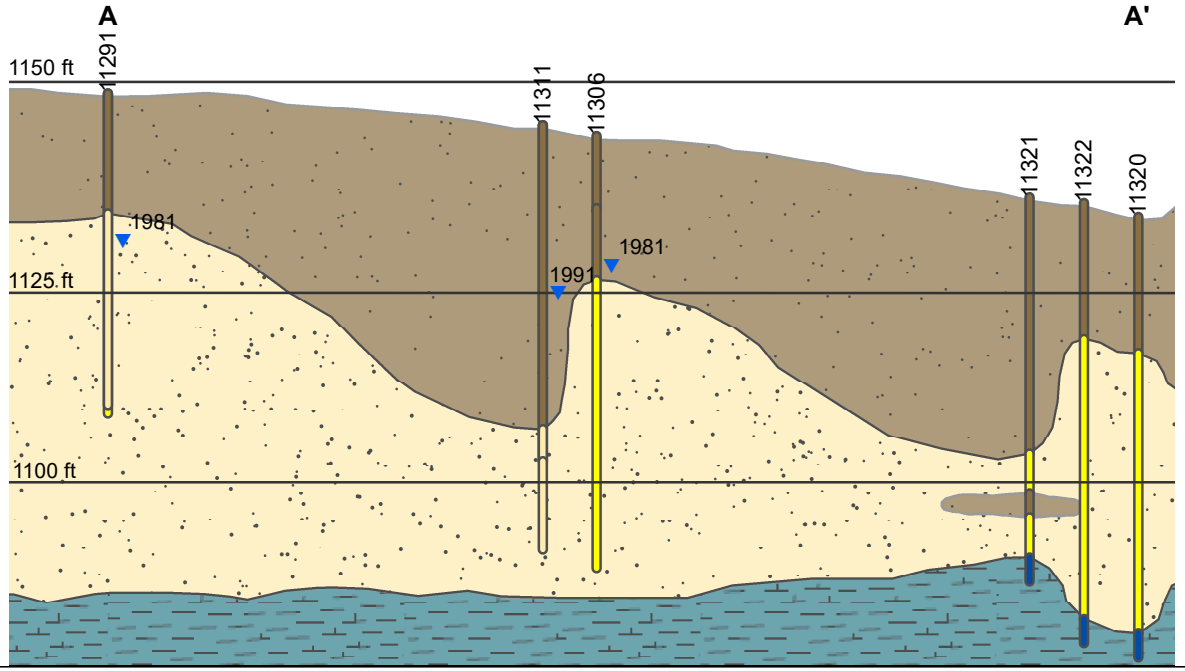
Geologic Cross-Sections Map

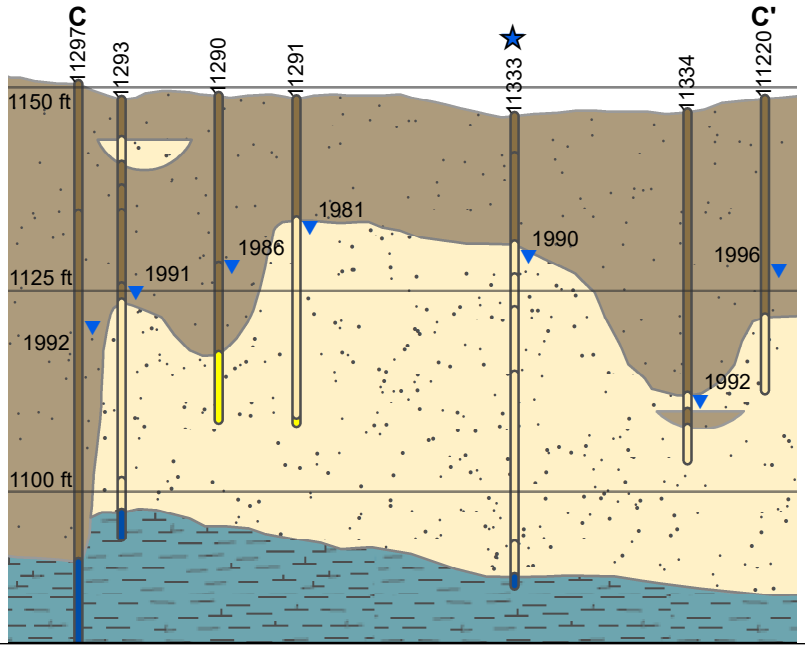
Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

6





Clay

Sand

Gravel

Bedrock

Water Level Measurement After Well Construction

City Well

Silt and Clay

Sand and Gravel

Bedrock

USCB TIGER Line shapefiles 2015

C:\Abilene\GIS\Xsection3.mxd PUBLISHED BY: cosborn DATE: May 04, 2017

OLSSON ASSOCIATES

N

0 600 1,200 2,400

1 " = 2,361 '

Original Published Resolution

ESRI World Imagery

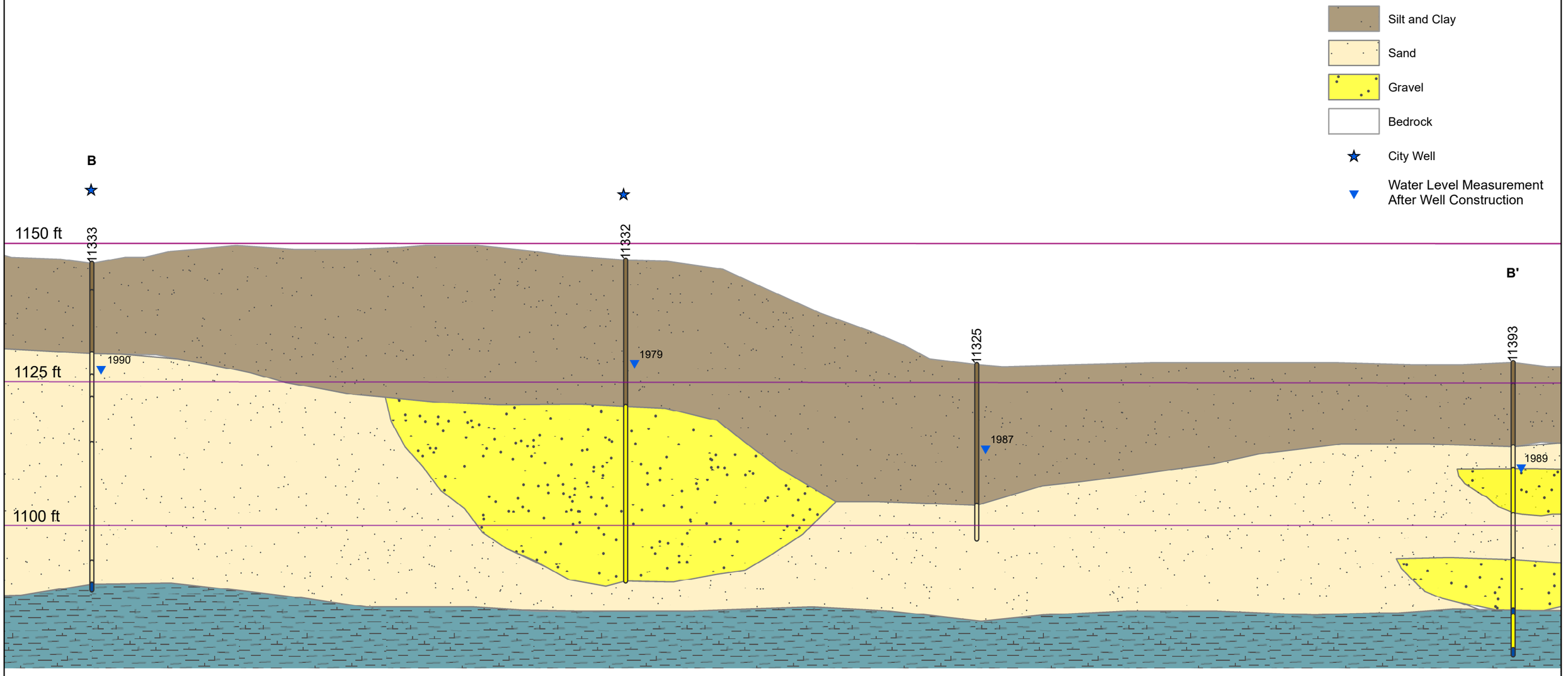
NOTE: The well locations on this cross section were estimated from location information provided in the Kansas Geological Survey Kansas Water Wells database (kgs.ku.edu) . The locations are estimated to the nearest quarter mile.

Cross-Section A-A' and C-C'

Hydrogeologic Evaluation Report
City of Abilene, Kansas

FIGURE

7



OLSSON ASSOCIATES

N

0 550 1,100 2,200 Feet

1 " = 1,669 '
Original Published Resolution
WGS 1984 UTM Zone 14N
USGS Topographic Map

NOTE: The well locations on this cross section were estimated from location information provided in the Kansas Geological Survey Kansas Water Wells database (kgs.ku.edu) . The locations are estimated to the nearest quarter mile.

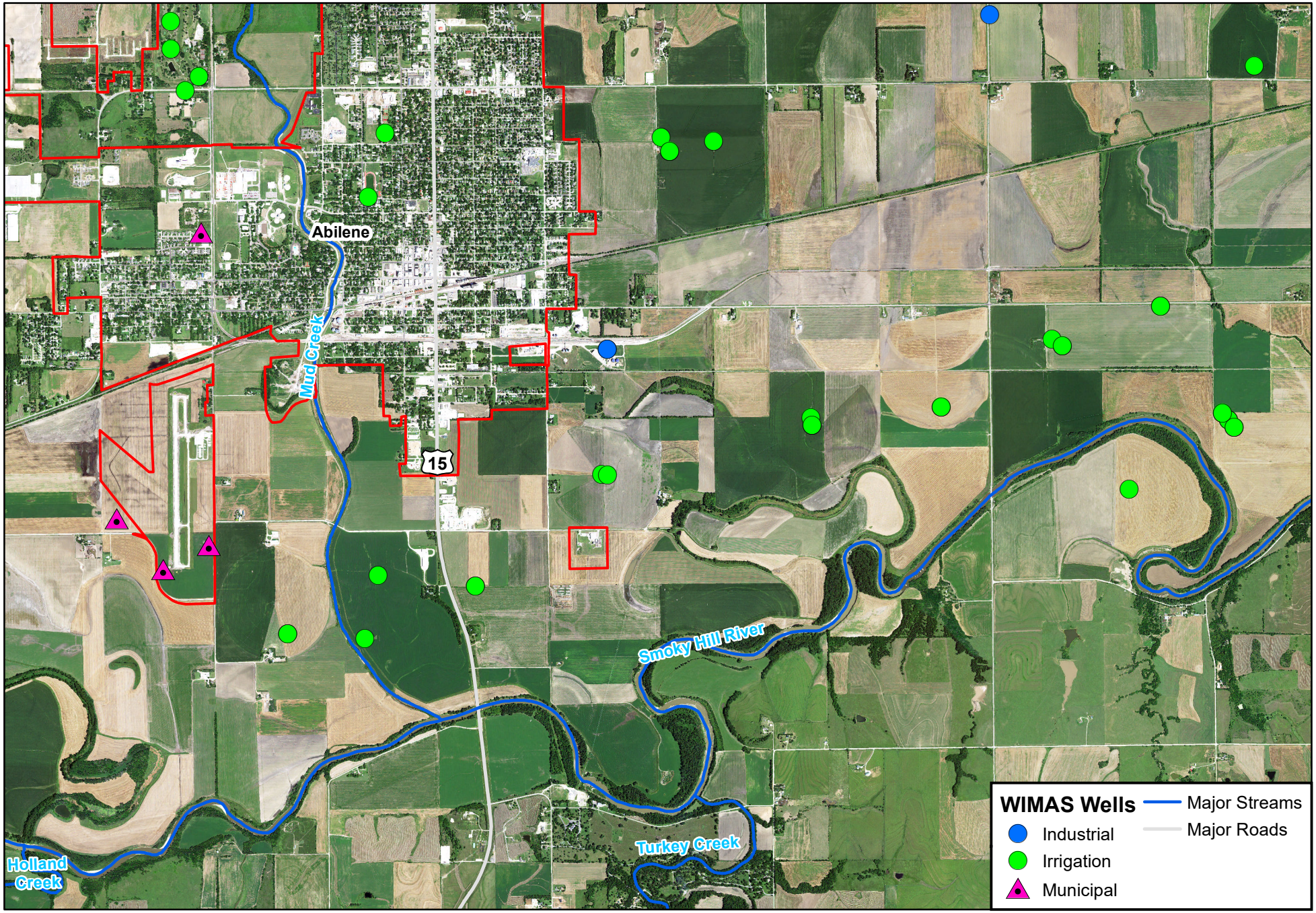
Cross-Section B-B'

Hydrogeologic Evaluation Report
City of Abilene, Kansas

FIGURE

8

C:\Abilene\GIS\Xsection3.mxd PUBLISHED BY: cosborn DATE: May 04, 2017



F:\Projects\015-21110\40-Design\GIS\AbileneMaps-BS6.mxd PUBLISHED BY: mmorton DATE: February 19, 2018

USCB TIGER Line shapefiles 2015

OLSSON ASSOCIATES

N

0 800 1,600 3,200

1 " = 3,094 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Feet

ESRI World Imagery

NOTE: The well locations on this map were estimated from location information provided in the Water Information Management and Analysis System database (kgs.ku.edu). The locations are estimated to the nearest quarter mile.

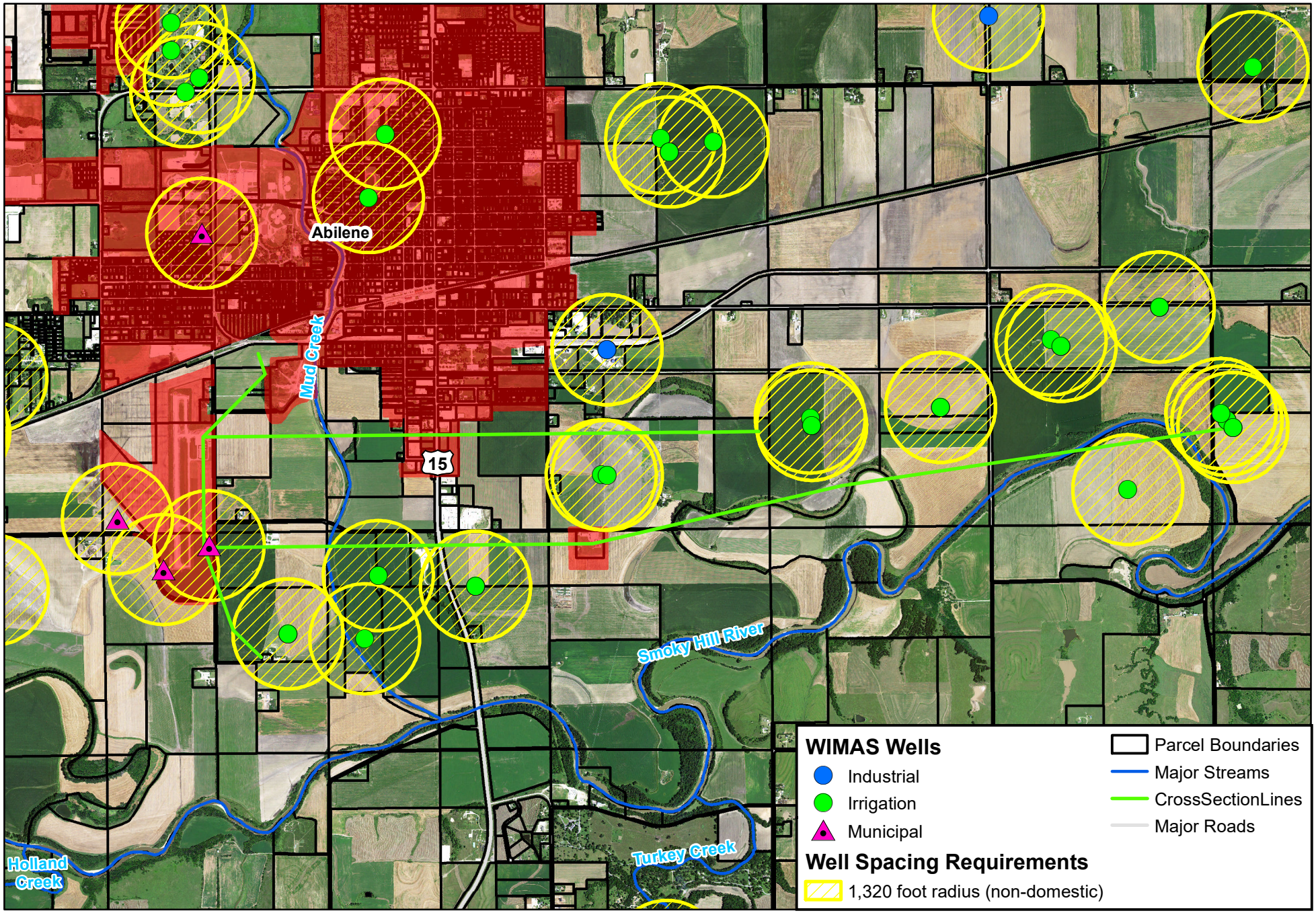
Existing Permitted Wells Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

9



USCB TIGER Line shapefiles 2015

F:\Projects\015-2110\40-Design\GIS\AbileneMaps-BS6.mxd PUBLISHED BY: mmorton DATE: February 19, 2018

OLSSON ASSOCIATES

N

0 800 1,600 3,200

1 " = 3,098 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

NOTE: The well locations on this map were estimated from location information provided in the Water Information Management and Analysis System database (kgs.ku.edu). The locations are estimated to the nearest quarter mile.

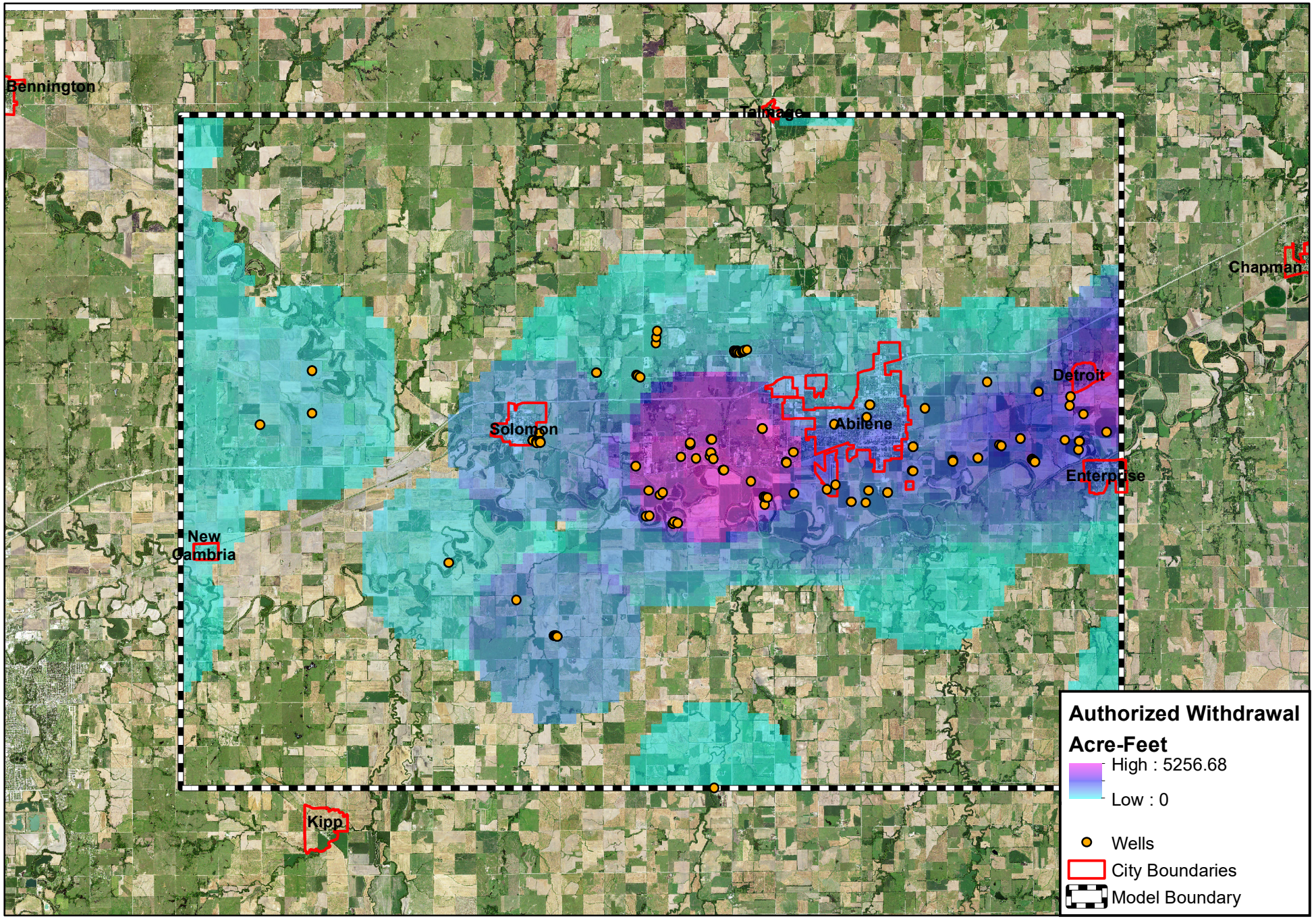
Existing Developed Well Spacing Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

10



USCB TIGER Line shapefiles 2015

F:\Projects\015-2110\40-Design\GIS\AbileneMaps-BS5.mxd PUBLISHED BY: bstarns DATE: February 19, 2018

OLSSON ASSOCIATES

N

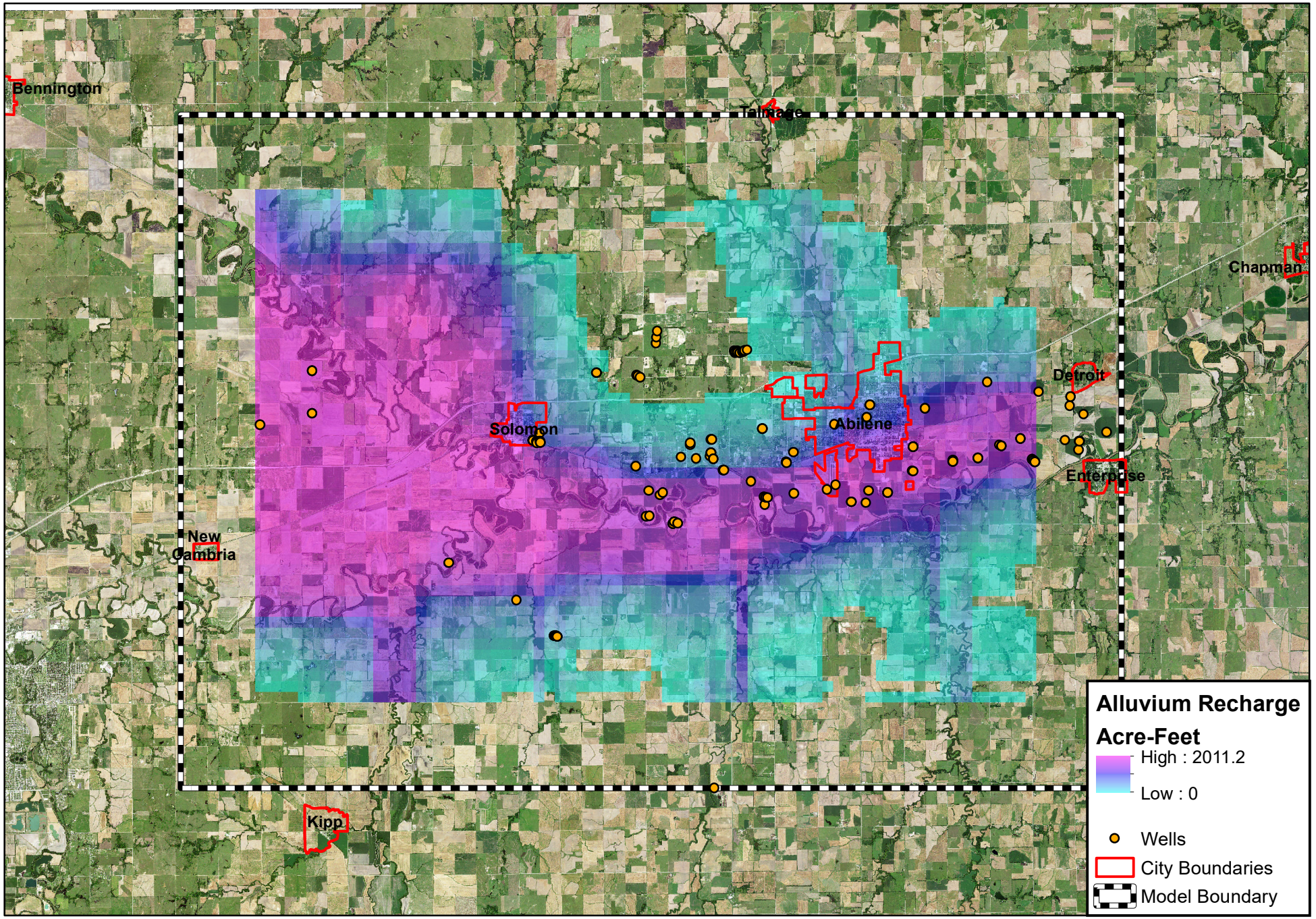
0 4,000 8,000 16,000

1 " = 16,000 '
Original Published Resolution
NAD 1983 StatePlane Kansas North FIPS 1501 Fee
ESRI World Imagery

Authorized Withdrawal
Hydrogeologic Evaluation Report
City of Abilene, Kansas

FIGURE

11



USCB TIGER Line shapefiles 2015

F:\Projects\015-2110\40-Design\GIS\AbileneMaps-BS5.mxd PUBLISHED BY: bstarns DATE: February 19, 2018

OLSSON ASSOCIATES

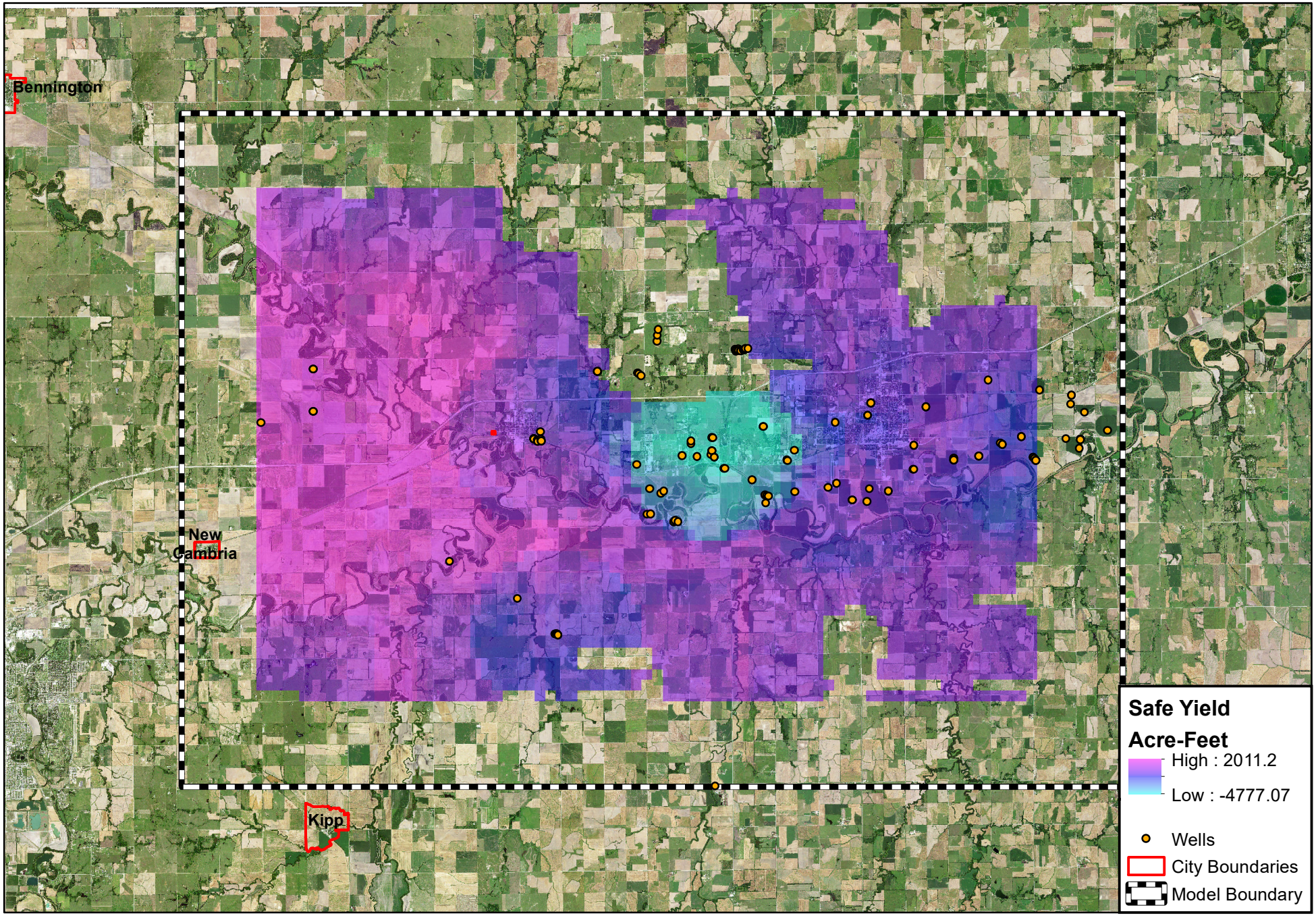
N

0 4,000 8,000 16,000

1 " = 16,000 '
Original Published Resolution
NAD 1983 StatePlane Kansas North FIPS 1501 Fee
ESRI World Imagery

Alluvium Recharge Map
Hydrogeologic Evaluation Report
City of Abilene, Kansas

FIGURE
12



USCB TIGER Line shapefiles 2015

F:\Projects\015-2110\40-Design\GIS\AbileneMaps-BS2.mxd PUBLISHED BY: bstarns DATE: February 19, 2018

OLSSON ASSOCIATES

N

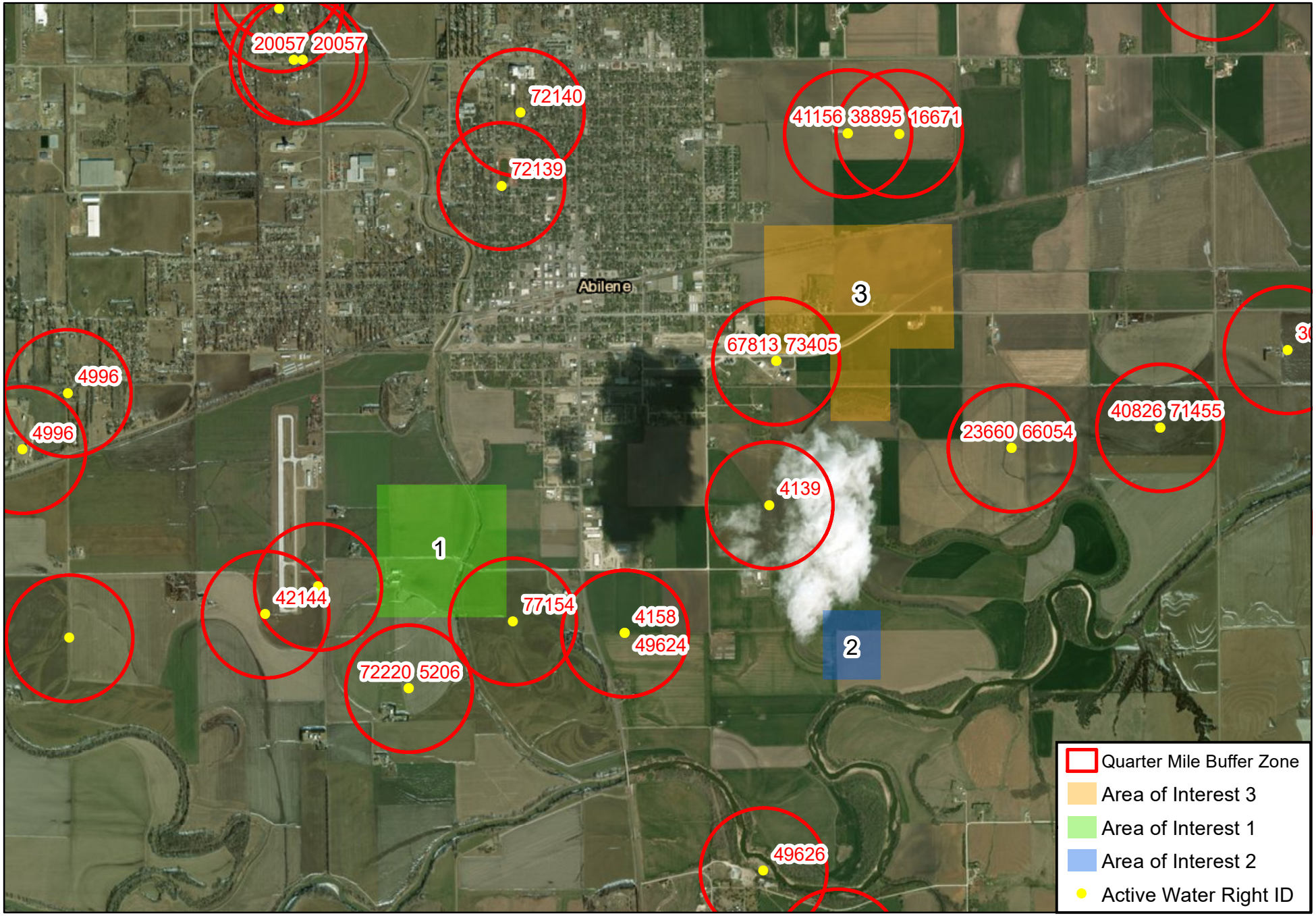
0 4,000 8,000 16,000

1 " = 16,000 '
Original Published Resolution
NAD 1983 StatePlane Kansas North FIPS 1501 Fee
ESRI World Imagery

Safe Yield Map
Hydrogeologic Evaluation Report
City of Abilene, Kansas

FIGURE

13



C:\Users\bstarns\Desktop\Abilene\Well_Locations.mxd PUBLISHED BY: bstarns DATE: February 19, 2018

USCB TIGER Line shapefiles 2015

OLSSON ASSOCIATES

N

0 650 1,300 2,600

1 " = 2,700 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

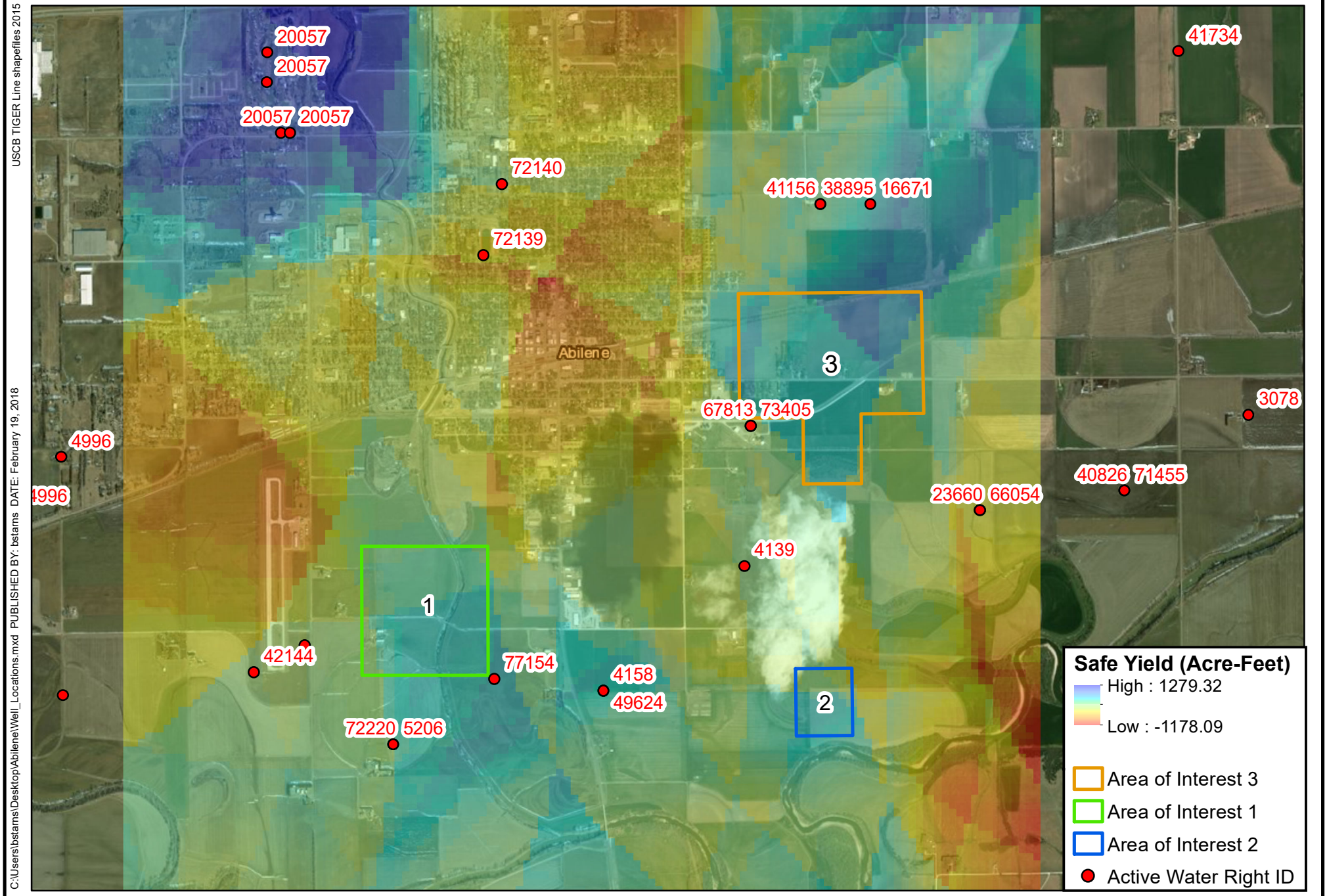
Well Locations

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

14



USCB TIGER Line shapefiles 2015

C:\Users\bstarns\Desktop\Abilene\Well_Locations.mxd PUBLISHED BY: bstarns DATE: February 19, 2018

OLSSON ASSOCIATES

N

0 650 1,300 2,600

1 " = 2,700 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

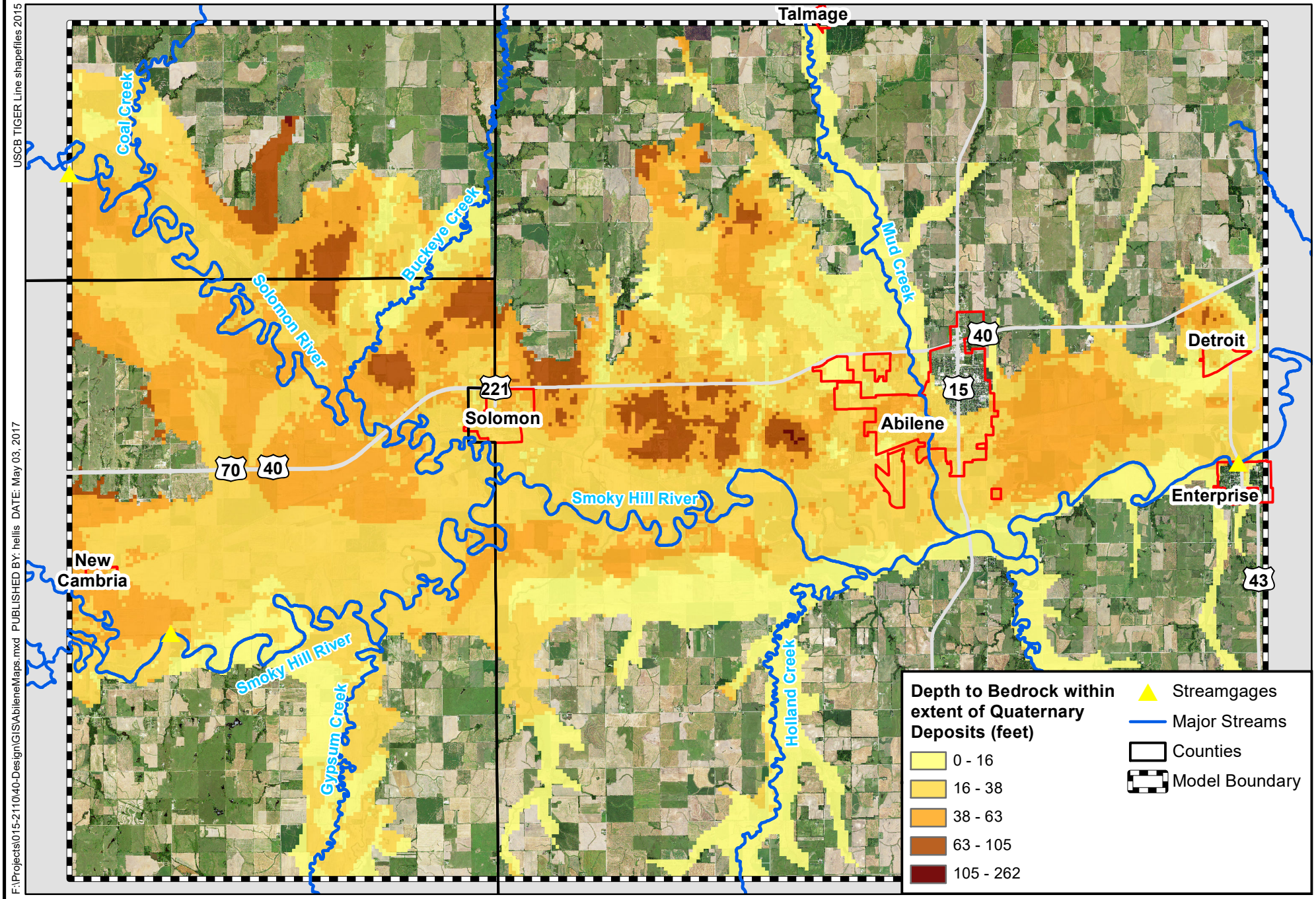
Safe Yield

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

15



F:\Projects\015-211040-Design\GIS\AbileneMaps.mxd PUBLISHED BY: hellis DATE: May 03, 2017

USCB TIGER Line shapefiles 2015

OLSSON ASSOCIATES

N

0 3,100 6,200 12,400

1 " = 12,321 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Feet

ESRI World Imagery

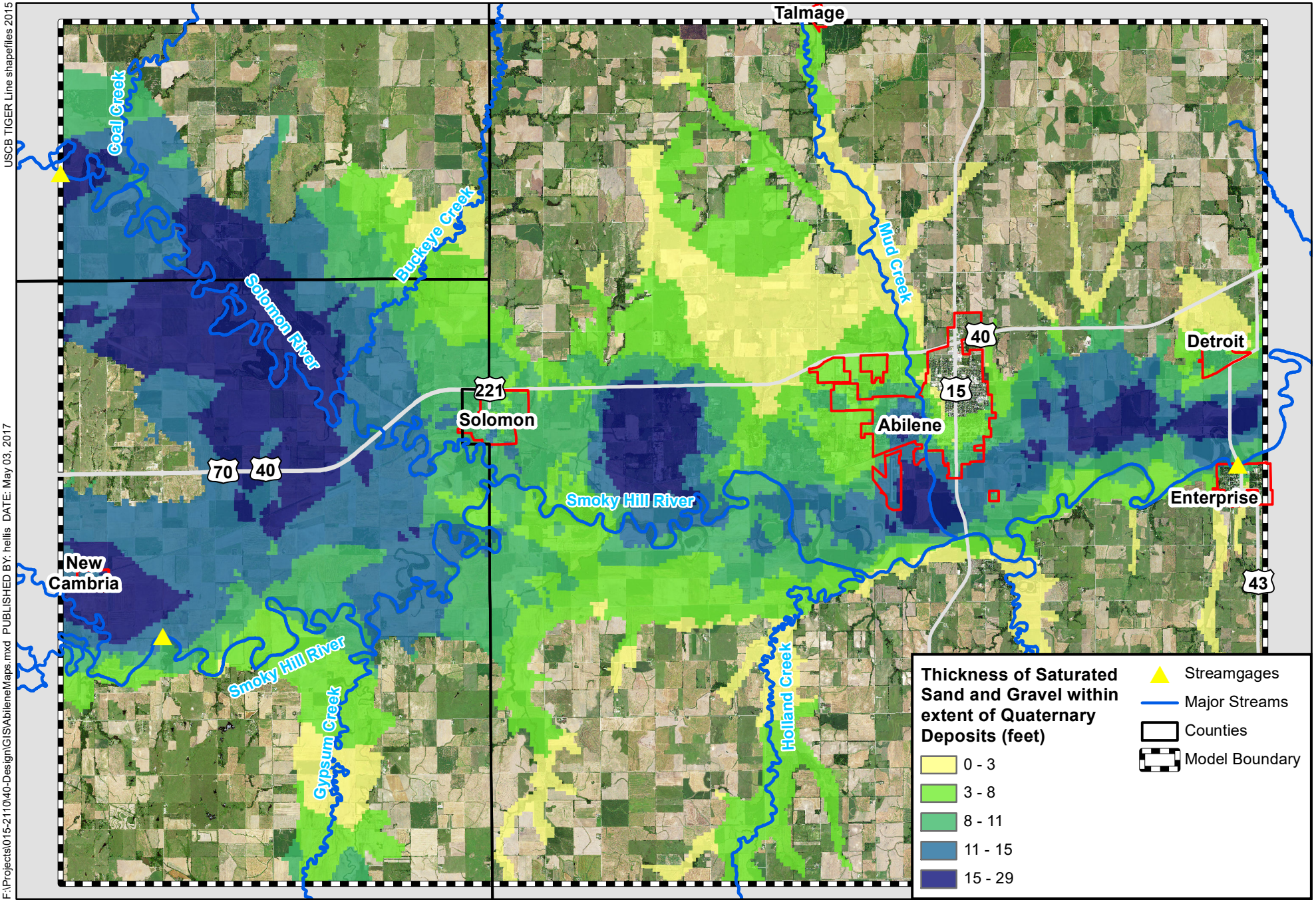
Depth to Bedrock Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

16



USCB TIGER Line shapefiles 2015

F:\Projects\015-211040-Design\GIS\AbileneMaps.mxd PUBLISHED BY: hellis DATE: May 03, 2017

OLSSON ASSOCIATES

N

0 3,100 6,200 12,400

1 " = 12,321 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Feet

ESRI World Imagery

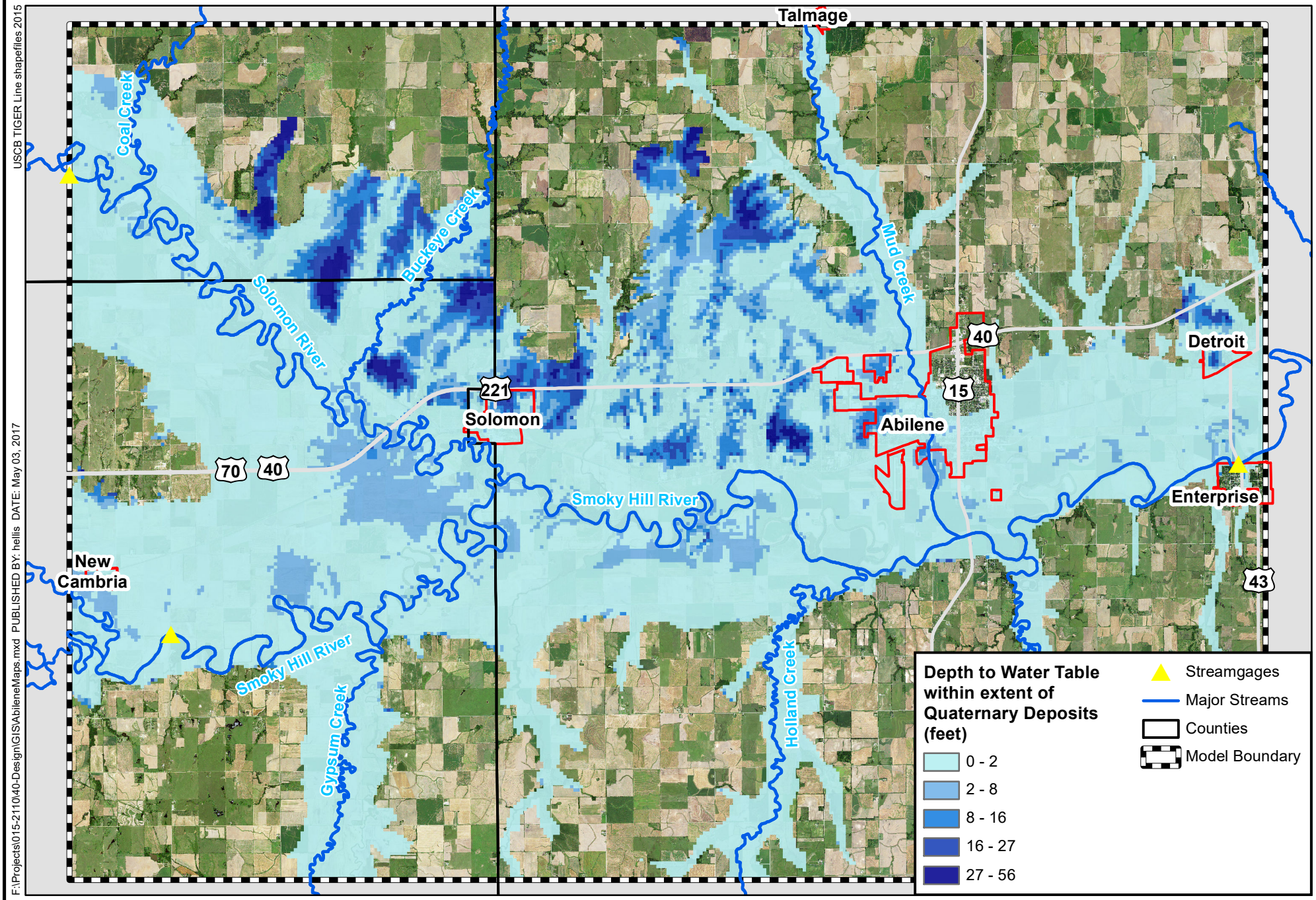
Thickness of Saturated Sand and Gravel Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

17



USCB TIGER Line shapefiles 2015

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OLSSON ASSOCIATES

N

0 3,100 6,200 12,400

1 " = 12,321 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Feet

ESRI World Imagery

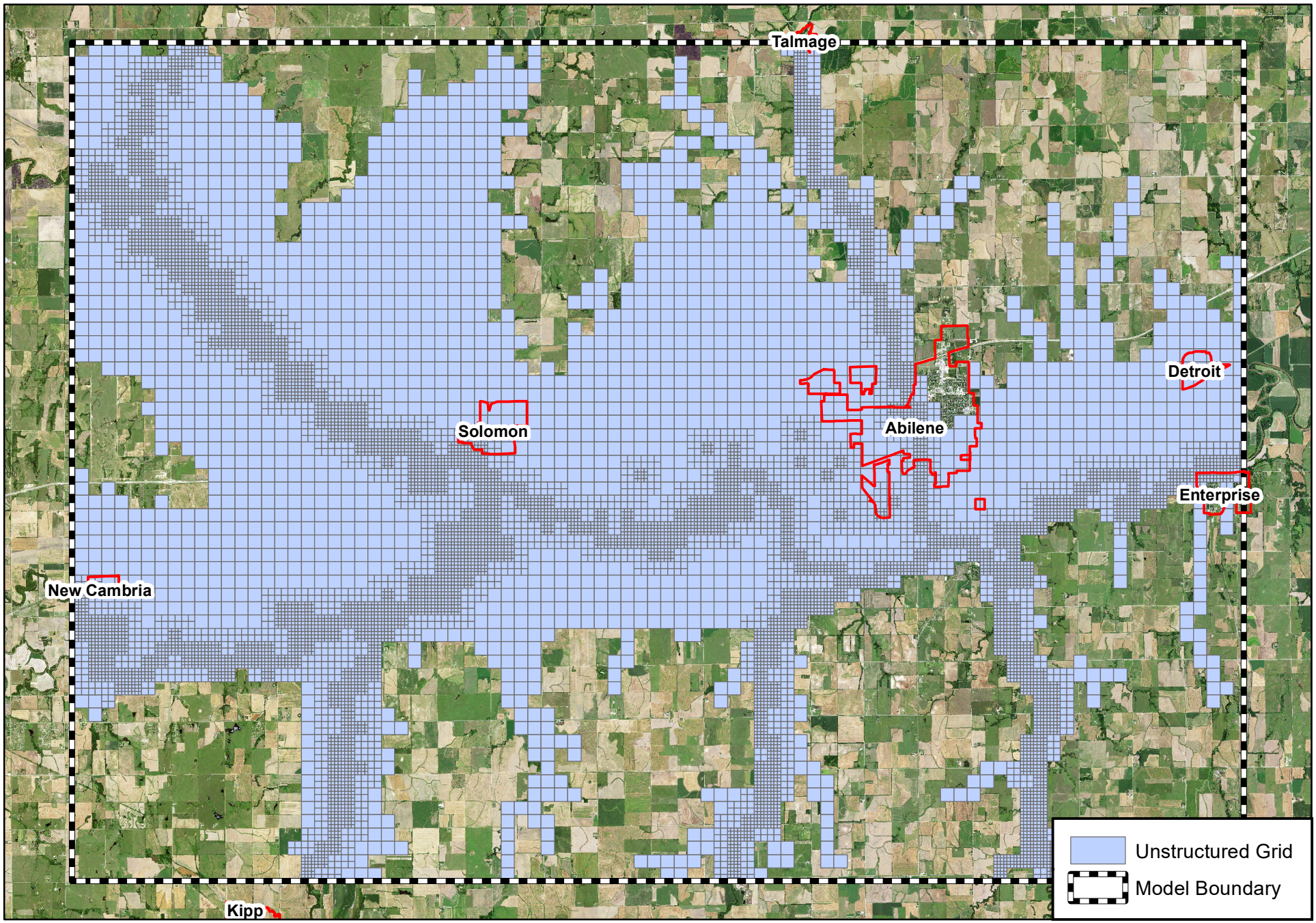
Water Table Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

18



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 08, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

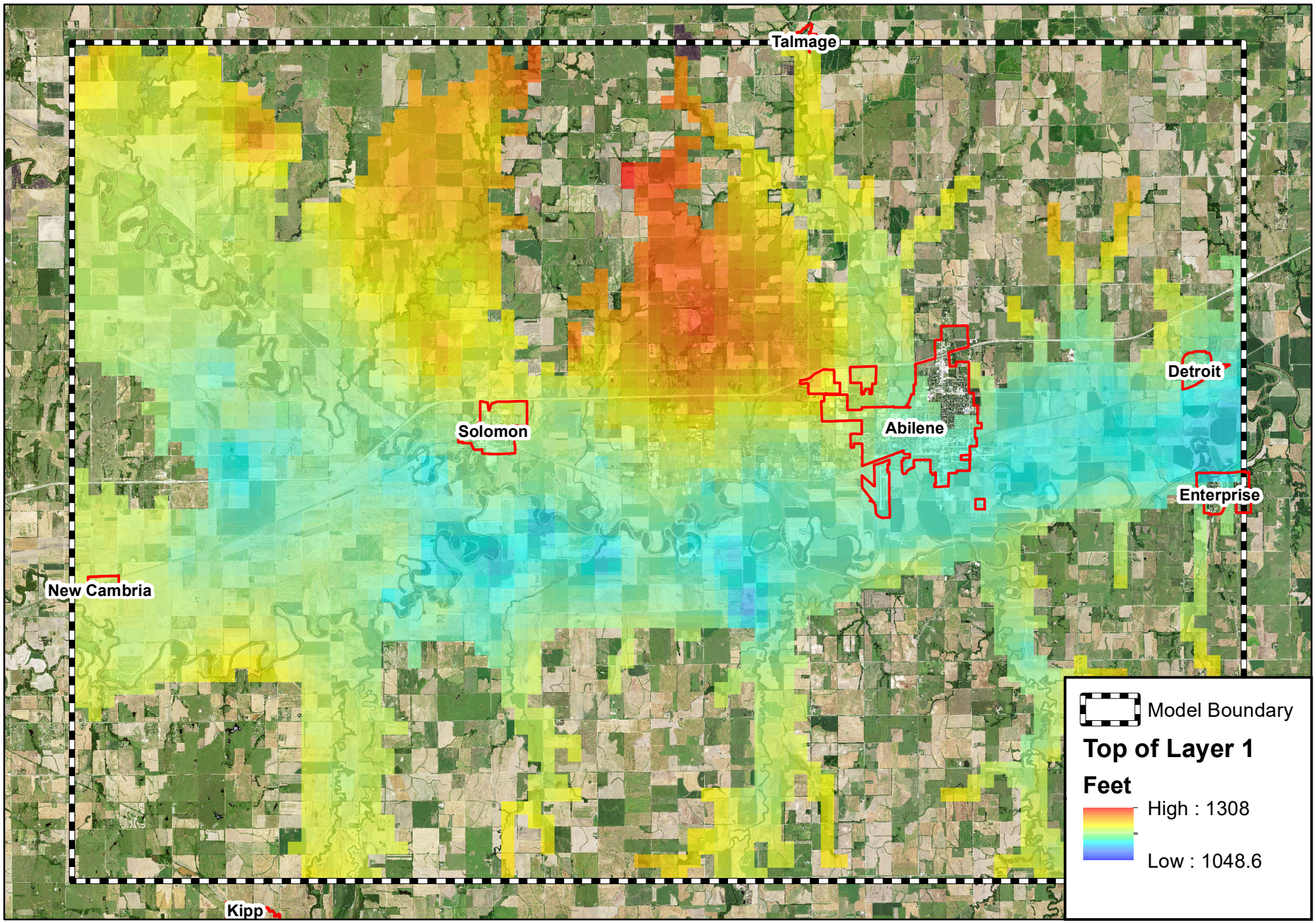
Unstructured Model Grid

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

19



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 08, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

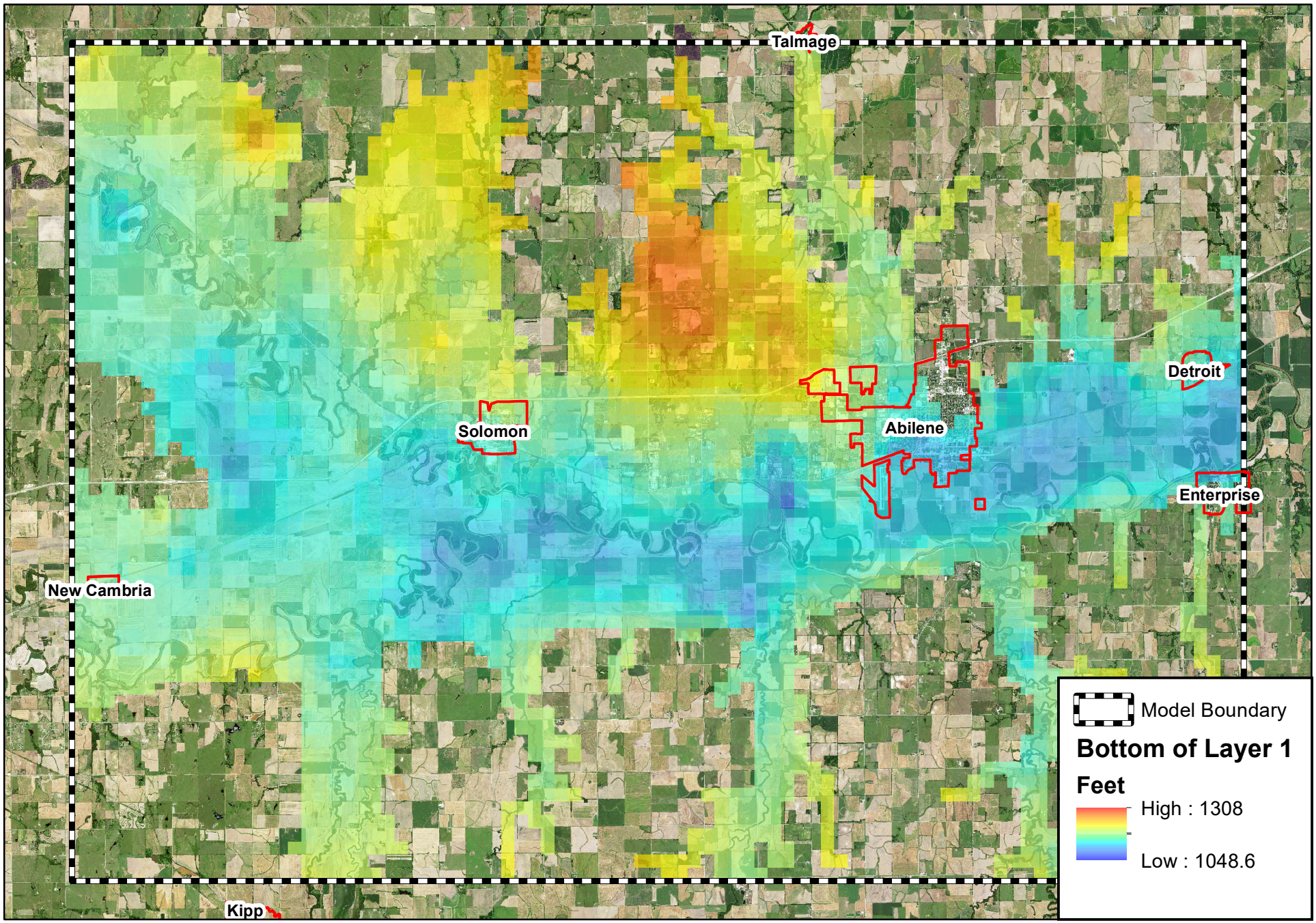
Top of Layer 1

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

20



USCB TIGER Line shapefiles 2015

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OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

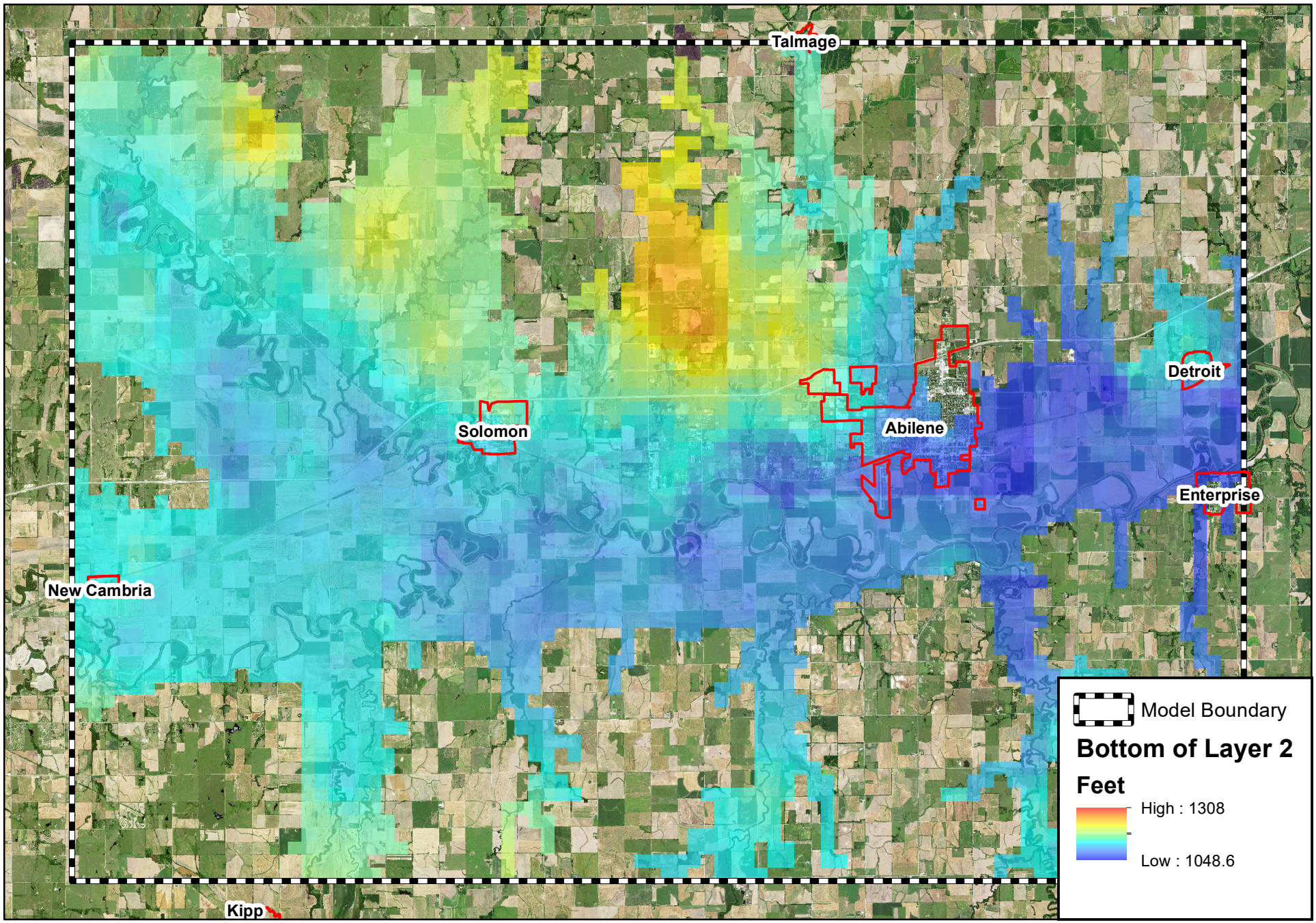
Bottom of Layer 1

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

21



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 08, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

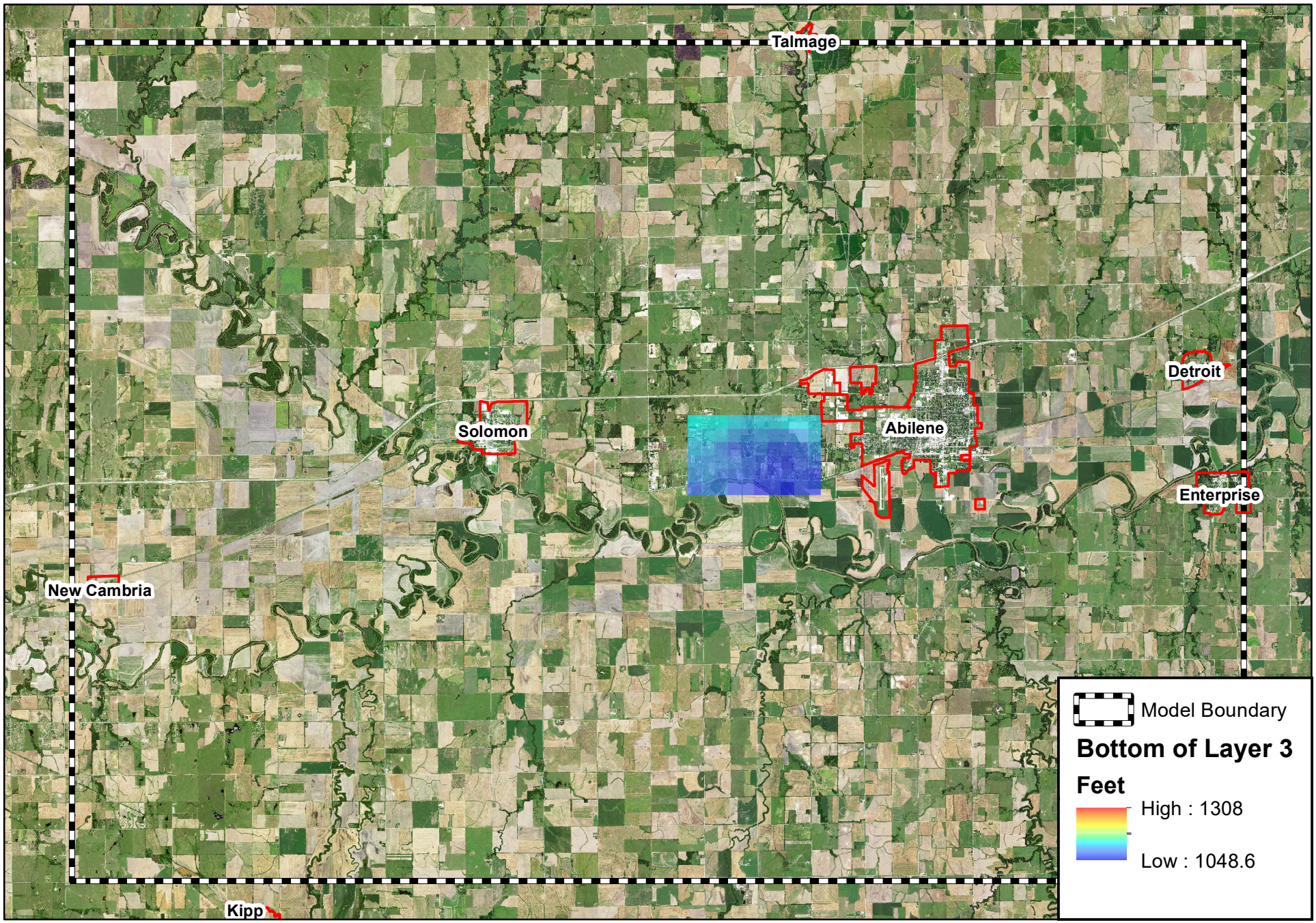
Bottom of Layer 2

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

22



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 08, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

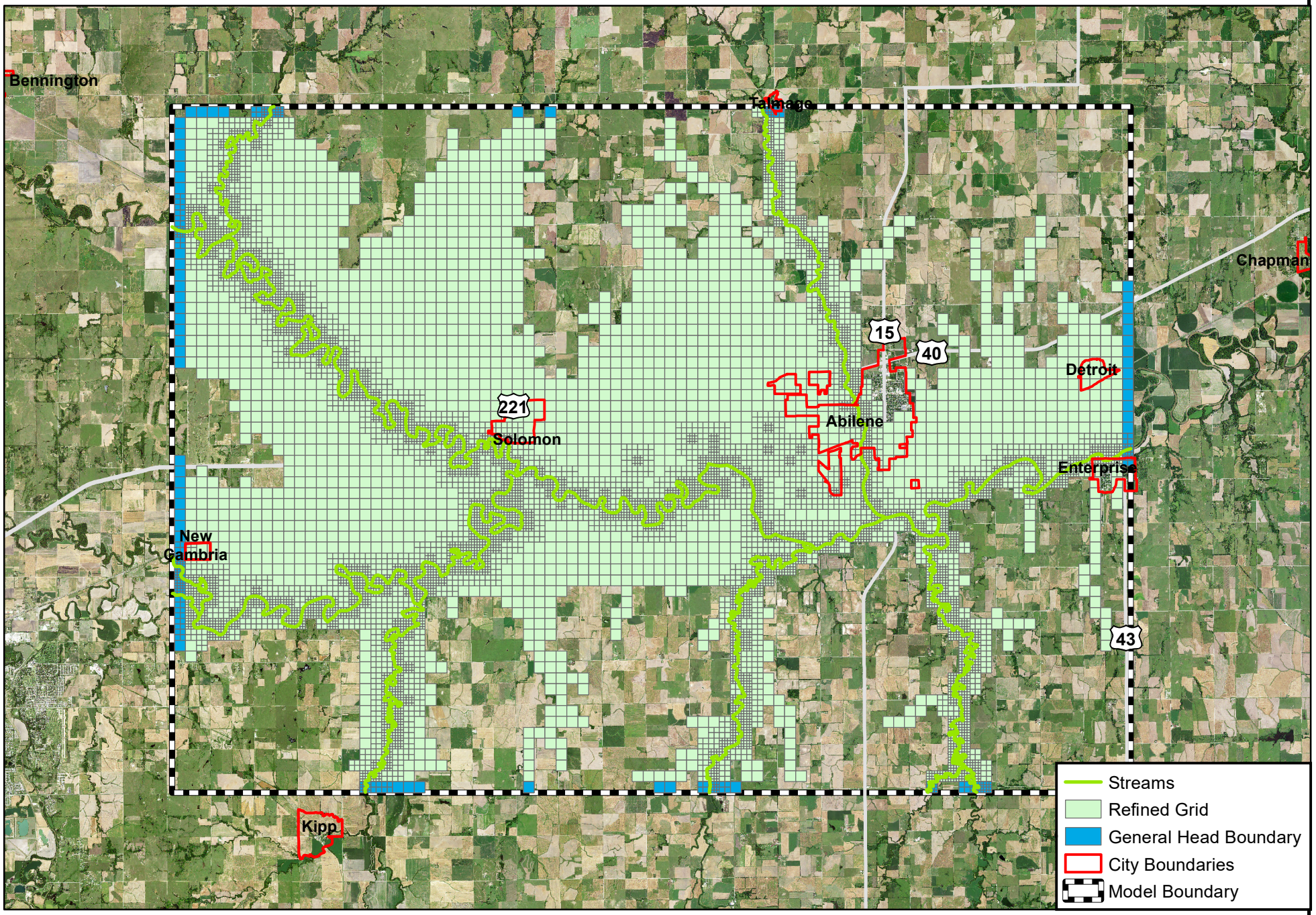
Bottom of Layer 3

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

23



USCB TIGER Line shapefiles 2015

F:\Projects\015-2110\40-Design\GIS\AbileneMaps-BS.mxd PUBLISHED BY: bstarns DATE: January 26, 2018

OLSSON ASSOCIATES

N

0 3,950 7,900 15,800

1 " = 15,614 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

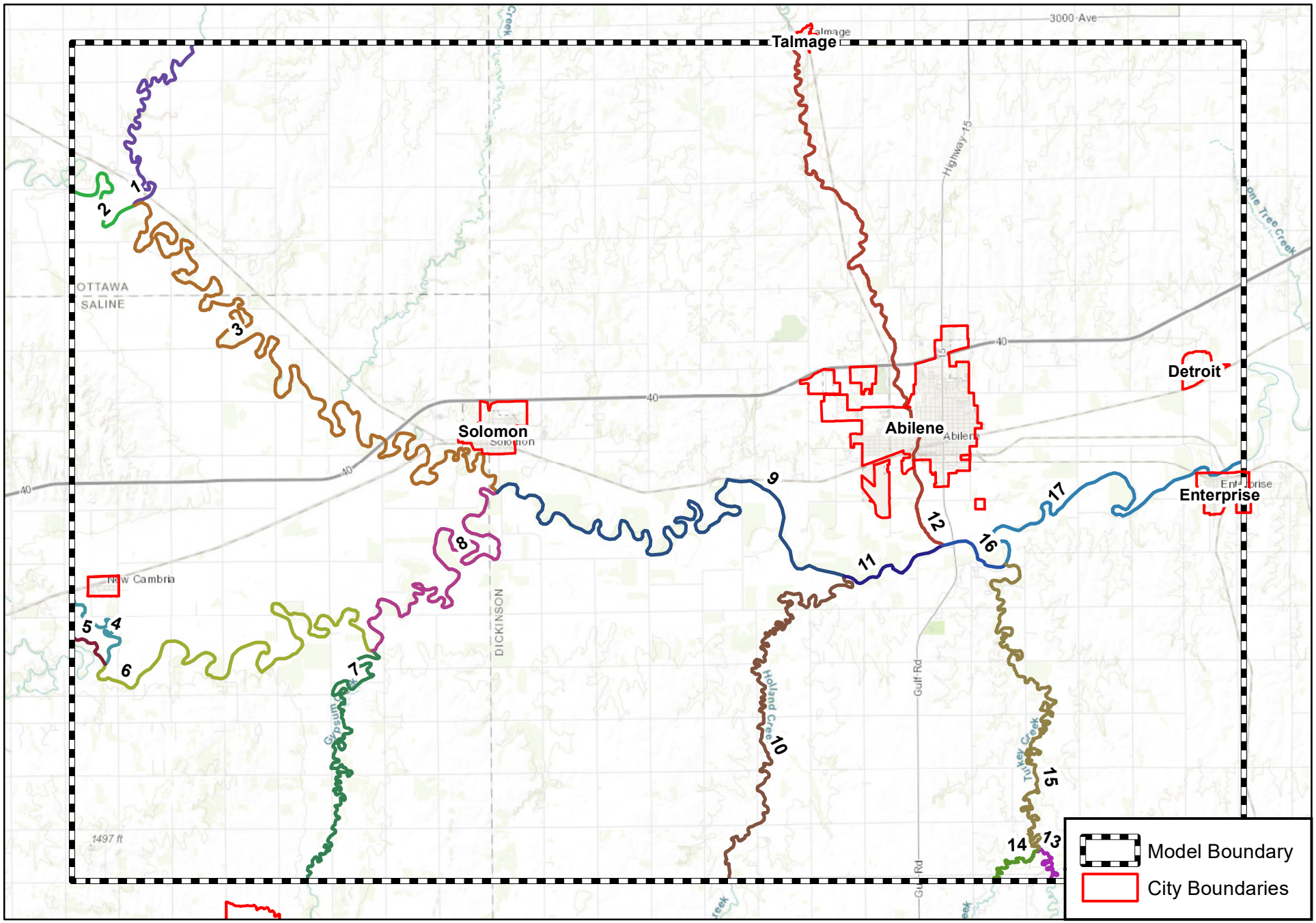
Boundary Conditions Map

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

24



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 16, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

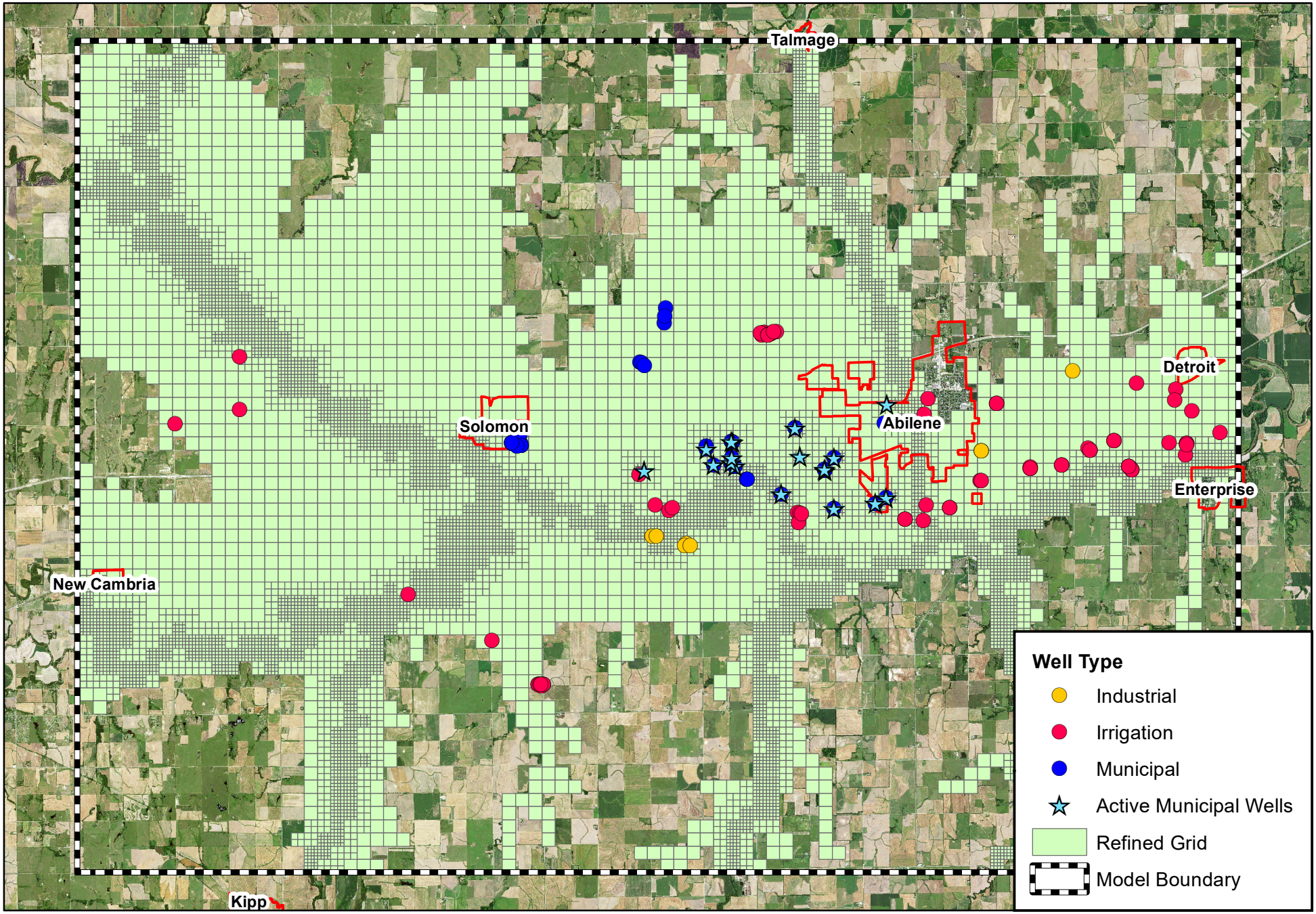
Stream Package

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

25



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 21, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '
Original Published Resolution
NAD 1983 StatePlane Kansas North FIPS 1501 Fee
ESRI World Imagery

Model Wells Map

Hydrogeologic Evaluation Report
City of Abilene, Kansas

FIGURE

26

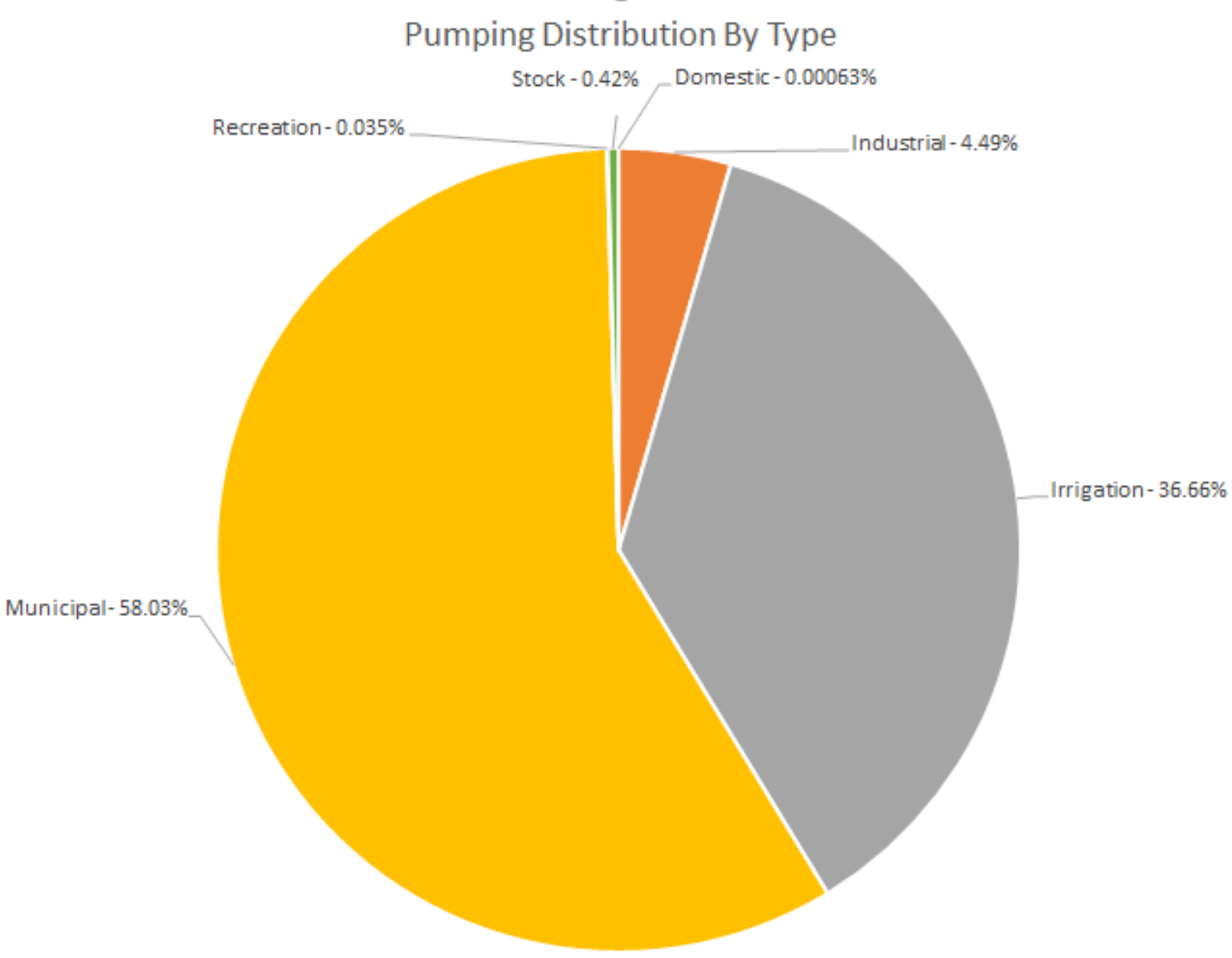


Figure 27. Pumping distribution by type for wells within the Abilene model area.

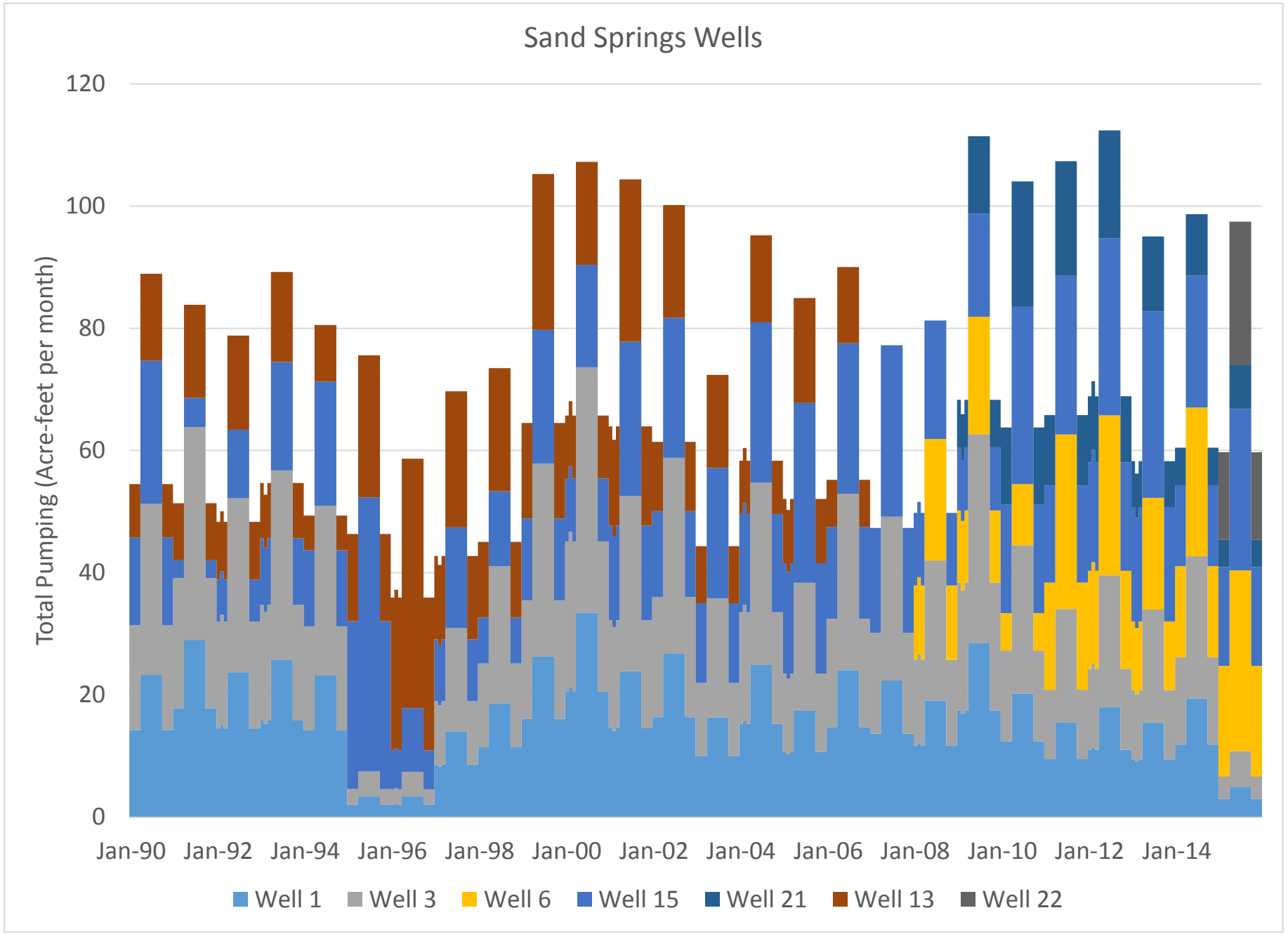


Figure 28. Monthly pumping over time for wells in the Sand Springs area.

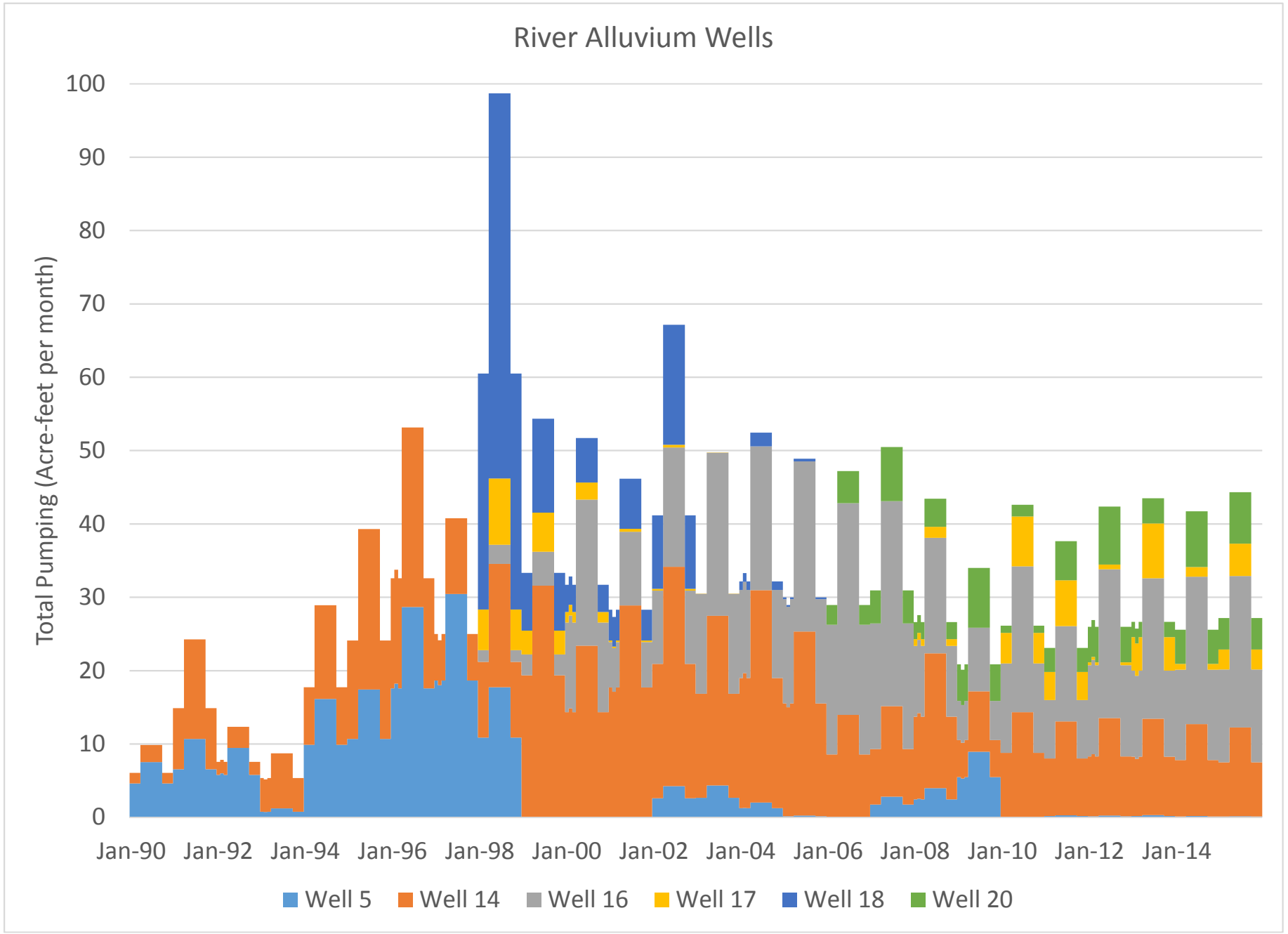


Figure 29. Monthly pumping over time for wells in the River Alluvium area.

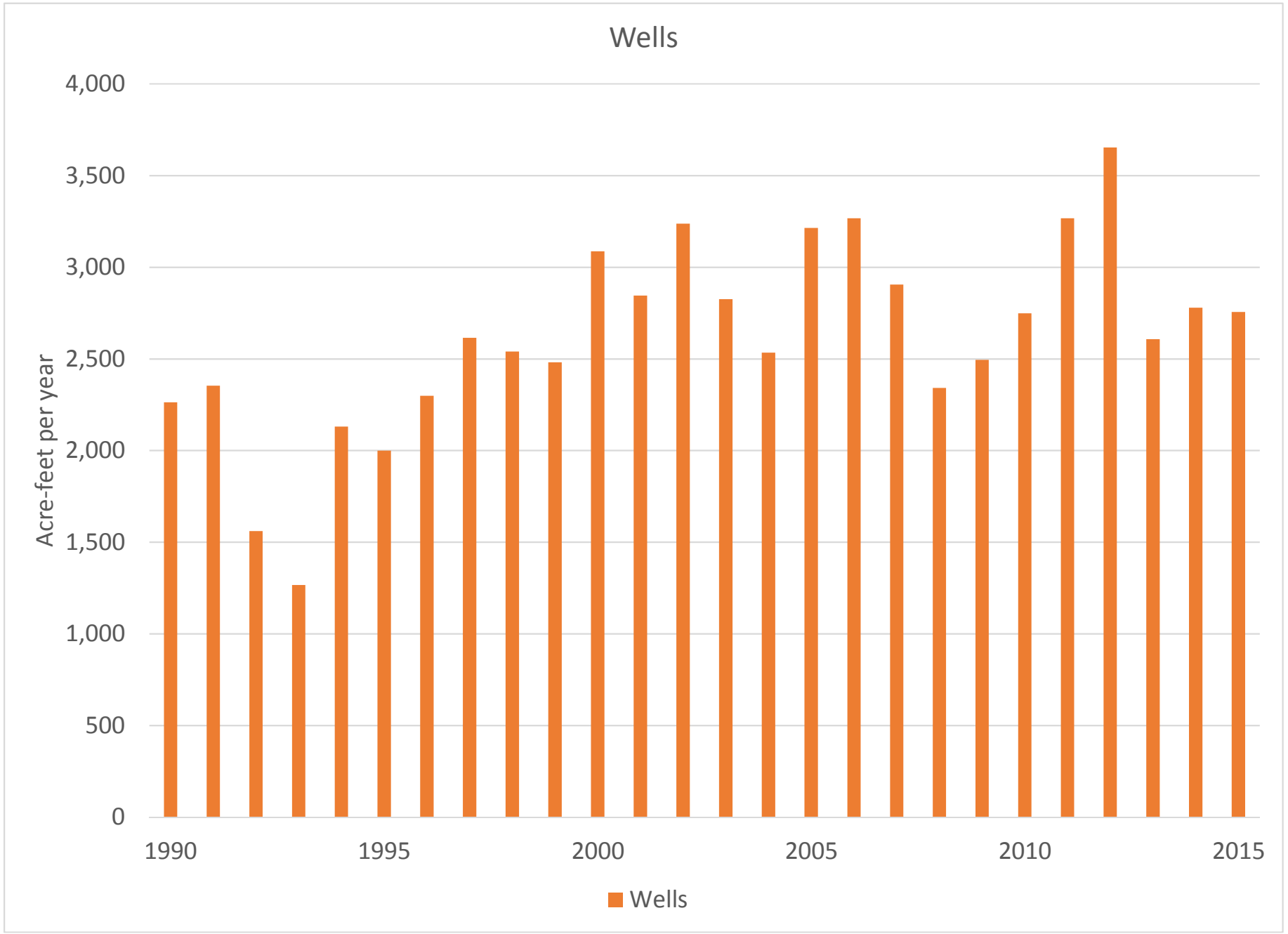


Figure 30. Total annual pumping for all wells in the Abilene model area.

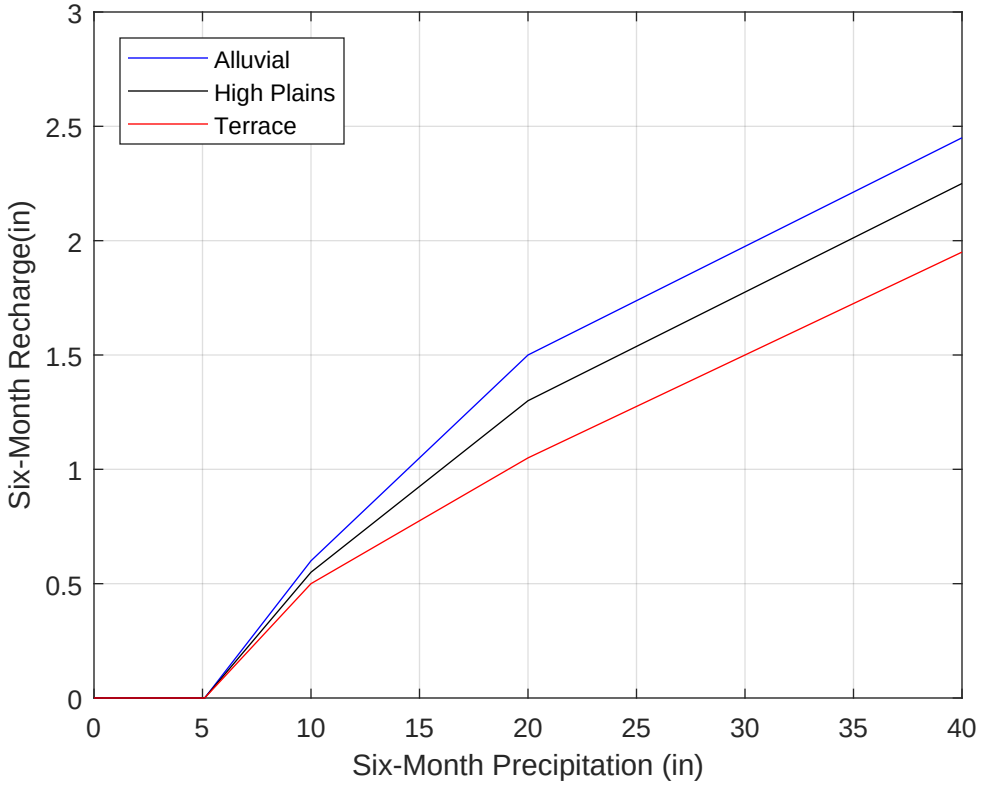


Figure 31. Recharge curves used for October-March time period (i.e. winter months).

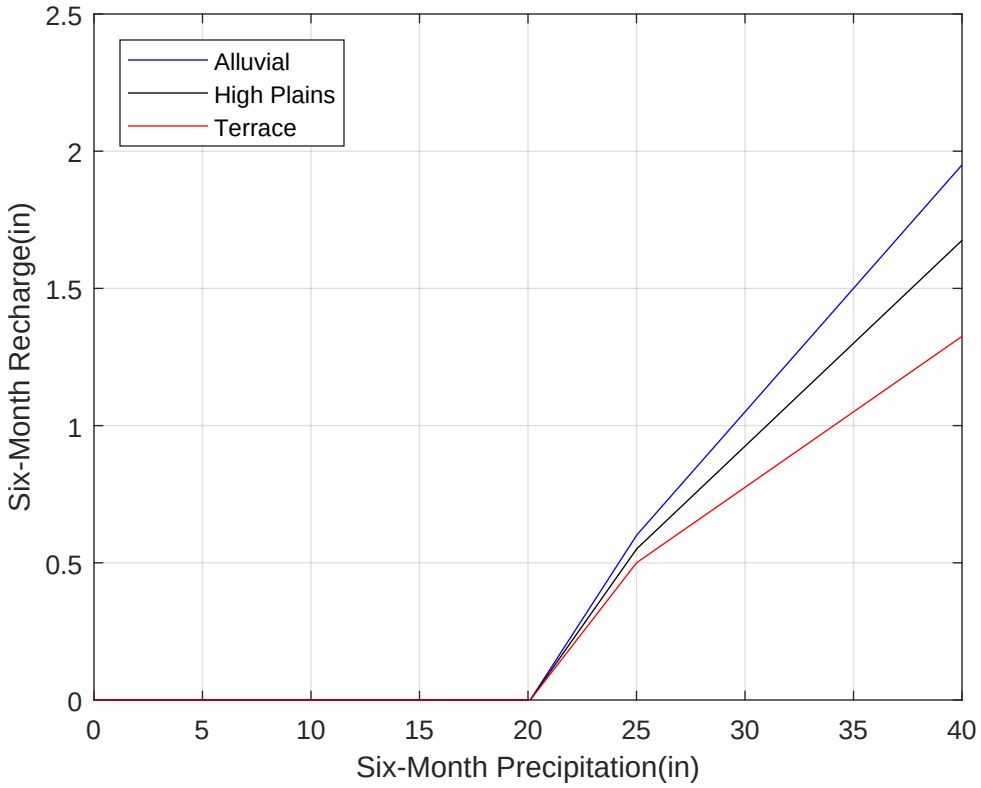
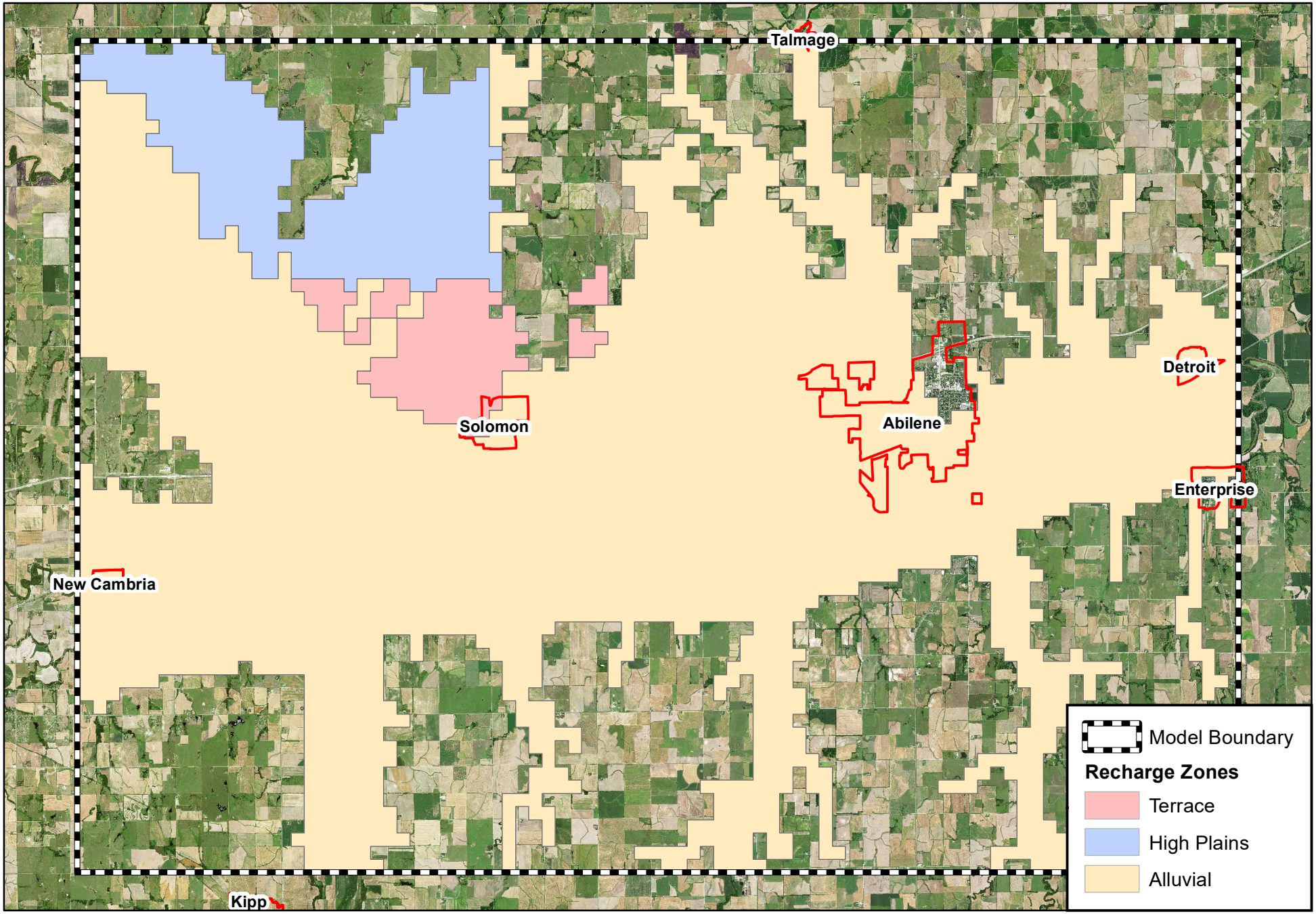


Figure 32. Recharge curves used for April-September time period (i.e. summer months).



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 21, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

Recharge Zones

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

33

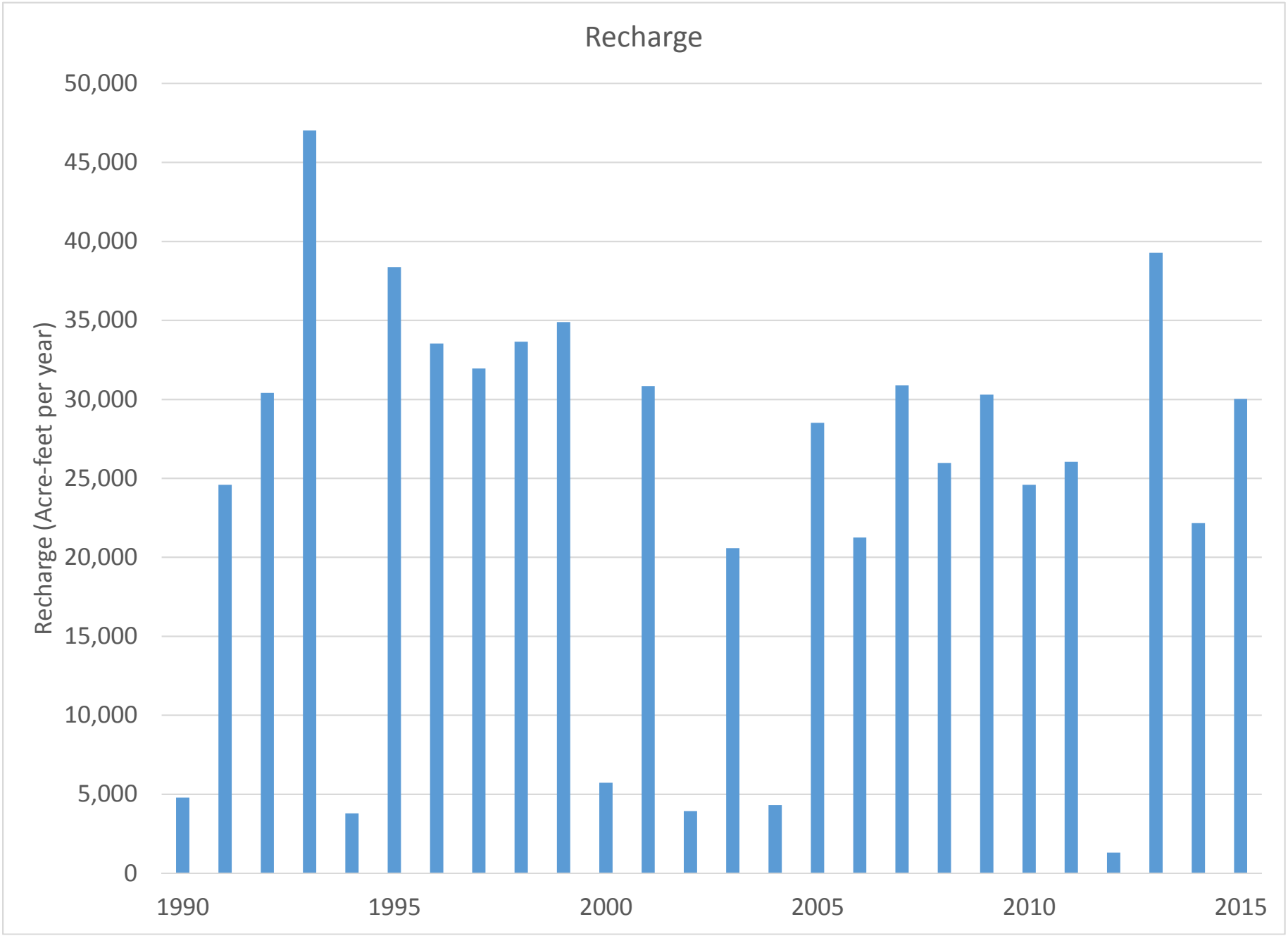


Figure 34. Annual recharge simulated in the Abilene model area.

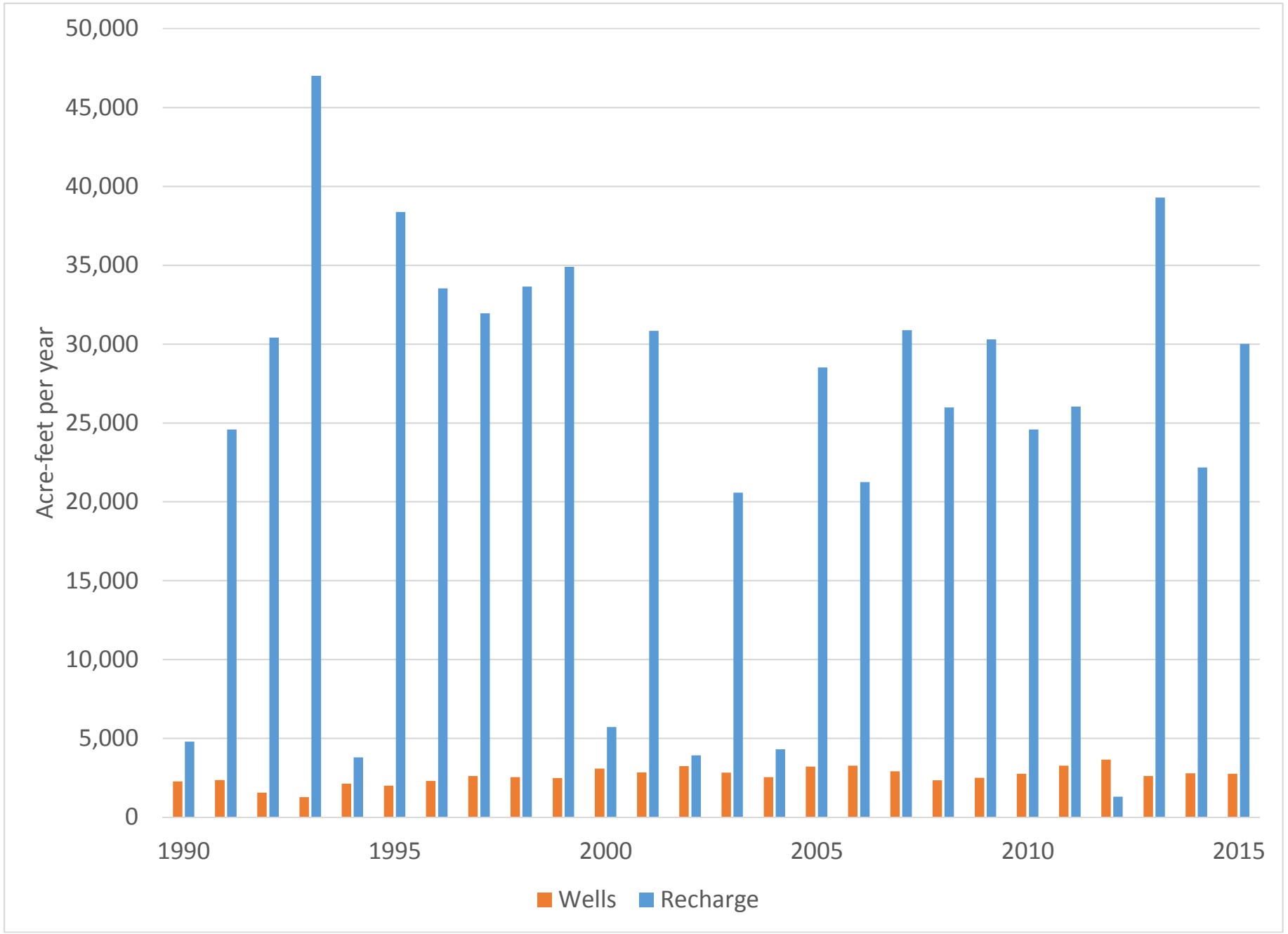
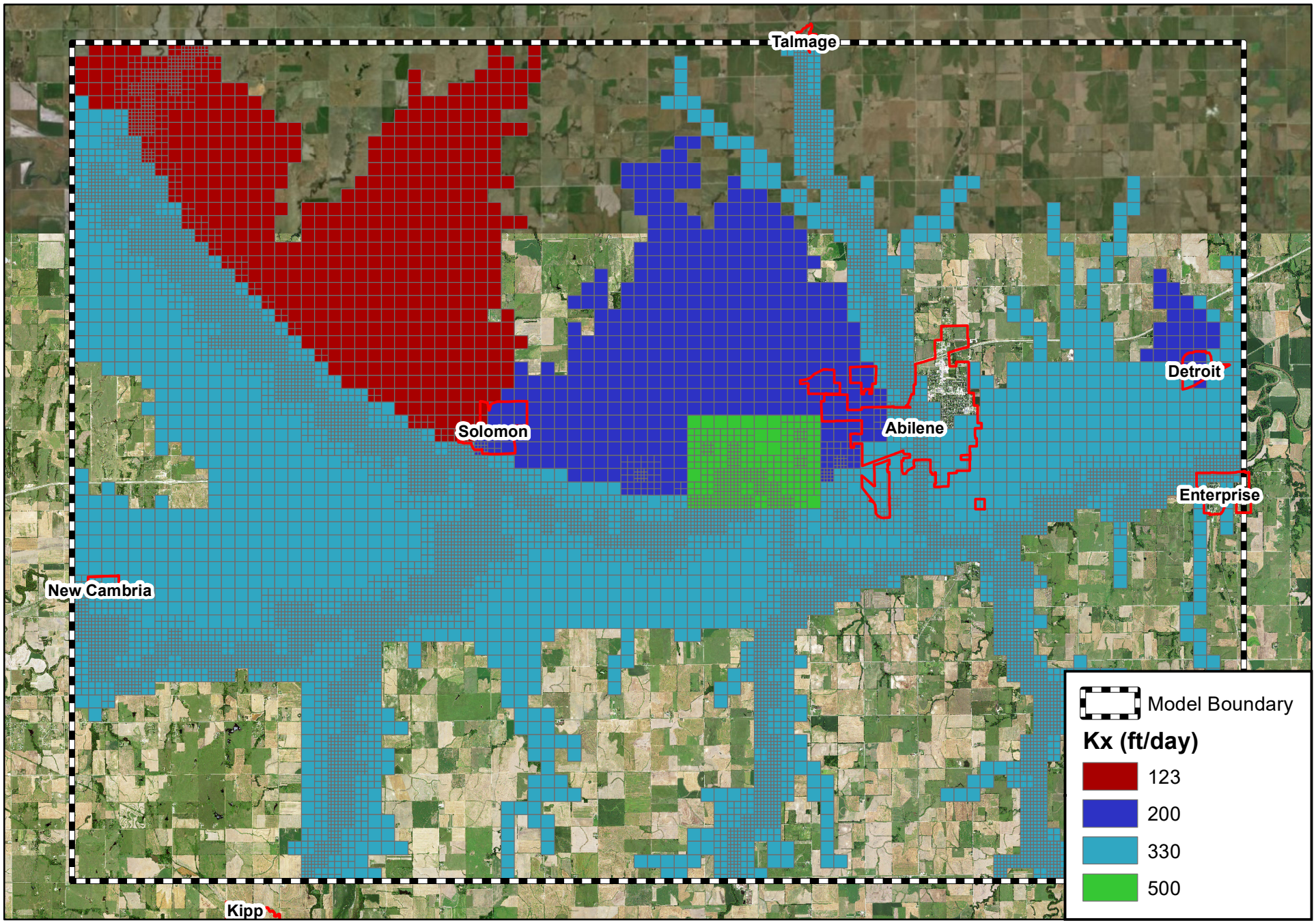


Figure 35. Annual pumping and recharge simulated in the Abilene model area.



USCB TIGER Line shapefiles 2015

D:\ABILENE\PresentationFigures.mxd PUBLISHED BY: mmorton DATE: February 09, 2018

OLSSON ASSOCIATES

N

0 3,250 6,500 13,000

1 " = 13,000 '

Original Published Resolution

NAD 1983 StatePlane Kansas North FIPS 1501 Fee

ESRI World Imagery

Hydraulic Conductivity

Hydrogeologic Evaluation Report

City of Abilene, Kansas

FIGURE

36

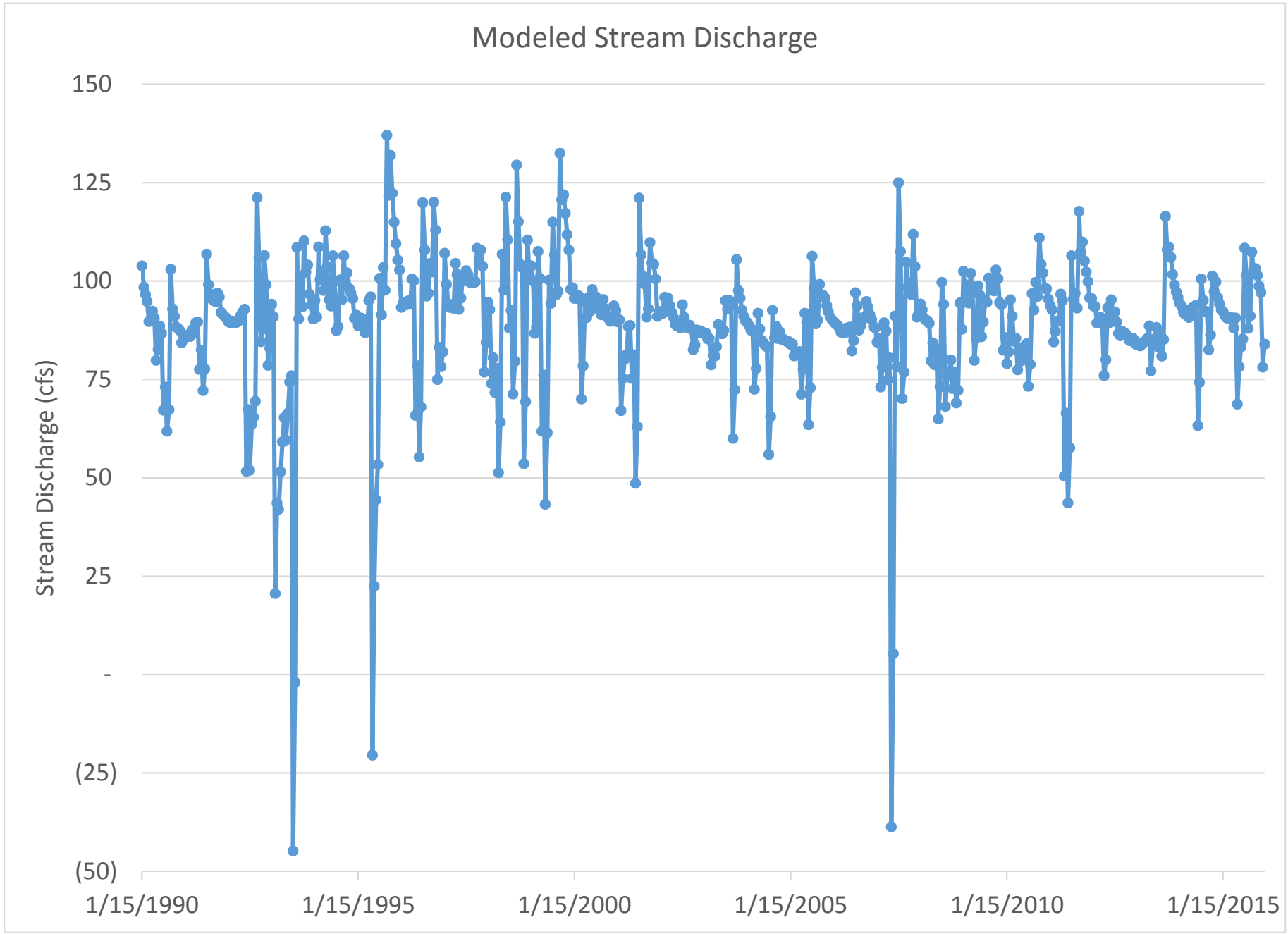


Figure 37. Simulated discharge from the aquifer to the Solomon and Smoky Hill Rivers.

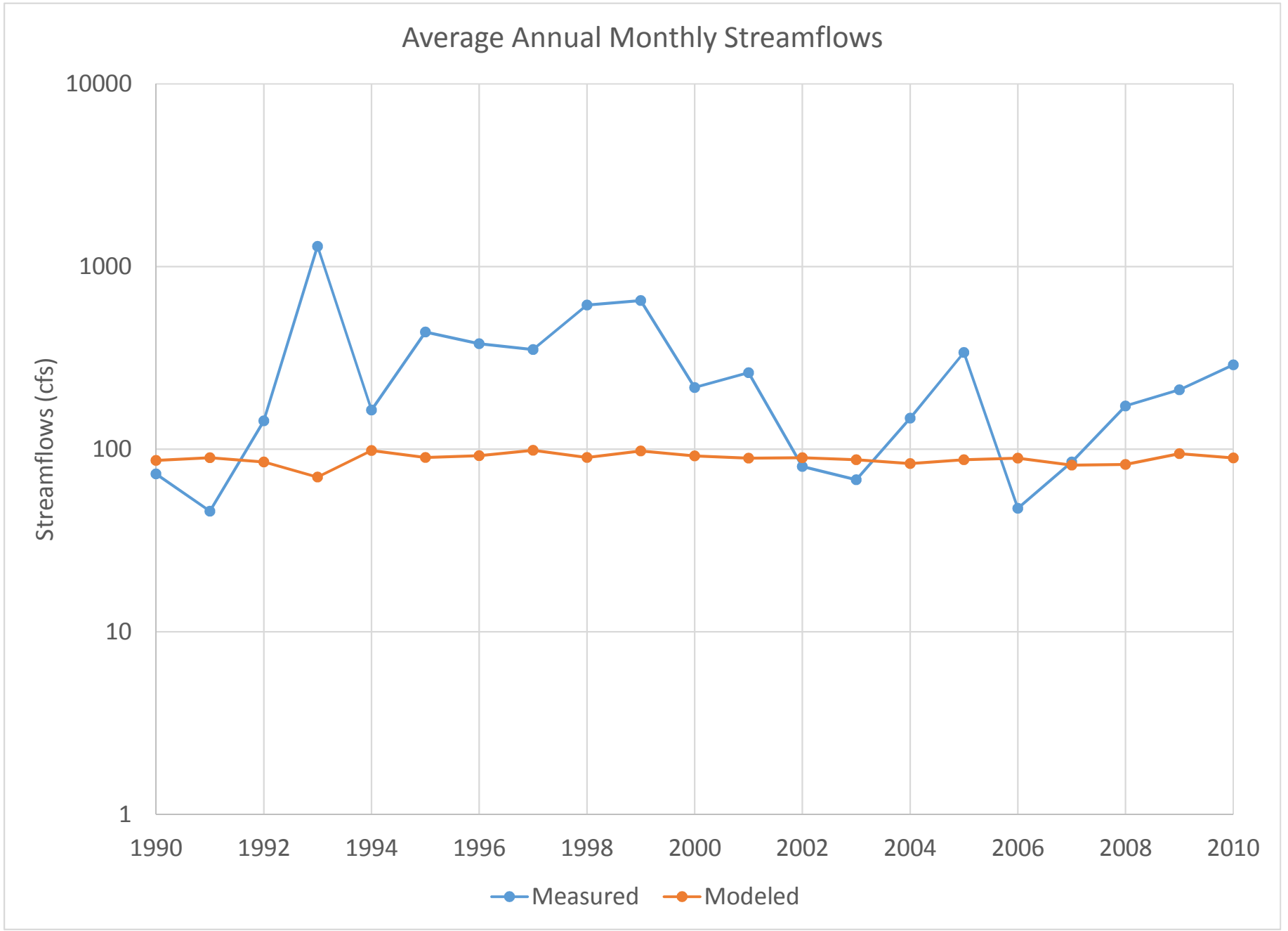
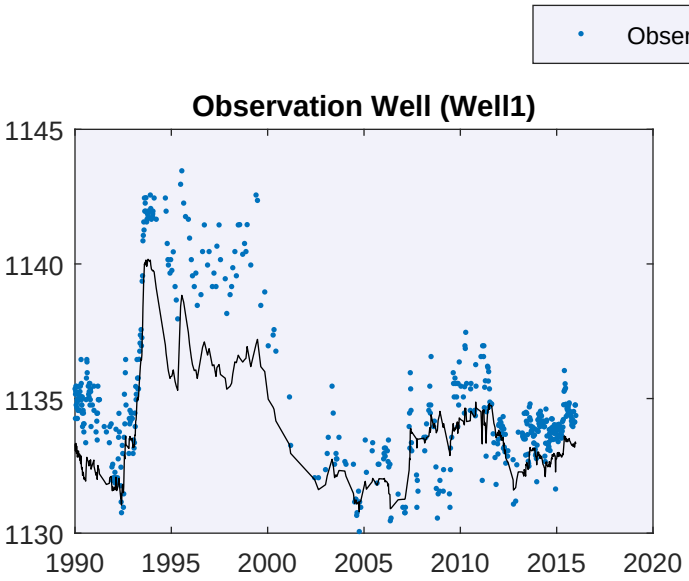
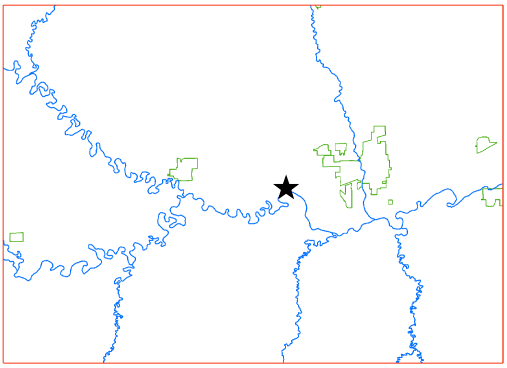


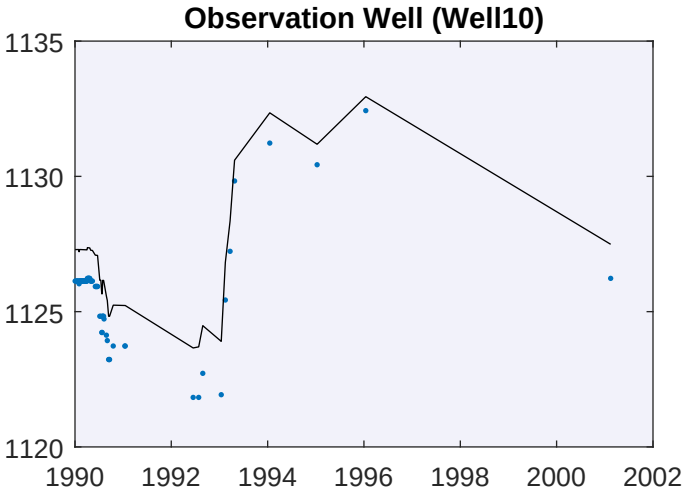
Figure 38. Comparison of modeled and measured streamflows within the Abilene model area.

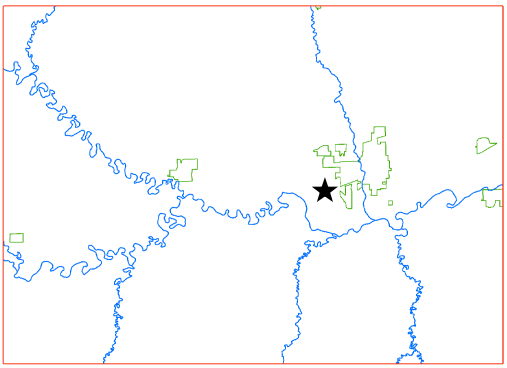
APPENDIX A

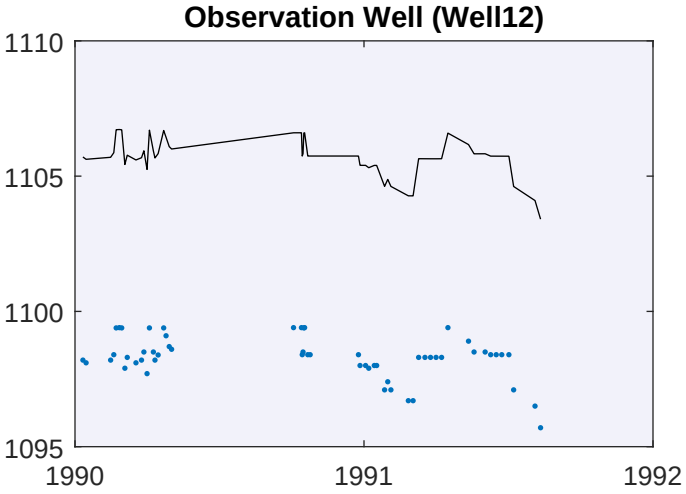
Target Hydrographs

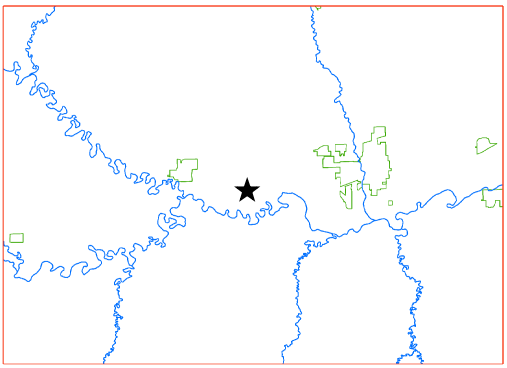












Year

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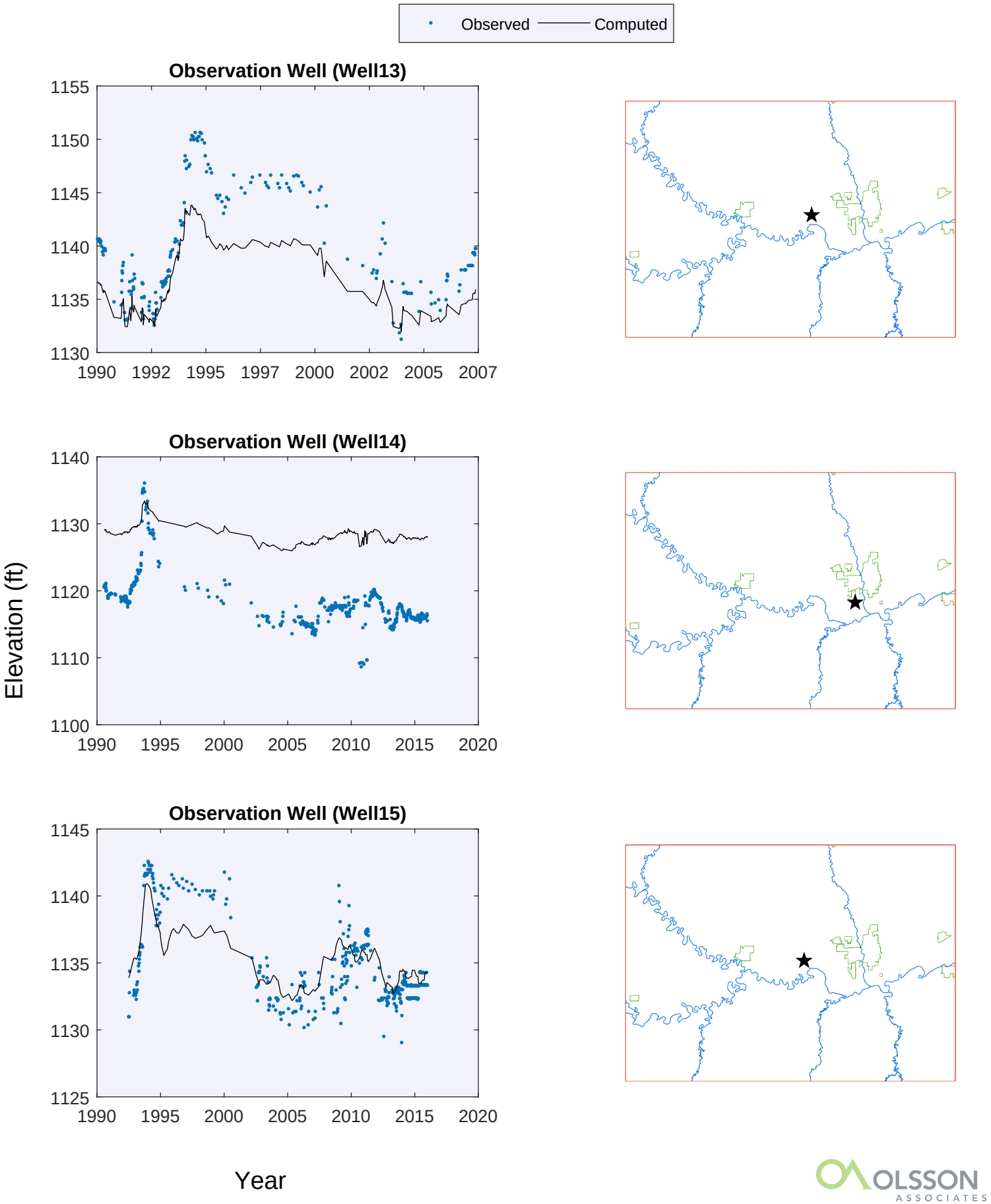
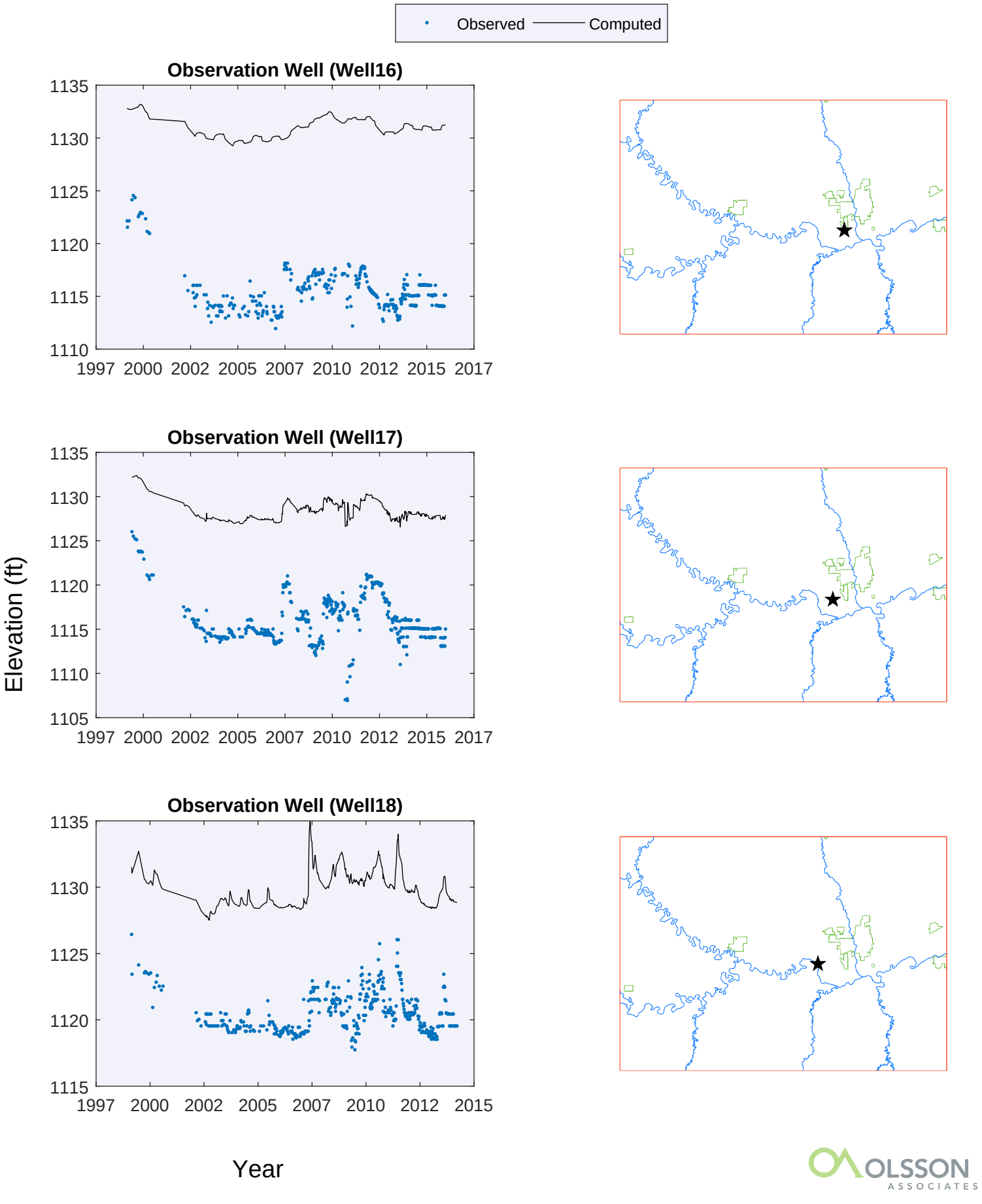

Observed
Computed
Observation Well (Well13)
1155
1150
1145
1140
1135
1130
1990
1992
1995
1997
2000
2002
2005
2007
Observation Well (Well14)
1140
1130
1120
1110
1100
1990
1995
2000
2005
2010
2015
2020
Observation Well (Well15)
1145
1140
1135
1130
1125
1990
1995
2000
2005
2010
2015
2020
Elevation (ft)
Year


Observed
Computed
Observation Well (Well16)
1135
1130
1125
1120
1115
1110
1997 2000 2002 2005 2007 2010 2012 2015 2017
Observation Well (Well17)
1135
1130
1125
1120
1115
1110
1105
1997 2000 2002 2005 2007 2010 2012 2015 2017
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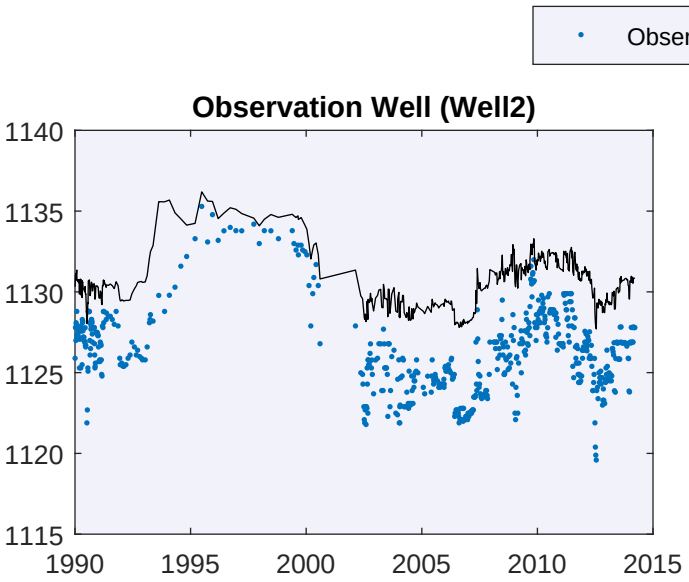
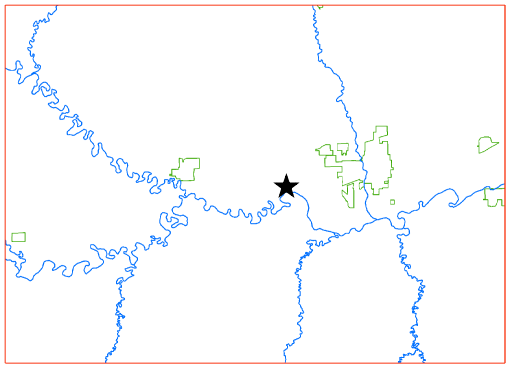
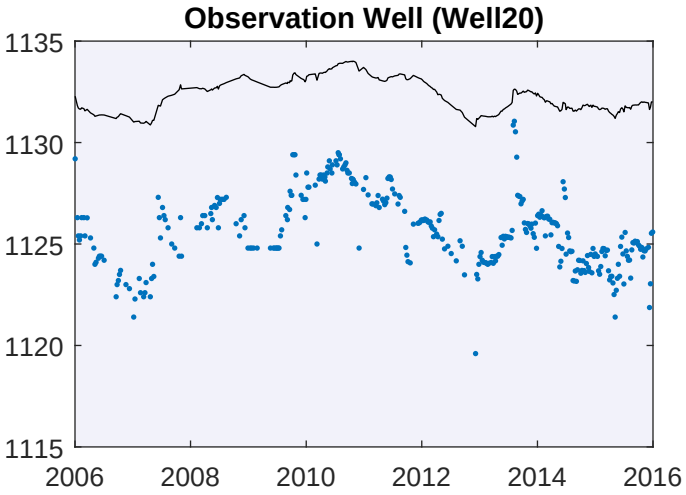
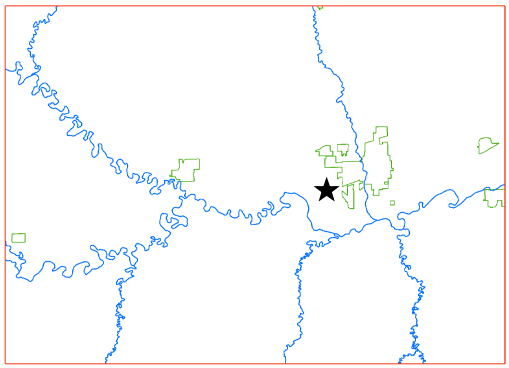
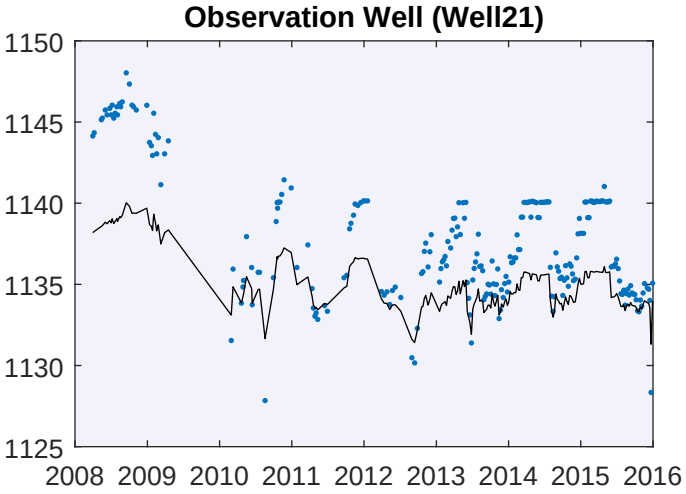
1135
1130
1125
1120
1115
1997 2000 2002 2005 2007 2010 2012 2015
Elevation (ft)
Year

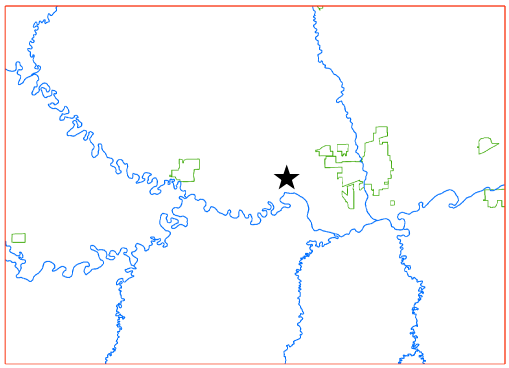












Year

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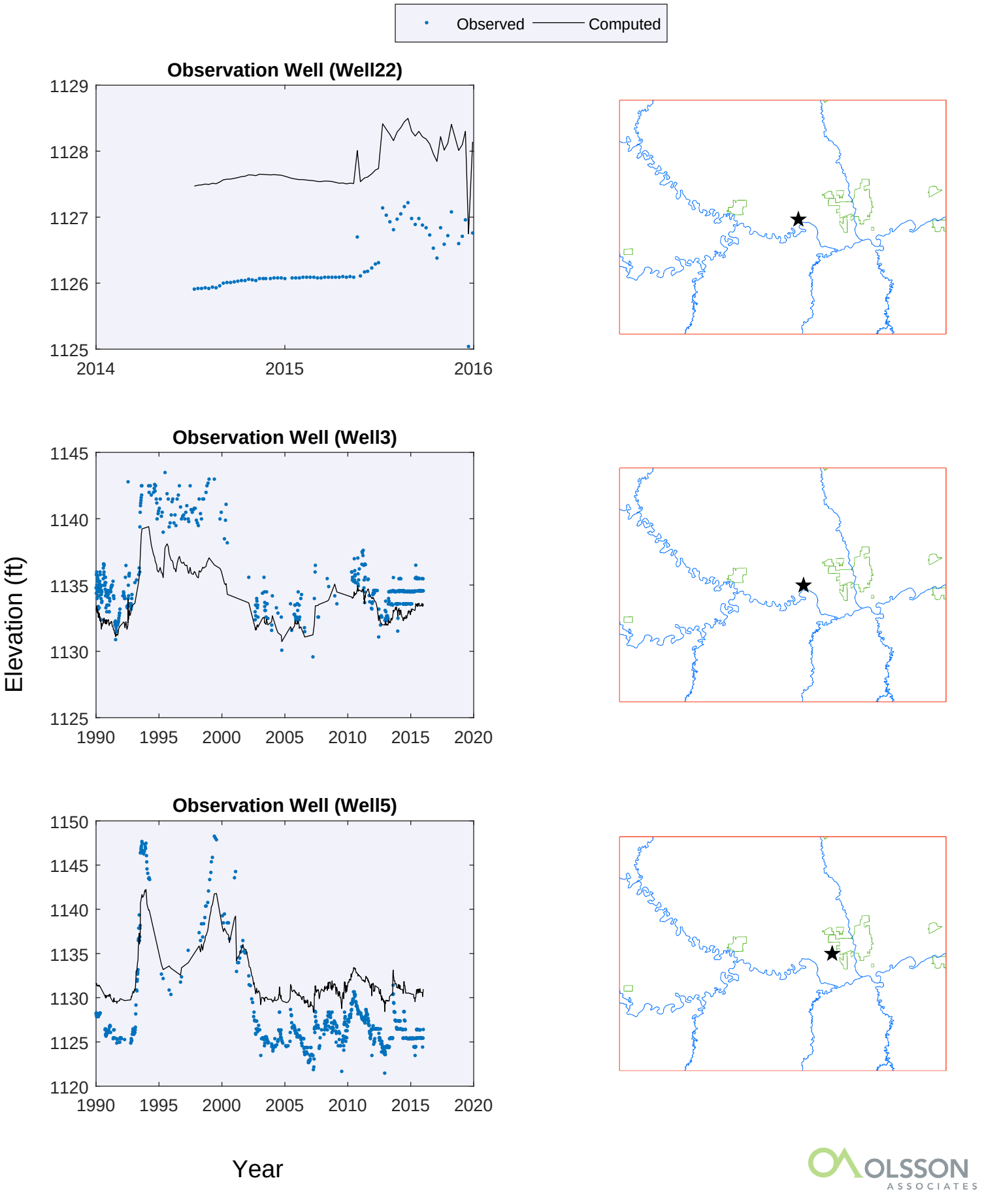
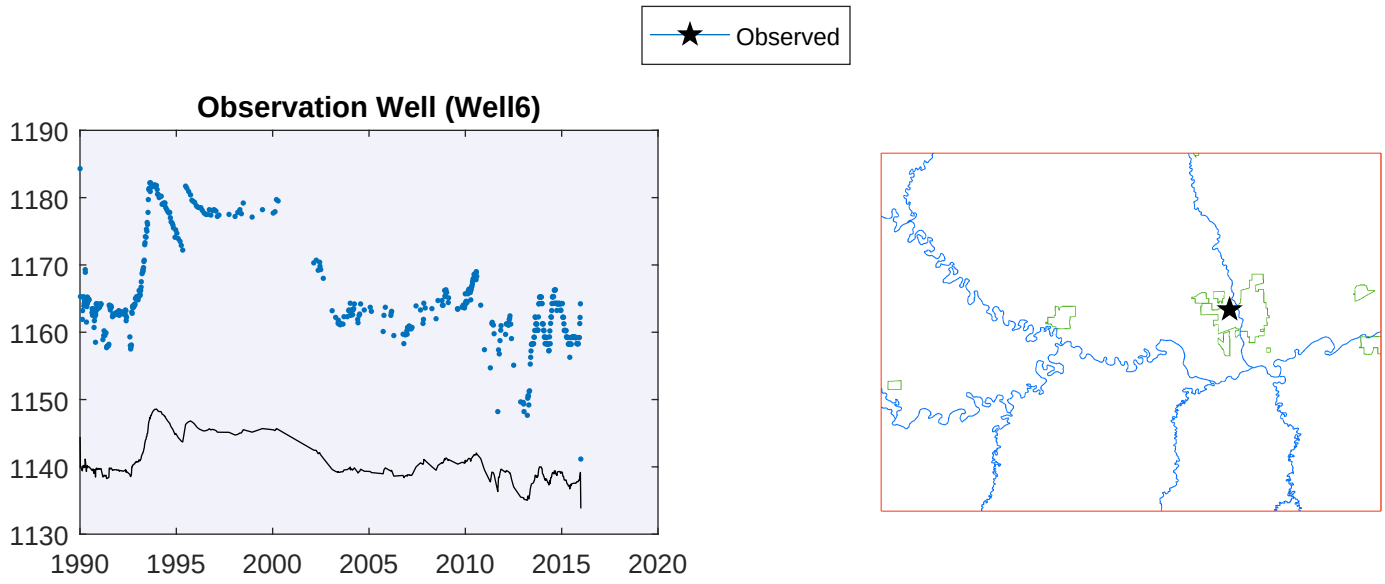

Observed
Computed
Observation Well (Well22)
1129
1128
1127
1126
1125
2014
2015
2016
Observation Well (Well3)
1145
1140
1135
1130
1125
1990
1995
2000
2005
2010
2015
2020
Elevation (ft)
Observation Well (Well5)
1150
1145
1140
1135
1130
1125
1120
1990
1995
2000
2005
2010
2015
2020
Year


Observed
Observation Well (Well6)
1190
1180
1170
1160
1150
1140
1130
1990
1995
2000
2005
2010
2015
2020
Elevation (ft)
Year