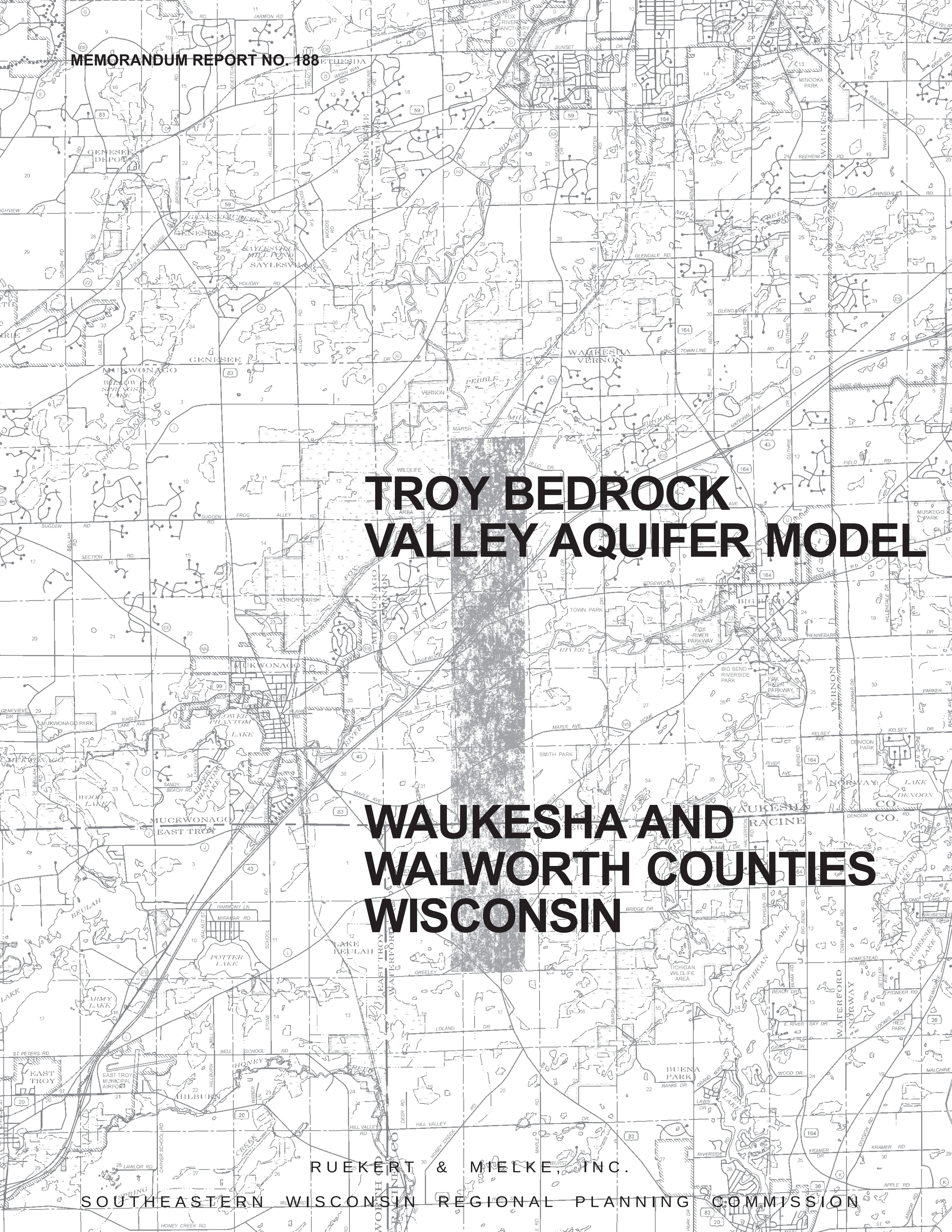

MEMORANDUM REPORT NO. 188

TROY BEDROCK VALLEY AQUIFER MODEL

WAUKESHA AND WALWORTH COUNTIES WISCONSIN

RUEKERT & MIELKE, INC.

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

The assistance provided by the University of Wisconsin-Madison Professor Emeritus, Dr. David M. Mickelson, Professor Emerita Dr. Mary P. Anderson, and Graduate Student, Kallina Dunkle, in coordinating and collaborating on a separate related University modeling project is greatly appreciated.

Funding for the preparation of this report was provided by the City of Muskego, the Villages of East Troy and Mukwonago, and the Waukesha Water Utility.

MEMORANDUM REPORT
NUMBER 188

TROY BEDROCK VALLEY AQUIFER MODEL

WAUKESHA AND WALWORTH COUNTIES, WISCONSIN

Prepared by

Ruekert & Mielke, Inc.
for the
Southeastern Wisconsin Regional Planning Commission
The Authors of This Report Are
John R. Jansen, PhD, PG, and Joy Loughry, PG
of Ruekert & Mielke, Inc.

The assistance provided by Dr. Kenneth R. Bradbury, PhD, PG, Hydrogeologist/Professor, and Dr. David J. Hart, PhD, Hydrogeologist, of the Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension, as project reviewers is greatly appreciated. In addition, the assistance provided by the University of Wisconsin-Madison Professor Emeritus, Dr. David M. Mickelson, Professor Emerita Dr. Mary P. Anderson, and Graduate Student, Kallina Dunkle, in coordinating and collaborating on a separate related University modeling project is greatly appreciated.

Funding for the preparation of this report was provided by the City of Muskego, the Villages of East Troy and Mukwonago, and the Waukesha Water Utility. Project management was provided by the Southeastern Wisconsin Regional Planning Commission.

November 2009

$10.00

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Ruekert·Mielke
engineering solutions for a working world

January 18, 2010

Mr. Kenneth R. Yunker
Executive Director
Southeastern Wisconsin Regional Planning Commission
P.O. Box 1607
Waukesha, WI 53187-1607

RE: SEWRPC Memorandum Report No. 188
Troy Bedrock Valley Aquifer Model, Waukesha and Walworth Counties, Wisconsin

Dear Mr. Yunker:

We are pleased to submit our final report entitled "Troy Bedrock Valley Aquifer Model, Waukesha and Walworth Counties, Wisconsin". We believe the information contained in this report will be important for the regional and local planning of our future water supplies in southeastern Wisconsin.

I would like to acknowledge the professional contributions to this document from John R. Jansen, P.G., Ph.D. and Joy Loughry, P.G. who were responsible for this report.

Very truly yours,

RUEKERT/MIELKE

William J. Mielke

William J. Mielke, P.E., R.L.S
President, CEO

WJM:tag

cc: File

~8009051 Troy Bedrock Valley Groundwater Model > 100 > Reports > Final Report/Supporting Information with Revisions Requested by SEWRPC 12/1/09 > Yunker-20100118-SEWRPC Memorandum Report No. 188.doc~

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TROY BEDROCK VALLEY AQUIFER MODEL WAUKESHA AND WALWORTH COUNTIES, WISCONSIN

INTRODUCTION

The Troy Bedrock Valley of southeastern Wisconsin contains a major glacial aquifer that lies near the growing suburbs of the Milwaukee metropolitan area. The seven-county Southeastern Wisconsin Region is the most densely populated portion of the State. Over the last several decades much of the growth in the Region has occurred west of the subcontinental topographic divide that traverses the Region and the Valley. These areas currently rely on groundwater for water supply.

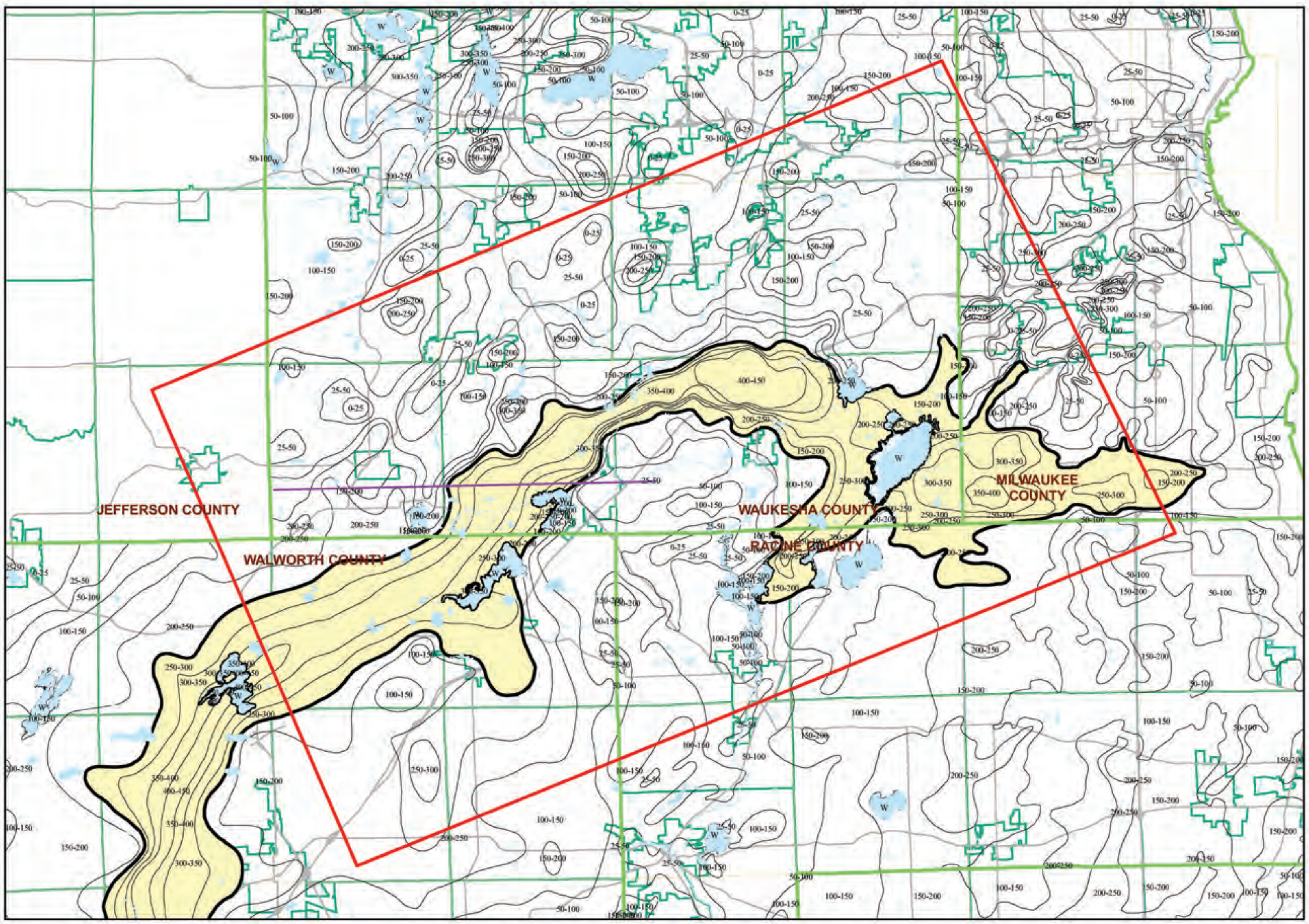
The Cambrian-Ordovician bedrock units that comprise the deep sandstone aquifer were heavily exploited for municipal and industrial demands beginning in the late 1800s. The heavy development of the deep sandstone aquifer caused a cone of depression over 500 feet deep in portions of southeastern Wisconsin, with water levels in parts of the aquifer declining several feet per year over the last several decades. The water produced by the aquifer frequently exceeds the Federal regulatory maximum contaminant level (MCL) for radium. Public water suppliers were required to provide water that complied with the MCL for radium by the end of 2006. Treatment for radium is expensive and generates waste products that can be difficult to dispose. The combination of declining head, the cost of water treatment, along with the substantial cost to drill and operate a deep sandstone aquifer well created strong incentives for additional development of wells in the shallow aquifer system.

The location of the Troy Bedrock Valley is shown on **Figure 1**. The Valley trends through southern Milwaukee and Waukesha Counties and across Walworth County. The Valley trend passes near several communities actively seeking sources of water that do not require treatment for radium. The Valley contains up to 500 feet of glacial deposits in its deepest parts. The bedrock is close to the ground surface in locations along the sides of the Valley. Several tributary bedrock valleys project outward from the Troy Bedrock Valley. Many of the smaller tributary valleys are poorly mapped and some may be currently unknown.

The glacial deposits within the Valley vary from dense clay to coarse sand and gravel. Many of the sand and gravel deposits are saturated and permeable and can serve as prolific shallow aquifers that can support high-capacity wells. These aquifers are discontinuous and occur at different elevations within the bedrock Valley. The glacial material within the Valley is collectively referred to in this report as the Troy Bedrock Valley aquifer, even though the aquifers are discontinuous and the yield of the deposits varies significantly with location and depth. **Figure 2** is a generalized geologic cross-section across the Valley that shows the complexity of the Valley shape and glacial deposits.

Figure 1

LOCATION OF TROY BEDROCK VALLEY



LEGEND

100-150	DEPTH TO BEDROCK		MAJOR HIGHWAYS
	TOWNSHIP LINES		MUNICIPAL BOUNDARY
	COUNTY LINE		APPROXIMATE MODEL NEAR FIELD
	TROY BEDROCK VALLEY		GEOLOGICAL CROSS-SECTION LOCATION (SEE FIGURE 2)

GRAPHIC SCALE

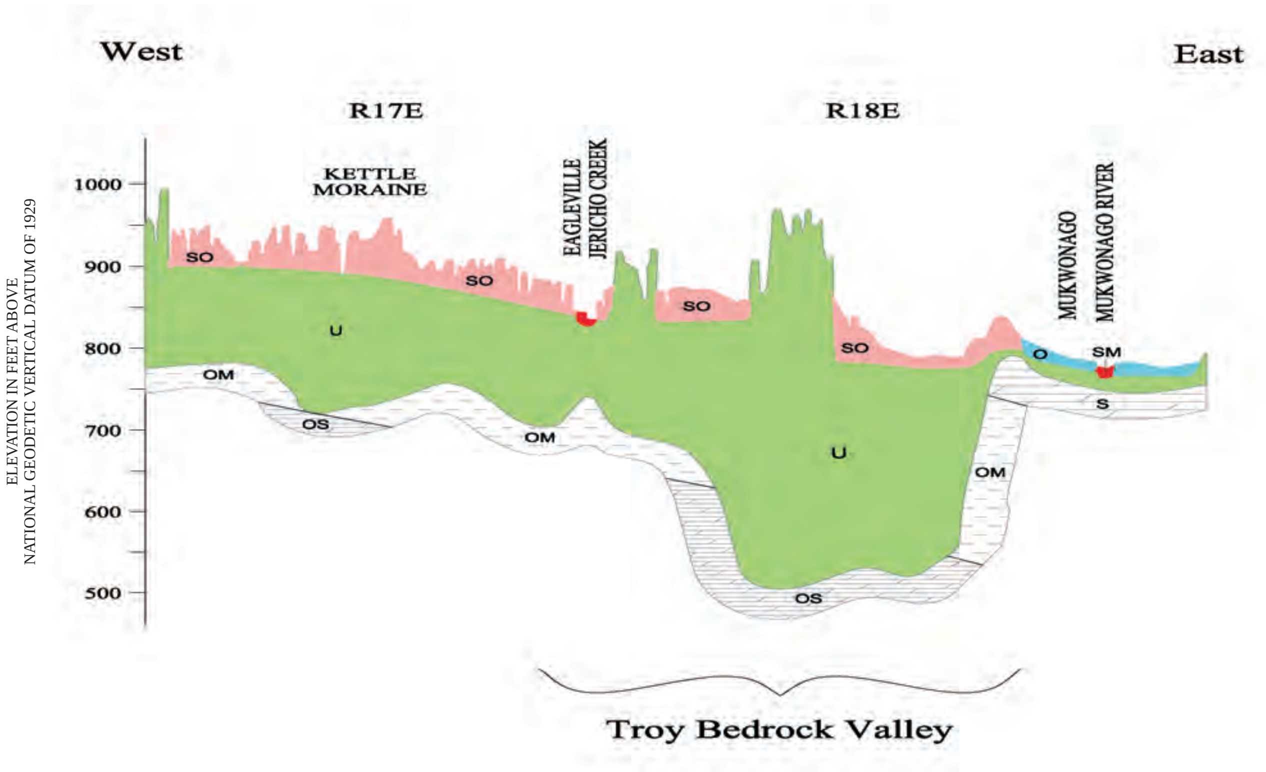
0 1/2 1 2 3 4 MILE

0 4,000 8,000 16,000 24,000 FEET

Source: Ruekert & Mielke, Inc.

Figure 2

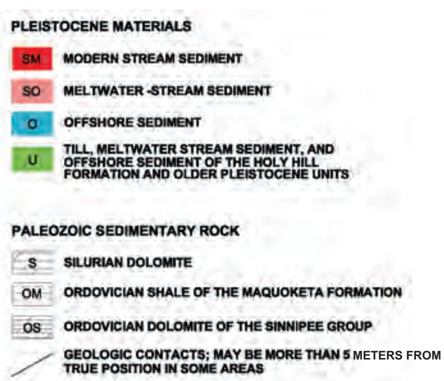
GEOLOGICAL CROSS-SECTION THROUGH THE TROY BEDROCK VALLEY IN SOUTHERN WAUKESHA COUNTY



0 10,000 20,000 20,000 FEET

HORIZONTAL SCALE

LEGEND



Source: Clayton 2001.

The proximity of the Troy Bedrock Valley aquifer to growing communities in need of low radium water has made it an obvious target for new municipal wells. Approximately a dozen communities in the Southeastern Wisconsin Region operate high-capacity wells, are currently exploring for new high-capacity wells, or have contemplated developing new high-capacity wells in the Troy Bedrock Valley aquifer or its tributary valleys. The increase in pumping is expected to alter the natural flux of groundwater and surface water within the Valley to some degree.

The Troy Bedrock Valley also contains ecologically and economically significant surface water features including streams, lakes, springs, and wetlands. Existing pumping and potential increases in pumping from the aquifers has created significant concern over the potential impact of groundwater withdrawals on these surface water features. It is difficult to quantify the impact that a well or group of wells will have on the flow system in a complex aquifer system. Traditionally these impacts have been addressed by interested parties conducting targeted hydrogeologic investigations, often including application of groundwater models, and usually designed to address a set of issues in a specific location. This approach can lead to multiple studies being completed in a relatively small area. These studies can occur at different times using different methods, and are often not coordinated. This can lead to duplication of effort and produce models that give conflicting information.

The confluence of multiple parties with similar interests provided an opportunity to work cooperatively. This report is intended to document a groundwater model that can be used as a management tool to assess the potential impacts of proposed new high-capacity wells in the Troy Bedrock Valley using consistent methods without duplication of effort. This effort was funded by a consortium of four entities, the City of Muskego, the Village of East Troy, the Village of Mukwonago, and the Waukesha Water Utility. The Southeastern Wisconsin Regional Planning Commission (SEWRPC) served as the project manager. The Wisconsin Geological and Natural History Survey provided peer review. Aquifer Science and Technology, a division of Ruekert & Mielke, Inc., served as the engineering consultant.

The groundwater model is intended for use by communities, lake management districts, environmental groups, and concerned citizens. The model provides a peer reviewed common platform to simulate the impact of new high-capacity wells in the Valley. The model is suitable for simulating the effect of pumping from new and existing wells and is intended to provide reasonable predictions of the potential impacts on the major surface water bodies of proposed well locations. The model is intended to be as complete a representation of the aquifer as is reasonably possible, but it cannot accurately account for all of the complexity present in nature. Refinements in the model design may be necessary to improve the performance in specific local applications. The model is based upon a regional model developed by the Southeastern Wisconsin Regional Planning Commission and as such, is known as an inset model. It can also serve as a parent model for more detailed inset models created to explore more specific local proposals.

A copy of the model data files and related explanatory text is included on a compact disc included in the pocket at the back of this report.

HYDROSTRATIGRAPHIC MODEL

Thousands of boreholes have been drilled in the Troy Bedrock Valley in the past. Most of these boreholes were drilled for water supply wells, the vast majority intended to supply private residences. Drillers are required to submit logs of the geologic formations they encounter while drilling water supply wells to the Wisconsin Department of Natural Resources (WDNR). These logs are included on the well construction reports that the WDNR keeps for each well. In theory, the geologic information provided on the reports provides a uniquely detailed data set on subsurface geologic conditions. However, standardized descriptions for the geologic material and collection techniques are not always used. In addition, the locations of some wells provided on the well construction reports may be inaccurate. Geostatistical methods can be used to improve the reliability of the data by using smoothed values of a large number of well logs (Dunkle, 2008; Mickelson et al., 2008). However, the validity of this approach can only be evaluated by comparison to data that are known to be reliable.

Several well siting investigations have been conducted by municipalities over the last ten years in the Troy Bedrock Valley. These investigations included geophysical surveys, test drilling, test wells, and pumping tests. Many of these investigations were conducted under the direct supervision of professional engineers and professional geologists and produced highly reliable data. The locations of these well site investigations are shown on **Figure 3**. The pumping test data are summarized in **Appendix A**.

The data shown on **Figure 3** were used to provide the core geologic information to build the geologic framework of the model. The driller's logs from these well siting investigations, along with some additional logs from private well were used to construct six geologic cross-sections across the Valley. The location of the cross-sections are shown on **Figure 4**. The cross-sections are presented on **Figures 5** through **Figure 10**. The cross-sections show the shape of the Bedrock Valley and distribution of glacial deposits within the Valley.

The composition of the Valley fill deposits varies widely throughout the Valley as is typical for units deposited in a near-glacial environment. The Valley fill is dominated by fine-grained units with layers that contain sand and gravel. The sequence suggests a glacial history of several glacial outwash deposits layered between at least one major till unit from a glacial advance. The depositional sequence is complex but can be generalized as consisting of four layers. The layers are not laterally continuous or horizontal, either due to the original depositional geometry or due to deformation and erosion from subsequent ice advances or erosion by melt water.

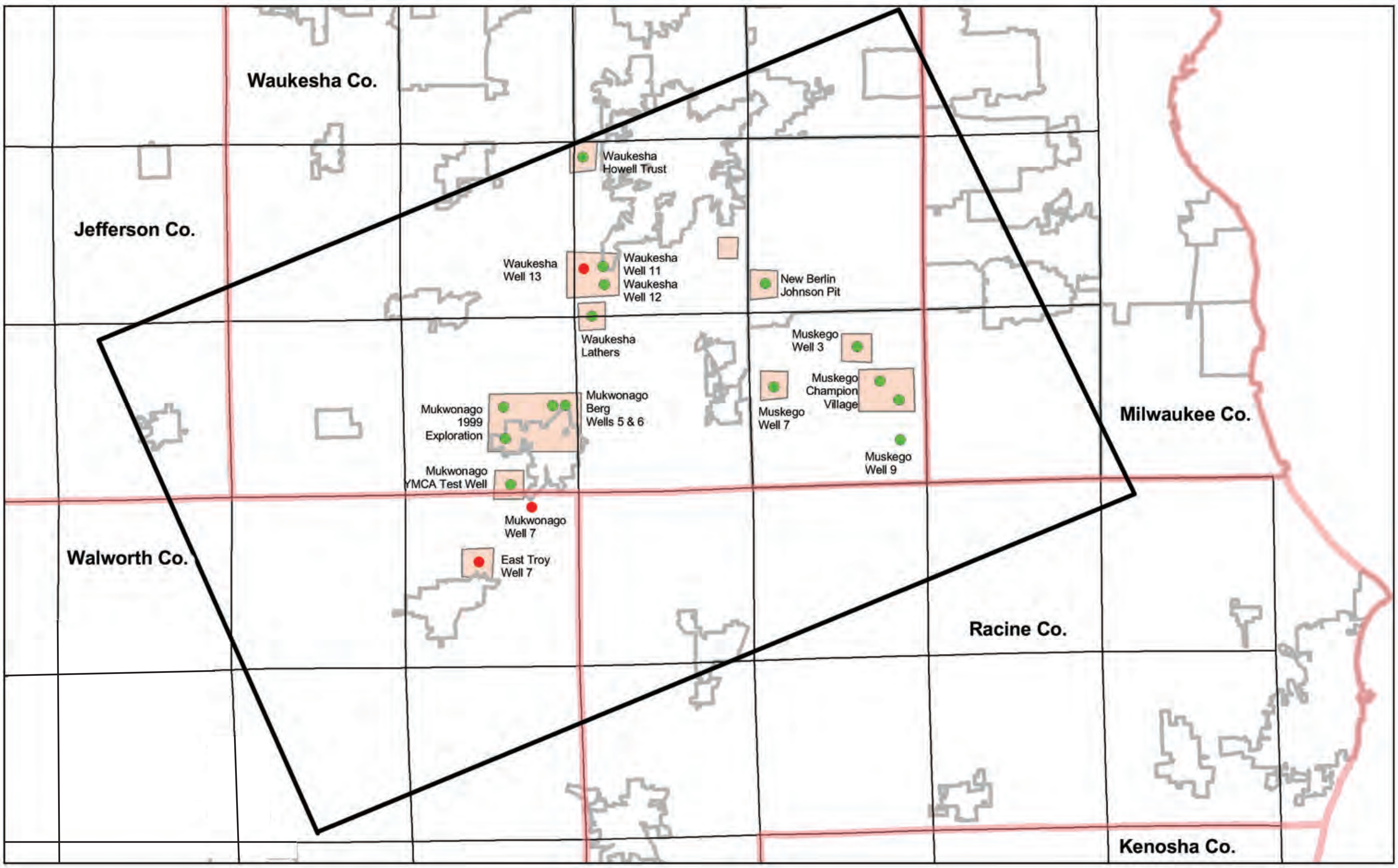
The upper layer consists of the shallow glacial material near the ground surface. This layer is relatively thin, absent in places, and has variable grain size. Below this layer lies an upper sand unit. The upper sand is typically about 50 to 100 feet thick, but is absent in many places and over 200 feet thick in a few places.

Beneath the upper sand unit lies a fine-grained layer that consists of clay-rich till, lacustrine clay, and hardpan (a drillers term for a dense clay-rich material, usually till). This unit is typically about 50 feet thick and forms a hydrologic confining unit, or aquitard, within the bedrock valley fill deposits. The confining unit limits the ability of water to flow vertically between permeable units within the bedrock valley fill deposits. The confining unit is more than 200 feet thick in many places and absent in a few areas informally called "windows".

The windows are hydrogeologically significant because water can flow vertically between aquifers more easily through the windows than where the confining unit is present. The location of the windows is difficult to predict, and only a few windows have been found by the drilling data used for this report. It is very likely that other windows through the confining unit are present, many of which may never be found due to their small size and irregular distribution. The windows may be very significant on a local scale for specific wells or surface water bodies. However, the presence of a preponderance of upward hydraulic gradients between the lower and upper sand units observed in most of the piezometer nests we have seen and the occurrence of several flowing wells in the lower sand, suggests that the confining unit has a significant regional hydraulic impact on the flow system and the confining unit acts as a consistent

Figure 3

PUMPING TEST AND TEST BORING LOCATIONS, AND GEOPHYSICAL DATA AREAS USED FOR MODEL DESIGN



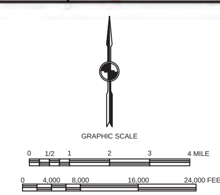
LEGEND

APPROXIMATE MODEL NEAR FIELD

PUMPING TEST OR TEST BORINGS

PUMPING TEST USED FOR GRADIENT CALIBRATION

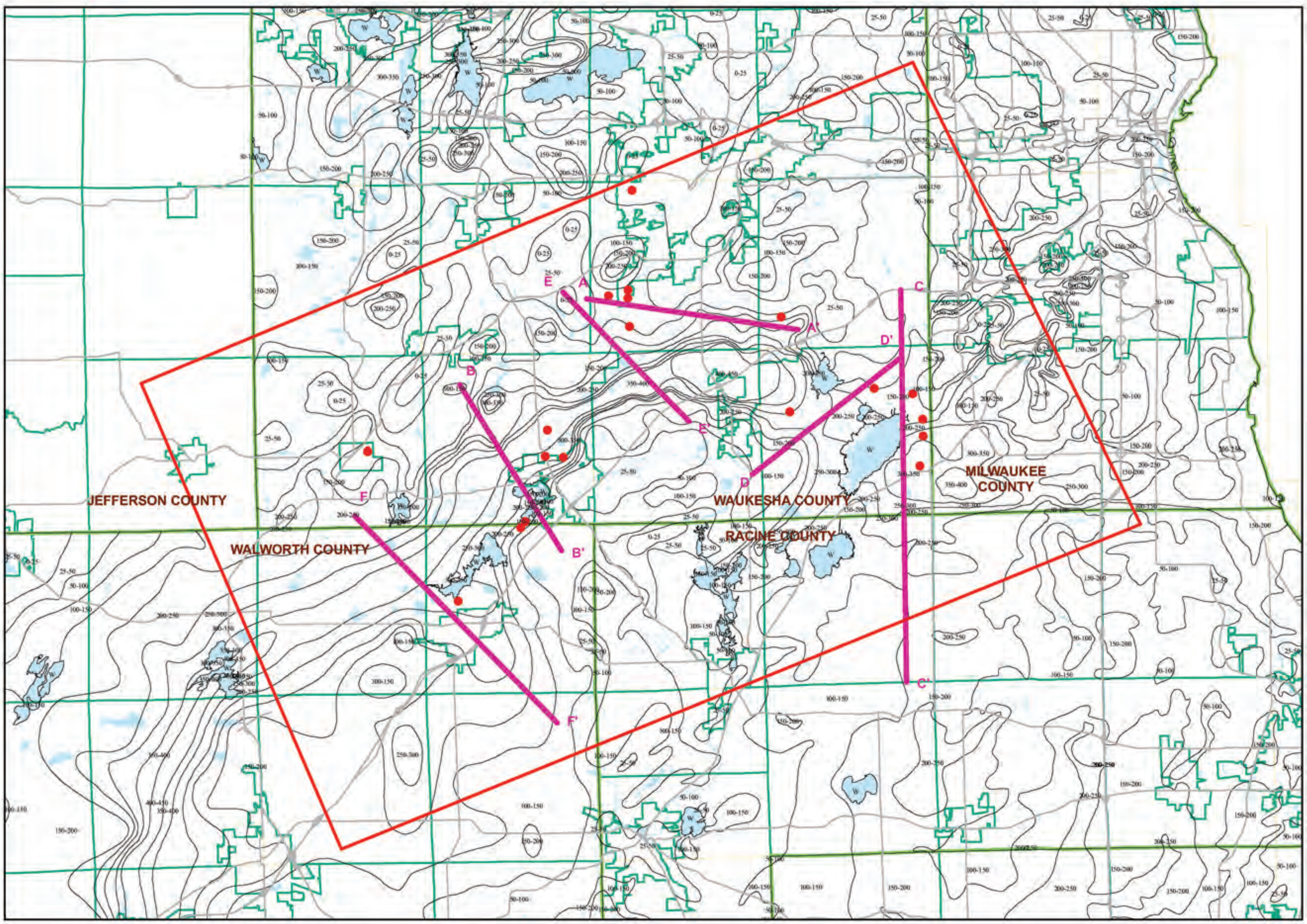
GEOPHYSICAL DATA



Source: Ruekert & Mielke, Inc.

Figure 4

GEOLOGIC CROSS-SECTION LOCATIONS



LEGEND

100-150	DEPTH TO BEDROCK		MUNICIPAL BOUNDARY
	TOWNSHIP LINES		APPROXIMATE MODEL NEAR FIELD
	COUNTY LINE	A A'	GEOLOGICAL CROSS-SECTION LOCATIONS A THROUGH F (SEE FIGURES 5 THROUGH 10)
	MAJOR HIGHWAYS		PUMPING TEST DATA POINT

GRAPHIC SCALE

0 1/2 1 2 3 4 MILE

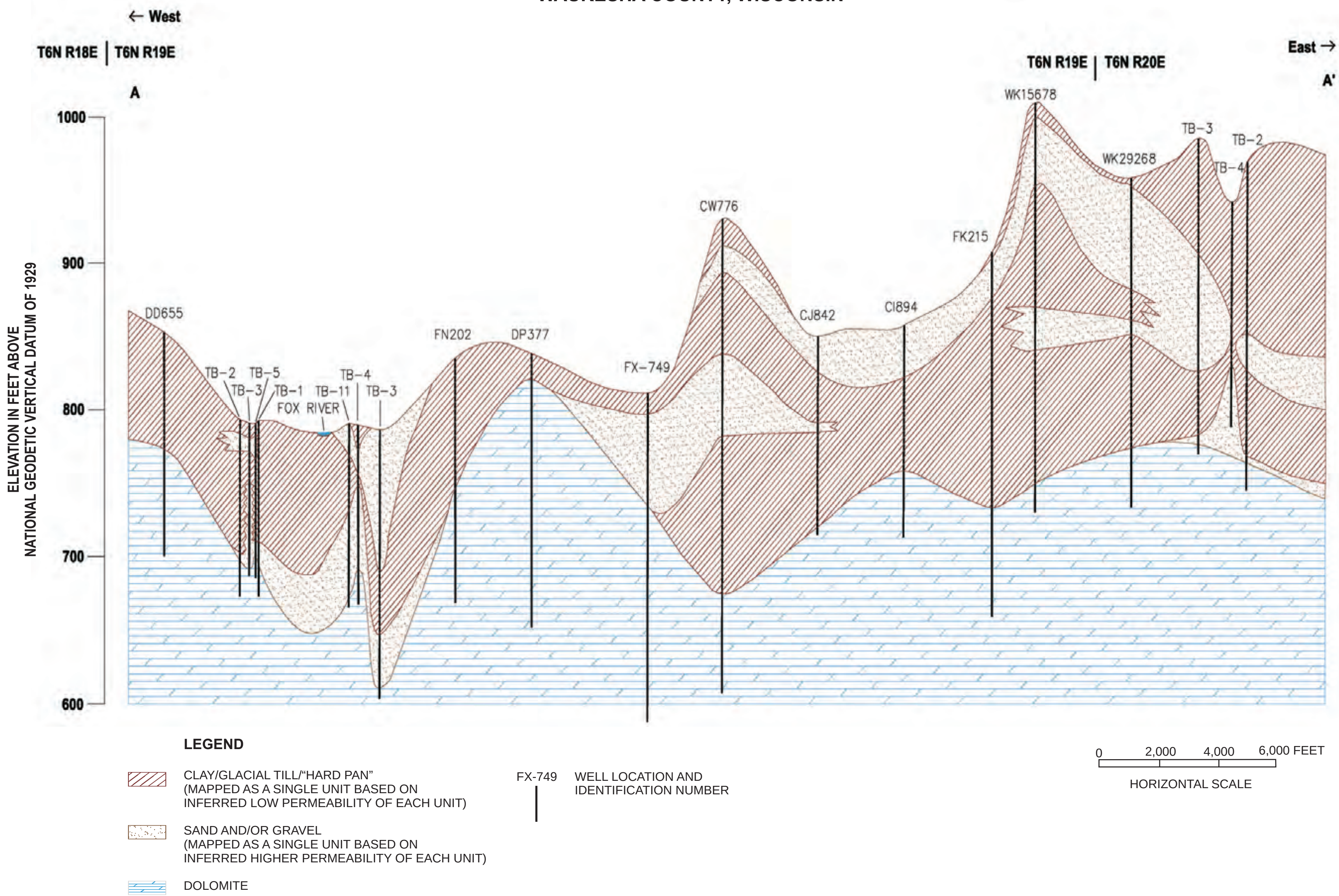
0 4,000 8,000 16,000 24,000 FEET

Source: Ruekert & Mielke, Inc.

Figure 5

CROSS-SECTION A - A'

TROY BEDROCK VALLEY
WAUKESHA COUNTY, WISCONSIN

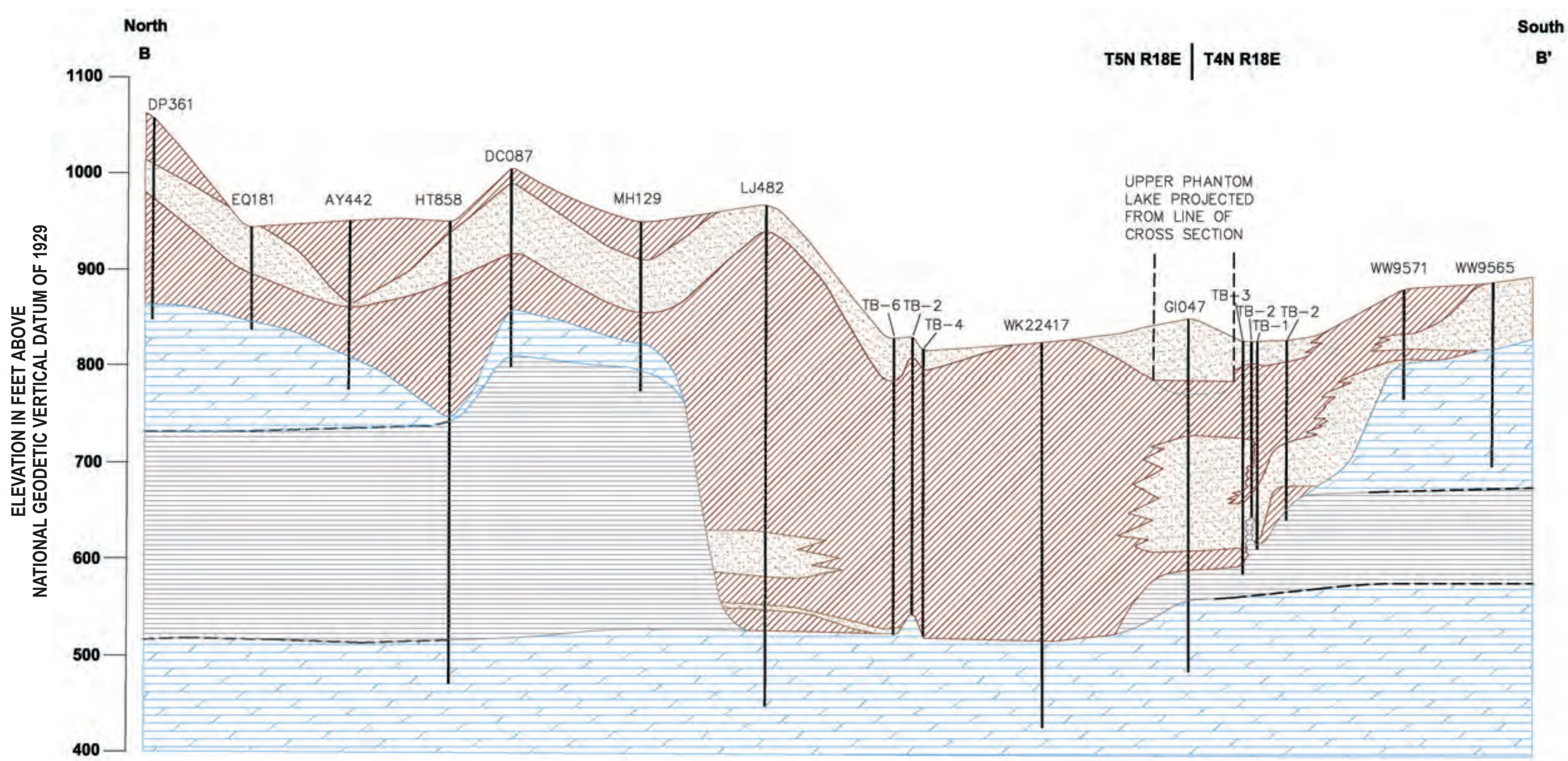


Source: Ruekert & Mielke, Inc.

Figure 6

CROSS-SECTION B - B’

TROY BEDROCK VALLEY
WAUKESHA AND WALWORTH COUNTIES, WISCONSIN



LEGEND

CLAY/GLACIAL TILL/“HARD PAN”
(MAPPED AS A SINGLE UNIT BASED ON
INFERRED LOW PERMEABILITY OF EACH UNIT)

SAND AND/OR GRAVEL
(MAPPED AS A SINGLE UNIT BASED ON
INFERRED HIGHER PERMEABILITY OF EACH UNIT)

SHALE

DOLOMITE

INFERRED LITHOLOGIC CONTACT

LJ-482 WELL LOCATION AND
IDENTIFICATION NUMBER

0 2,000 4,000 6,000 FEET

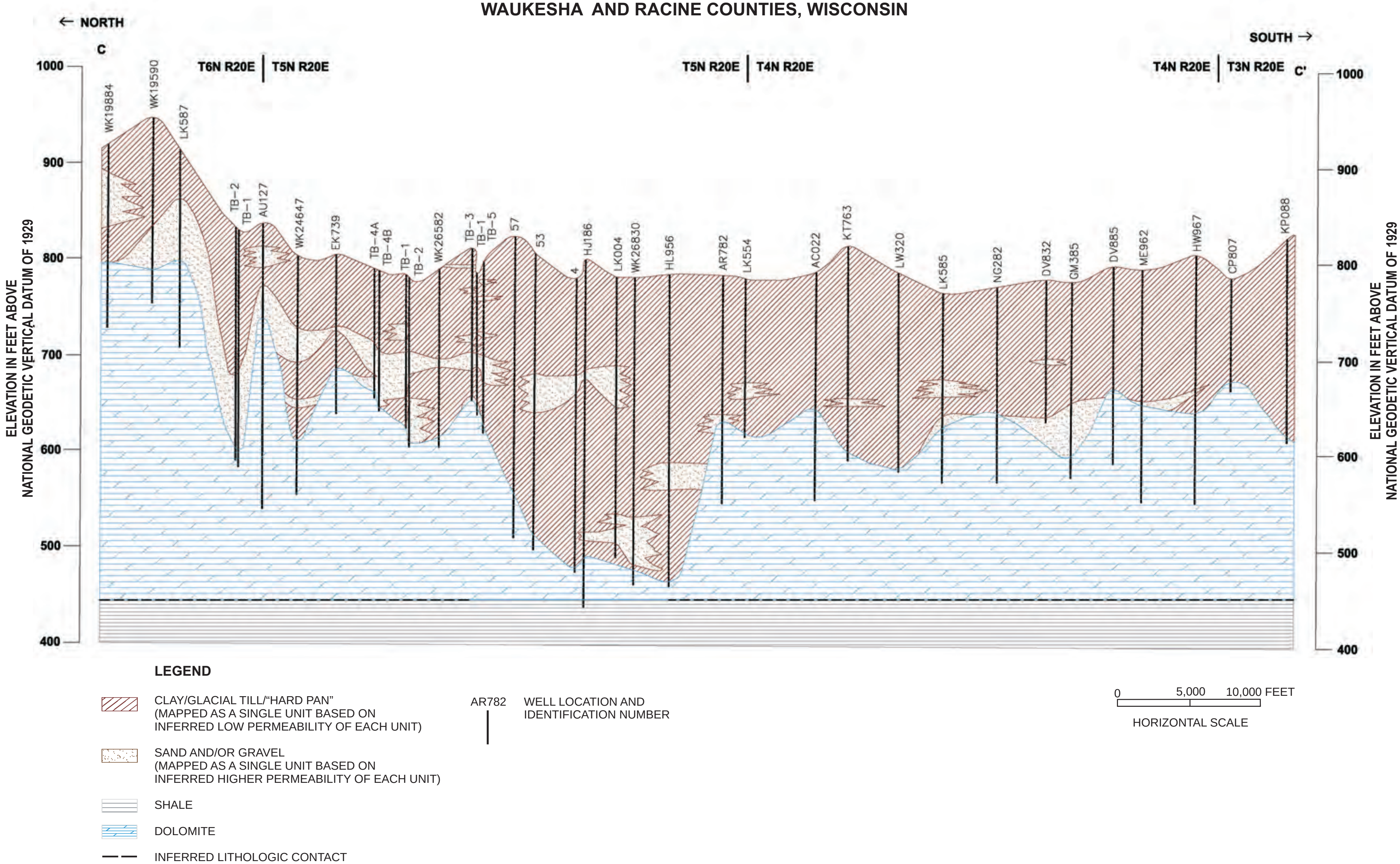
HORIZONTAL SCALE

Source: Ruekert & Mielke, Inc.

Figure 7

CROSS-SECTION C - C’

TROY BEDROCK VALLEY
WAUKESHA AND RACINE COUNTIES, WISCONSIN

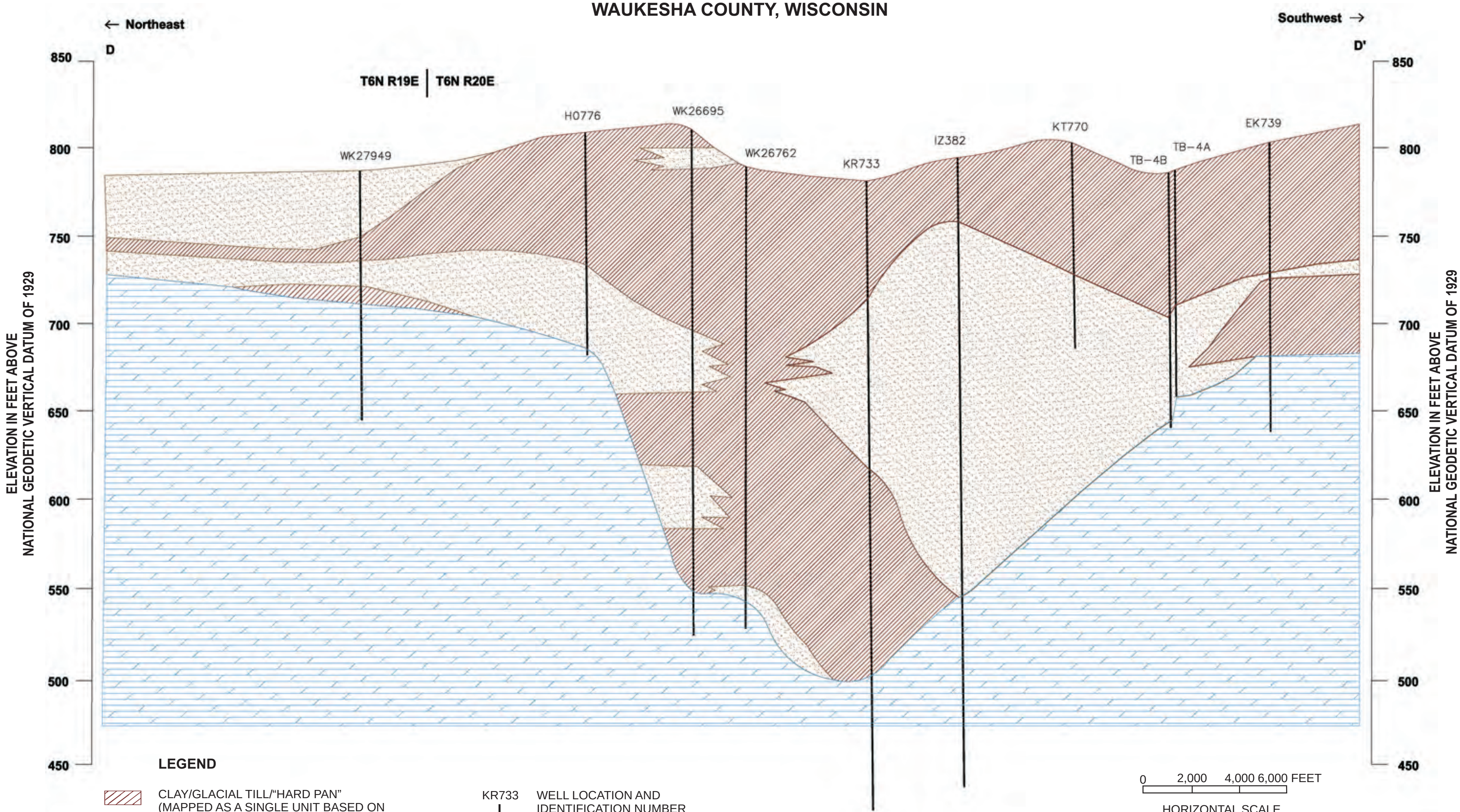


Source: Ruekert & Mielke, Inc.

Figure 8

CROSS-SECTION D - D’

TROY BEDROCK VALLEY
WAUKESHA COUNTY, WISCONSIN



LEGEND

CLAY/GLACIAL TILL/“HARD PAN”
(MAPPED AS A SINGLE UNIT BASED ON INFERRED LOW PERMEABILITY OF EACH UNIT)

SAND AND/OR GRAVEL
(MAPPED AS A SINGLE UNIT BASED ON INFERRED HIGHER PERMEABILITY OF EACH UNIT)

DOLOMITE

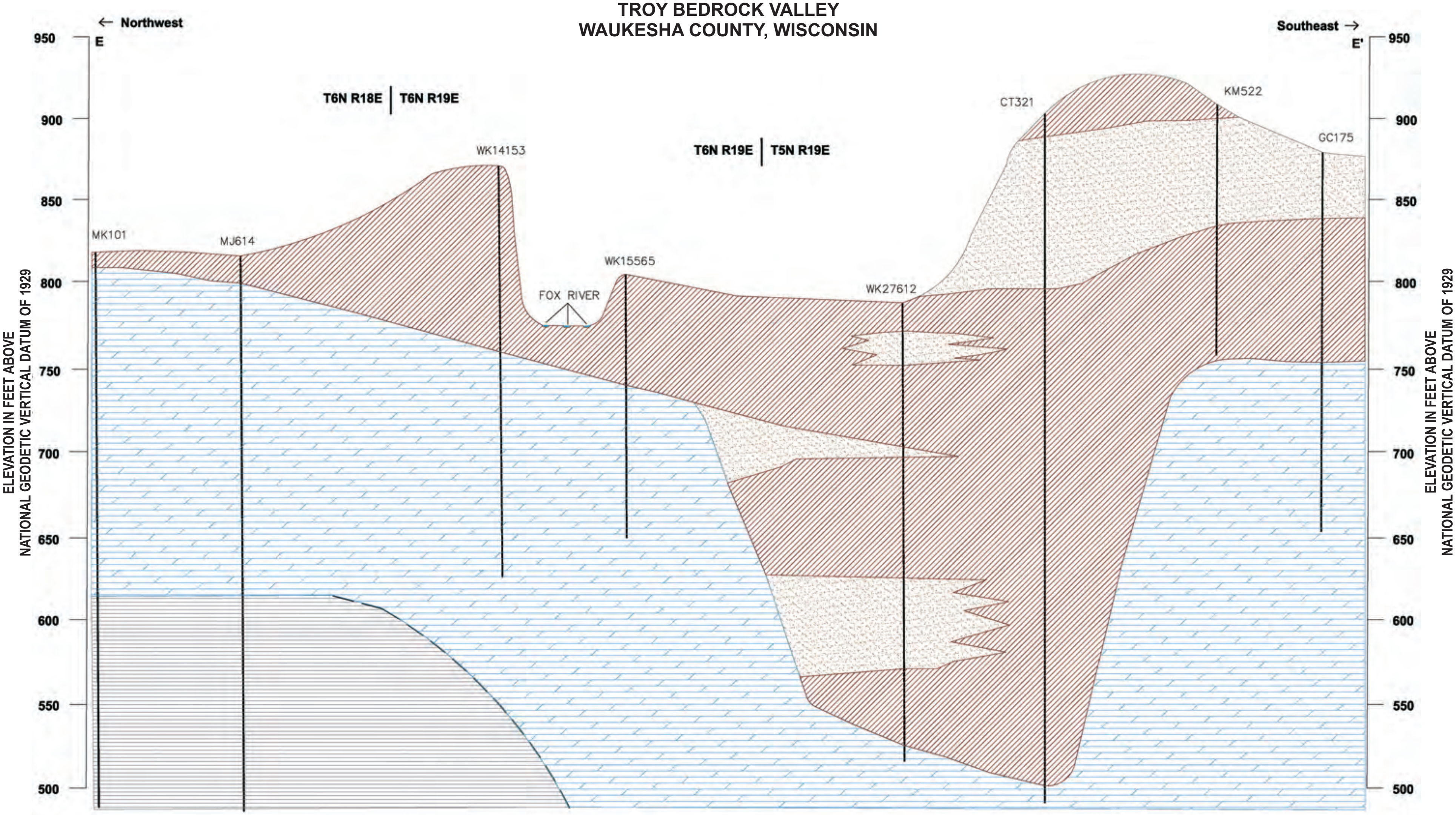
KR733 WELL LOCATION AND IDENTIFICATION NUMBER

Source: Ruekert & Mielke, Inc.

Figure 9

CROSS-SECTION E - E’

TROY BEDROCK VALLEY
WAUKESHA COUNTY, WISCONSIN



LEGEND

- CLAY/GLACIAL TILL/“HARD PAN” (MAPPED AS A SINGLE UNIT BASED ON INFERRED LOW PERMEABILITY OF EACH UNIT)
- SAND AND/OR GRAVEL (MAPPED AS A SINGLE UNIT BASED ON INFERRED HIGHER PERMEABILITY OF EACH UNIT)
- SHALE
- DOLOMITE
- INFERRED LITHOLOGIC CONTACT
- MJ614 WELL LOCATION AND IDENTIFICATION NUMBER

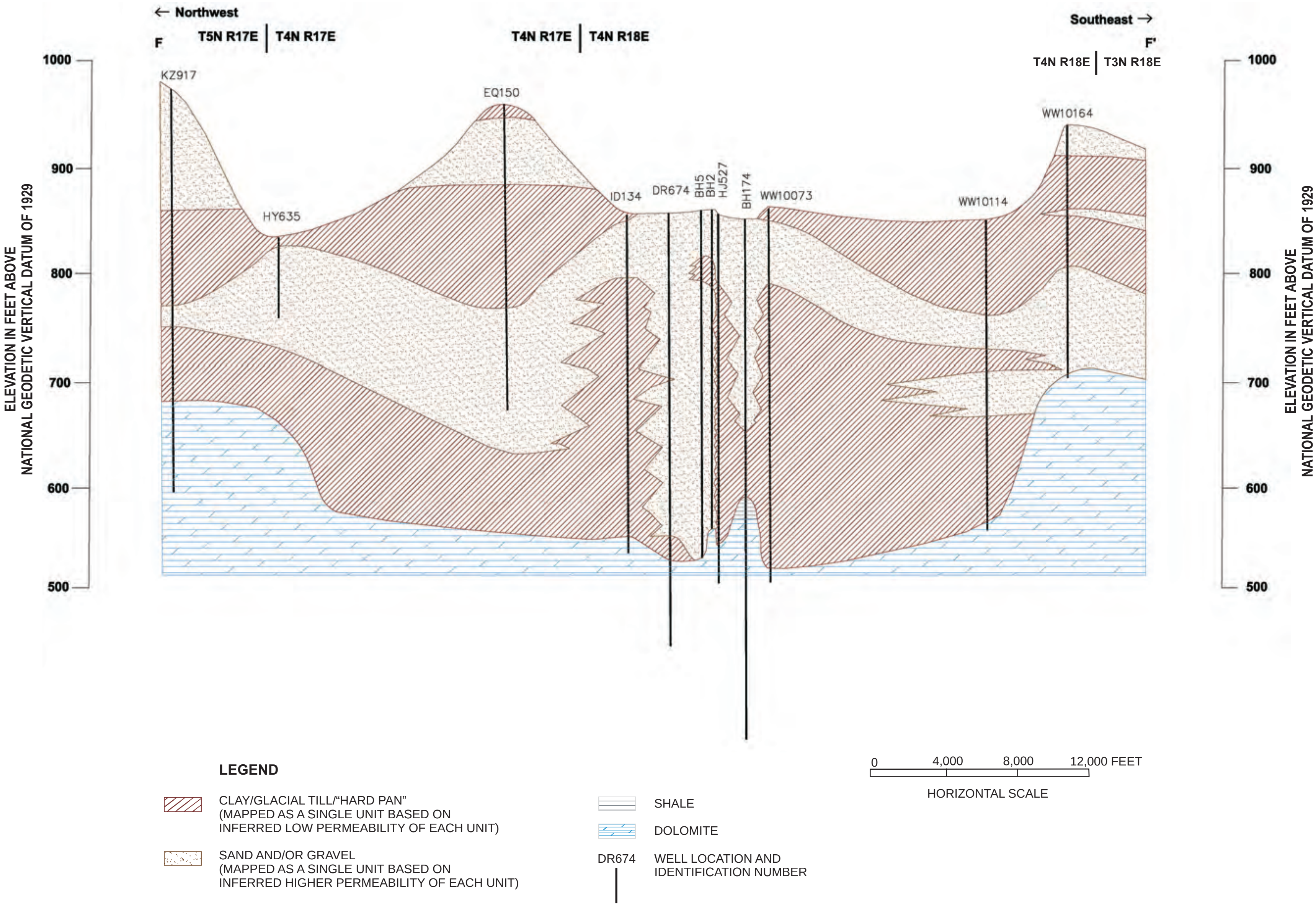
0 2,000 4,000 6,000 FEET
HORIZONTAL SCALE

Source: Ruekert & Mielke, Inc.

Figure 10

CROSS-SECTION D - D'

TROY BEDROCK VALLEY
WALWORTH AND WAUKESHA COUNTIES, WISCONSIN



Source: Ruekert & Mielke, Inc.

unit on a regional level. Any local scale groundwater studies within the Troy Bedrock Valley Aquifer should consider the potential impact of unknown windows through the confining unit on vertical flow between the units.

Beneath the confining unit lies a lower sand unit. The lower sand unit is not continuous but occurs as patchy deposits within a finer-grained matrix. The sand bodies were probably continuous while being deposited by outwash channels. They may still be largely continuous through sinuous channel deposits or truncated by subsequent ice advances or erosional processes. While the lower sand unit may not be continuous, it is a major aquifer in several areas and supports several high-capacity municipal wells.

Figure 11 is a conceptual representation of the depositional environments of the glacial units within the Troy Bedrock Valley. Sand and gravel deposits may have been present in the Valley prior to a glacial event. Water flowing away from the ice mass of the advancing glacier can deposit coarser grained outwash deposits with particle sizes ranging from fine sand to cobbles and boulders in front of the glacier on top of, or replacing, the pre-existing sand units. These deposits form the major aquifers in the Valley including the upper and lower sand units. The grain size of the outwash deposits varies with the velocity of the water in the melt water channel. Portions of the outwash plain with higher water velocity will have coarser and more permeable sand deposits. Areas with low flow velocities will have finer grained and less permeable deposits. The braided nature of the melt water channels across the relatively flat outwash plains created a complex mixture of coarser and finer grained facies that tend to be intertwined in elongated and often elliptical patterns.

When the glacier advanced in eastern Wisconsin, it deposits dense clay-rich till units at the base of the ice. The deposition of the till units can cover and distort underlying glacial deposits, such as outwash sands. When the glacier retreats, outwash sand is deposited on the till units. The flowing water can also cut into the till sheets, forming breaches—or windows—through the otherwise continuous till sheet. Lakes may form in front of the glacier and fine-grained glacio-lacustrine material may be deposited that consist of sand near the ice front with silt or clay particles farther into the lake basin.

Using this as a geologic model, the glacial deposits within the Troy Bedrock Valley may be interpreted as consisting of a lower aquifers of outwash or pre-glacial sand covered by till units, with an upper aquifer of outwash and ice contact deposits above the till units. It should be noted that while the geologic interpretation of the hydrostratigraphic sequence presented here is reasonable and conservative, other interpretations are possible and may indicate different spatial relationships between the geologic units, particularly at a local scale. For example, Dunkle (2008) and Mickelson and others (2008) used a geostatistical approach to interpolate data from several thousand local well construction reports and developed a slightly different hydrostratigraphic framework than presented here.

The Valley floor and Valley walls consist of Silurian dolomite over most of the model area. The Silurian dolomite is absent in the southwest portion of the model. The Maquoketa shale forms the Valley floor where the dolomite is absent. The deeper glacial units truncate against the Valley walls along the sides of the Valley.

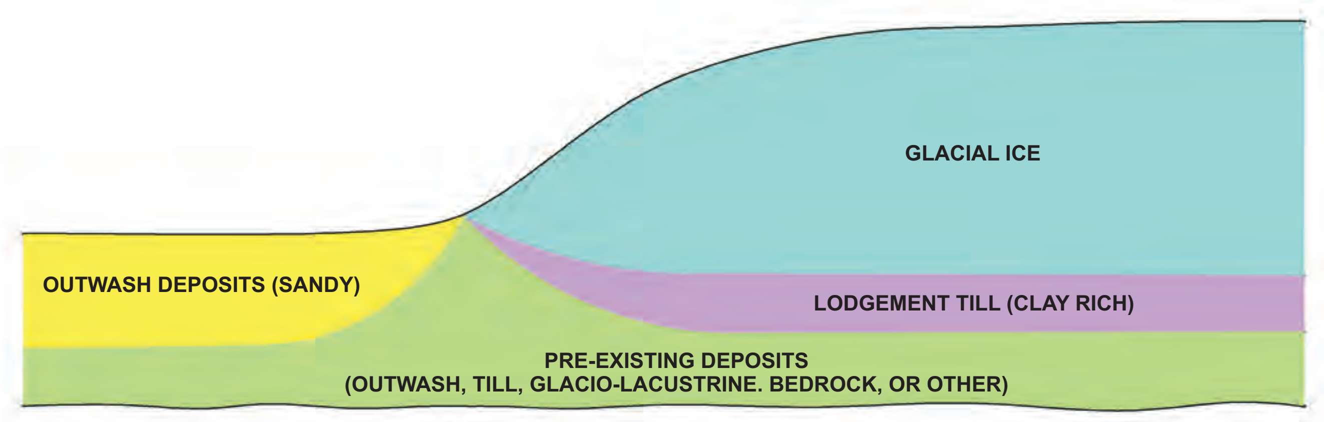
MODEL DESIGN

A three-dimensional MODFLOW model (McDonald and Harbaugh, 1984) was constructed using the geologic cross-sections as the framework to set the geometry of the model layers. The model was constructed using the Groundwater Vistas (Version 5) (ESI 2007) graphical user interface to create the data files and process the model output. Over 200 well construction reports from private wells were used

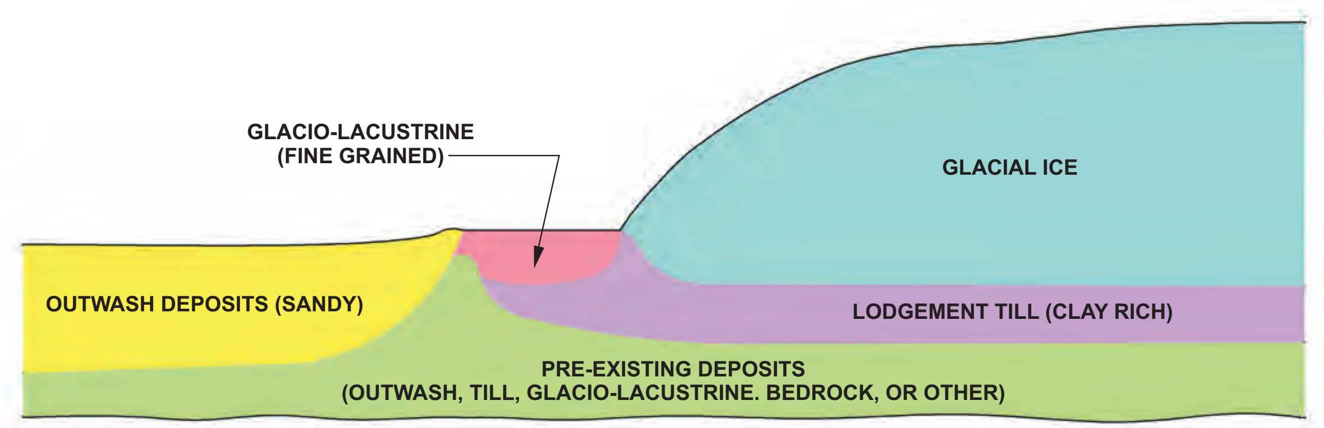
Figure 11

CONCEPTUAL MODEL OF THE DEPOSITIONAL ENVIRONMENT OF THE GLACIAL UNITS WITHIN THE TROY BEDROCK VALLEY

DEPOSITIONAL ENVIRONMENTS OF
AN ADVANCING CONTINENTAL GLACIER



DEPOSITIONAL ENVIRONMENTS OF
AN RECEDING OR STAGNANT CONTINENTAL GLACIER



Source: Ruekert and Mielke, Inc.

to help extrapolate the model geometry between the cross-sections and fill in areas with little information. Wells were chosen that had accurate locations and detailed and reasonable geologic logs. The model covers an area of approximately 34 by 23 miles across parts of Milwaukee, Waukesha, Walworth, and Jefferson Counties (**Figure 4**).

The model was extracted from the Regional Aquifer Model for Southeastern Wisconsin (the regional model—SEWRPC 2005) using the telescoping mesh refinement method. The regional model simulates the full thickness of the aquifer system in southeastern Wisconsin, including the Cambrian-Ordovician aquifer system, which is not included in the Troy Bedrock Valley Aquifer model. The regional model also has grid spacing of 2,500 feet, which is too coarse to simulate interactions between the surface water and groundwater on a local scale. The extracted model was modified to add additional detail including a smaller grid size, finer scale zonation of aquifer properties and recharge, more detailed discretization of the surface water features, and additional layers in the glacial deposits.

The Troy Bedrock Valley Aquifer model consists of 6 layers with 400 rows and 600 columns, for a total of 1,440,000 cells. The spacing on the rows and columns is constant at 300 feet. The grid is rotated 25 degrees from the model grid of the regional aquifer model to put the long axis of the Valley along the long axis of the model to minimize the size of the model domain required, allow the simulated flow to occur directly along rows or columns, and facilitate the potential use of anisotropic terms in the hydraulic conductivity field.

Significant rivers and lakes were simulated using 13,753 river cells in the River Package of the model. The elevations of the lake and stream surfaces were imported from the regional model and edited using U.S. Geological Survey (USGS) topographic maps to more accurately reflect the locations, model layers, widths, and elevations of the bodies at the finer resolution of the finer grid. Each river cell was assigned a length and width based on the portion of the cell occupied by the body based on the USGS topographic maps. The thickness of the stream bed was arbitrarily assumed to be 1 foot and the hydraulic conductivity of the bed was assigned the value of the layer it occupied. These values were used to compute a riverbed conductance term that was assigned to each river cell.

Wetlands were simulated using 59,714 drain cells in Layer 1. The location and elevation of the drain cells were assigned based on the location and elevation of wetlands on the USGS topographic maps.

The model layers correspond to the layering identified by the geologic cross-sections. The elevation of the layer tops and bottoms vary according to the geologic data. Where geologic layers truncate, the model layers thin to about 10 feet and take on the properties of the underlying layer. Plots of the bottom elevations and horizontal hydraulic conductivity fields of the layers are included in **Appendix B**.

The hydraulic conductivity zones of each layer were defined based on the geologic information on the well logs. A total of 11 hydraulic conductivity zones were defined. The initial horizontal hydraulic conductivity values for each zone were estimated from pumping test data, where available, and from the Regional Aquifer Model for Southeastern Wisconsin where no site specific data were available. Vertical hydraulic conductivity was initially assumed to be 10 percent of the horizontal hydraulic conductivity but was modified during the calibration process. The hydraulic conductivity values were also modified during the calibration process. The calibrated horizontal hydraulic conductivity values for each zone are provided on **Table 1**.

Layer 1 corresponds to the near surface glacial material and has more variable properties than the other layers. The top elevation of Layer 1 was defined as the land surface elevation from one inch equals 100

Table 1

SUMMARY OF CALIBRATED MODEL PARAMETERS

Zone	Kh (ft/day)	Kz (ft/day)	Recharge (ft/day)
1	7.1	1.5	5.80E-08
2	0.83	0.05	2.40E-03
3	6.49	0.5	1.40E-03
4	1.09E-03	1.00E-04	1.50E-07
5	1.32E-06	1.32E-06	9.97E-05
6	3.80E-03	5.10E-04	3.20E-04
7	1.82	0.5	4.56E-03
8	1.42	1	5.70E-04
9	50.00	5	6.85E-04
10	300.00	30	7.99E-04
11	100.00	10	2.57E-04
12	N/A	N/A	1.14E-04
13	N/A	N/A	4.56E-04

NOTE: The following abbreviations were used:

N/A = Not Applicable
Kh = Horizontal Hydraulic Conductivity
Kz = Vertical Hydraulic Conductivity
E = Exponentiation Indicator followed by the exponent to the power of 10 and preceded by the base. For example, 1.40E-3 = 1.40 X 10^{-3} or 0.00140

Source: Ruekert & Mielke, Inc.

feet and one inch equals 200 feet, two foot contour interval topographic maps prepared to SEWRPC standards. Layer 2 corresponds to the upper sand unit. The confining unit is simulated as Layer 3. Layer 4 represents the lower sand unit. The bedrock is simulated by Layer 5. Layer 6 represents the Maquoketa shale. Layer 1 was specified as a type 1 (unconfined) layer. Layers 2, 3, and 4 were specified as type 0 (confined) layers.

Small areas with high hydraulic conductivity were added to Layer 4 around several high-capacity wells. Aquifer properties from pumping tests showed that the transmissivity of the lower sand was significantly higher in these areas than is typical for the aquifer as a whole. These values were selected to represent a higher range of aquifer transmissivity because extensive geophysical exploration and test drilling were used to site these wells in the portions of the aquifer with the highest well yield, and the yield of these wells is much greater than an average well in the aquifer.

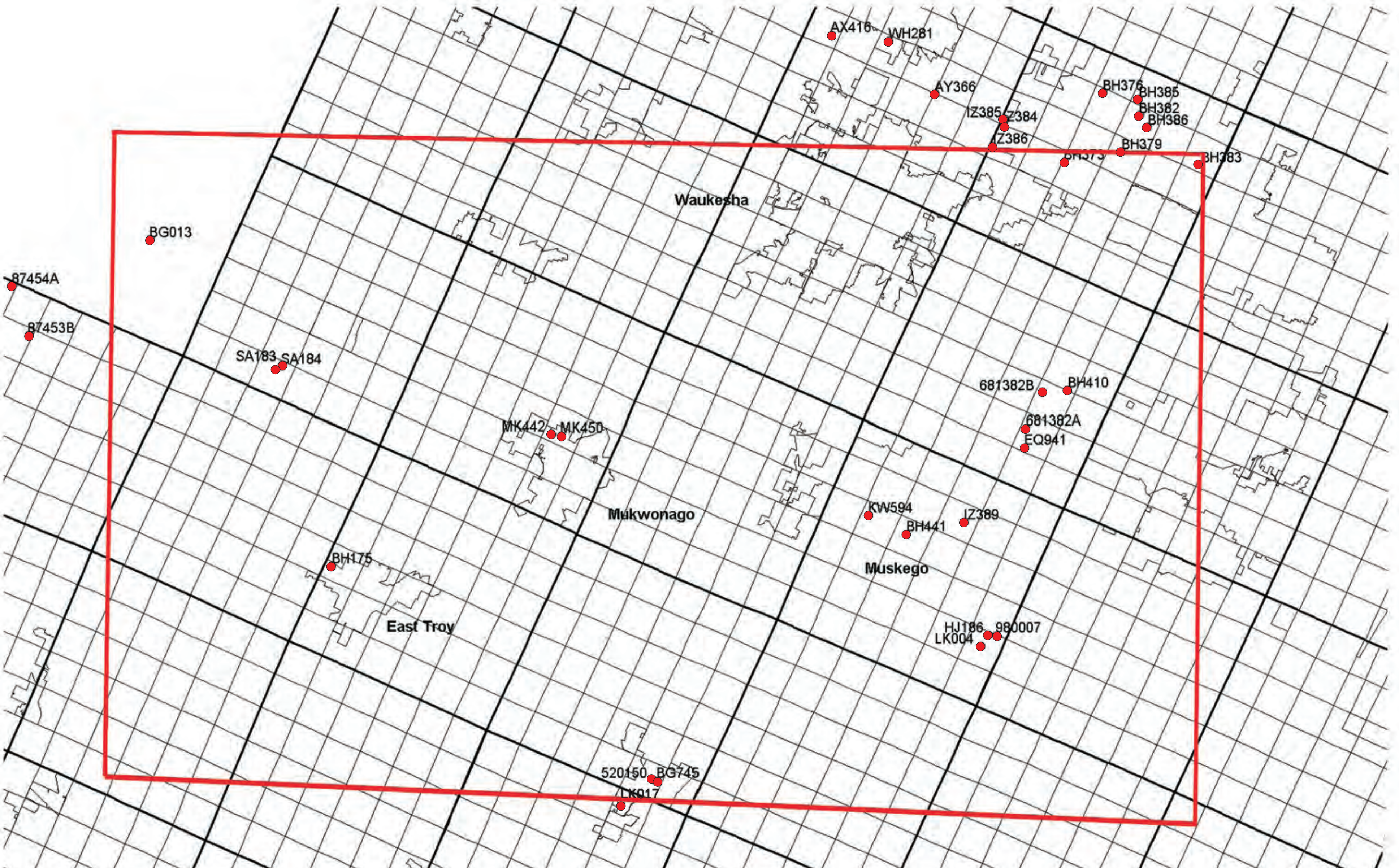
Test drilling results indicate that the most permeable sand and gravel deposits are limited in extent, but the actual extent of the high transmissivity zones around each well is not known. The pumping test data typically did not show any barrier boundaries during the extent of the tests, which were typically two to three days in duration. The radius of influence from the test data were used to set the minimum extent of the high transmissivity zones, and to modify the shape of the zones as indicated by geophysical or test drilling data. It is likely that the zones extend in an accurate fashion some distance down the long axis of the bedrock valley due to the geometry of the outwash channels that deposited the coarsest sand and gravel units. The true shapes of these zones are not known and may be important for some local scale flow patterns, but are not expected to be significant at the scale of this model.

The model boundaries were set as general head boundaries extracted from a calibrated simulation using the regional model. The boundaries were specified with 10,484 general head boundary cells across all six layers. Fluxes to and from the Cambrian-Ordovician aquifer are simulated by 3,427 flux wells in Layer 6 with flux values extracted from the regional model. The Troy Bedrock Valley aquifer model included 34 pumping wells taken from the latest update to the regional model. The location of the wells is shown on **Figure 12**. **Table 2** lists the pumping rates of the wells, which were taken from the SEWRPC regional model and represent the reported average pumpage from the well.

Initial recharge values were taken from SEWRPC Technical Report 47 (SEWRPC 2008), with the exception of the portion of Jefferson County covered by the model, which is outside of the SEWRPC planning area. Initial recharge values for this area were taken from the SEWRPC regional model (SEWRPC 2005). The larger grid size of the regional model gives the recharge zones in this area a much more blocky appearance. This area is relatively far from the Troy Bedrock Valley Aquifer and the coarser zonation should not significantly impact the model results. The recharge values were modified during the calibration process to improve the simulation results.

Figure 12

LOCATION OF PUMPING WELLS

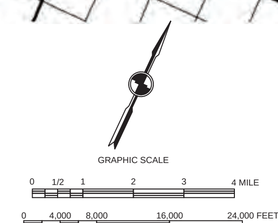


LEGEND

APPROXIMATE MODEL NEAR FIELD

BH379 PUMPING WELL LOCATION AND IDENTIFICATION NUMBER (SEE TABLE 2)

NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL



Source: Ruekert & Mielke, Inc.

Table 2

LIST OF PUMPING WELLS TROY BEDROCK VALLEY

Pumping Wells	Rate (ft^3/day)	Layer
87454A	-8,851.5	4 & 5
AX416	-5,040.4	4 & 5
KW594	-47,902.6	4
WH281	-57,516.0	1 & 2
BH441	-48,649.6	4
AY366	-37,053.0	4 & 5
IZ389	-19,250.0	5
LK004	-40,000.0	4
HJ186	-88,200.0	4 & 5
IZ386	-31,224.2	4 & 5
98007	-3,974.6	4 & 5
IZ384	-14,206.2	4 & 5
IZ385	-26,275.2	4 & 5
EQ941	-2,9504.0	5
681382A	-35,432.0	4 & 5
681382B	-35,432.0	4 & 5
BH373	-30,825.2	4 & 5
BH410	-26,051.0	4 & 5
BH376	-14,570.2	4 & 5
BH379	-14,443.2	4 & 5
BH385	-11,404.2	4 & 5
BH382	-53,041.2	4 & 5
BH386	-14,552.2	4 & 5
BH383	-35,760.2	4 & 5
BG013	-11,707.0	1
87453B	-8,851.4	4 & 5
SA184	-38,500.0	4
SA183	-38,500.0	4
BH175	-32,508.0	4
MK442	-6,605.0	4
MK450	-6,605.0	4
LK017	-24,009.3	4 & 5
520150	-30,608.0	4 & 5
BH745	-30,608.3	4 & 5

Source: Ruekert & Mielke, Inc.

MODEL CALIBRATION

The steady state model was calibrated to head, flux, and vertical gradient using data from wells, water table elevation maps, and stream gauges. The calibration was performed by both manual variation of aquifer properties and UCODE estimation of sensitive parameters.

A total of 133 head targets were assigned to the model using monitoring well data from the well siting studies used as the core of the model design, USGS monitoring wells, construction reports for private wells, and water table elevations taken from the SEWRPC water table map (SEWRPC 2002). All head targets were assigned a weighting factor of one for calibration purposes.

Initial calibration was accomplished by running sensitivity analyses on hydraulic properties to determine which parameters would produce the biggest changes in model results. Horizontal hydraulic conductivity of Zones 1, 2, 3, 5, 6, 7 and 8 and recharge in Zones 1, 2, 3 and 4 were found to be the most sensitive parameters. Hydraulic conductivity zone 1 represents the upper sand unit. Zone 3 represents the dolomite bedrock. Conductivity zones 5 and 6 represent low permeability glacial deposits in layer 1. Hydraulic conductivity zones 7 and 8 represent moderately permeable glacial units in layer 1. The UCODE automated calibration package was used to optimize the sensitive parameters using the head and flux targets. Manual modification of zone boundaries, river reach stages, and drain cell distribution and head values were made to optimize the calibration results. Stream flow data from three stream gauges were also used as flux reach calibration targets. The gauges were selected because they had relatively long periods of record and because the river reaches measured by the gauges were within the domain of the model. The flow values for each gauge were corrected to remove the discharge from upstream waste water treatment plant discharge which does not reflect true base flow conditions.

The goal of the flux target calibration was to produce modeled flows that lie between the stream flow exceeded 50 percent of the time (Q_{50}) and stream flow exceeded 80 percent of the time (Q_{80}) flows, and as close to the Q_{80} flows as possible. The Q_{50} and Q_{80} flows are the flow volumes that the stream flow exceeds in 50 percent and 80 percent of the period of record. USGS Stream Gauge 5543830 on the Fox River near Watertown Road was not used for calibration because most of the river reach contributing to the gauge extends beyond the limits of the model. Flux targets were assigned a weighting factor of 10 to 100 for calibration purposes.

Table 3 shows the modeled flux and the observed fluxes at each gauge. USGS Stream Gauges 5544371 and 5544385 were calibrated to between the observed Q_{50} and Q_{80} values. Gauge 5544200 has observed fluxes approximately one order of magnitude higher than the other gauges. The calibrated flux was below the Q_{80} value, but very near the stream flow exceeded 90 percent of the time (Q_{90}) value of 1.81 million ft^3 per day. The flux at this gauge could not be increased without unreasonable modification to the model. The Q_{90} value may be an adequate representation of the base flow in this gauge due to the high measured flow rates relative to the other gauges.

After the model was calibrated for head and flux, three transient simulations were conducted to calibrate the model to the vertical gradient observed during several high-capacity pumping tests for which data from wells in the upper and lower sand were available. Unconfined storage coefficients ranged between 0.05 and 0.35. Confined units were assigned a value of 0.01 to represent semi-confined conditions. The transient runs indicated that the vertical hydraulic conductivity of Zone 2 in Layer 3, the middle confining unit, was too high to support the vertical gradients observed during the pumping tests. The vertical hydraulic conductivity of Zone 2 was manually calibrated across the whole model to best fit the vertical gradient data of the three tests. The manual calibration resulted in a decrease in the vertical hydraulic conductivity of Zone 2 by about 40 percent. The reduction in vertical hydraulic conductivity of Zone 2 increased the residual mean error for the model from -3.4 feet to -5.0 feet and changed the flux targets by about 1 percent to 6 percent, but was necessary to reproduce the vertical gradients in the aquifer. This was deemed to be a more valid calibration value because it produced the best fit for all three calibration criteria.

The three transient calibration simulations were run for pumping tests on high-capacity wells for municipal well siting projects. The tests were chosen due to their location in the Valley and the availability of reliable water level measurements from both the upper and lower sand units. The wells used were: Village of East Troy Well No. 7, Village of Mukwonago Well No. 7, and Waukesha Water Utility Well No. 13. The locations of the wells are shown on **Figure 3**.

The transient simulations were run at the test pumping rate of the well using a single time step equal to the duration of the test. The vertical gradient at the end of the test between monitoring wells completed in the upper and lower sand were used for calibration. Monitoring wells were chosen at distances of several hundred feet from the pumping well to minimize discrepancies between the predicted drawdown and the observed drawdown due to the size of the grid cells.

Table 3 presents the results of the calibration. The residual mean of the head calibration was -5.0 feet for the model and ranged from -10.2 feet in Layer 4 to -0.5 feet in Layer 2. **Figure 13** is a plot of the observed heads and modeled heads. The plot shows a linear trend of points that cluster around a diagonal line, indicating good correlation between the observed and modeled heads with no consistent offset or clustering that would indicate a systematic error.

MODEL RESULTS

The model converges in less than 500 iterations and runs in about two minutes on an average 2009 vintage laptop computer, with an overall mass balance error of less than 0.1%. **Figure 14** is a plot of the simulated heads in Layer 1, shown as a color flood, and the water table map from SEWRPC Technical Report No. 37, (SEWRPC 2002) shown as contours. The modeled heads show strong correlation to the water table map in terms of general trends and absolute magnitude. On closer examination, several areas can be found where the model is not able to reproduce steep gradients seen on the water table map and produces a smoother water table surface. These areas may be caused by some combination of

Table 3

CALIBRATION SUMMARY: TROY BEDROCK VALLEY

Head Calibration		
Layer	# Targets	Residual Mean (ft)
All	133	-5.0
1	46	-7.1
2	36	-0.5
4	17	-10.2
5	34	-4.3

Flux Calibration				
Gauge Number	Location	Q50 (ft^3/day)	Q80 (ft^3/day)	Modeled Flux (ft^3/day)
5544200	Mukwonago River	3.98×10^6	2.36×10^6	1.52×10^6
5544371	Jewel Creek	6.05×10^5	2.59×10^5	3.49×10^5
5544385	Muskego Lake Outlet	7.72×10^5	2.97×10^5	6.33×10^5

Vertical Gradient Calibration				
Site	Pumping Rate (gpm)	Pumping Duration (hours)	Observed Gradient	Modeled Gradient
East Troy Well 7	400	72	-0.11	-0.080
Mukwonago Well 7	485	48	-0.09	-0.014
Waukesha Well 13	430	24	-0.38	-0.460

NOTES: Negative is downward gradient.

Q50 = Streamflow exceeded 50 percent of the time.
Q80 = Streamflow exceeded 80 percent of the time.

Source: Ruekert & Mielke, Inc.

insufficient complexity in the model to simulate local conditions, or errors in the water table map caused by the variable reliability of the well data used to make the map.

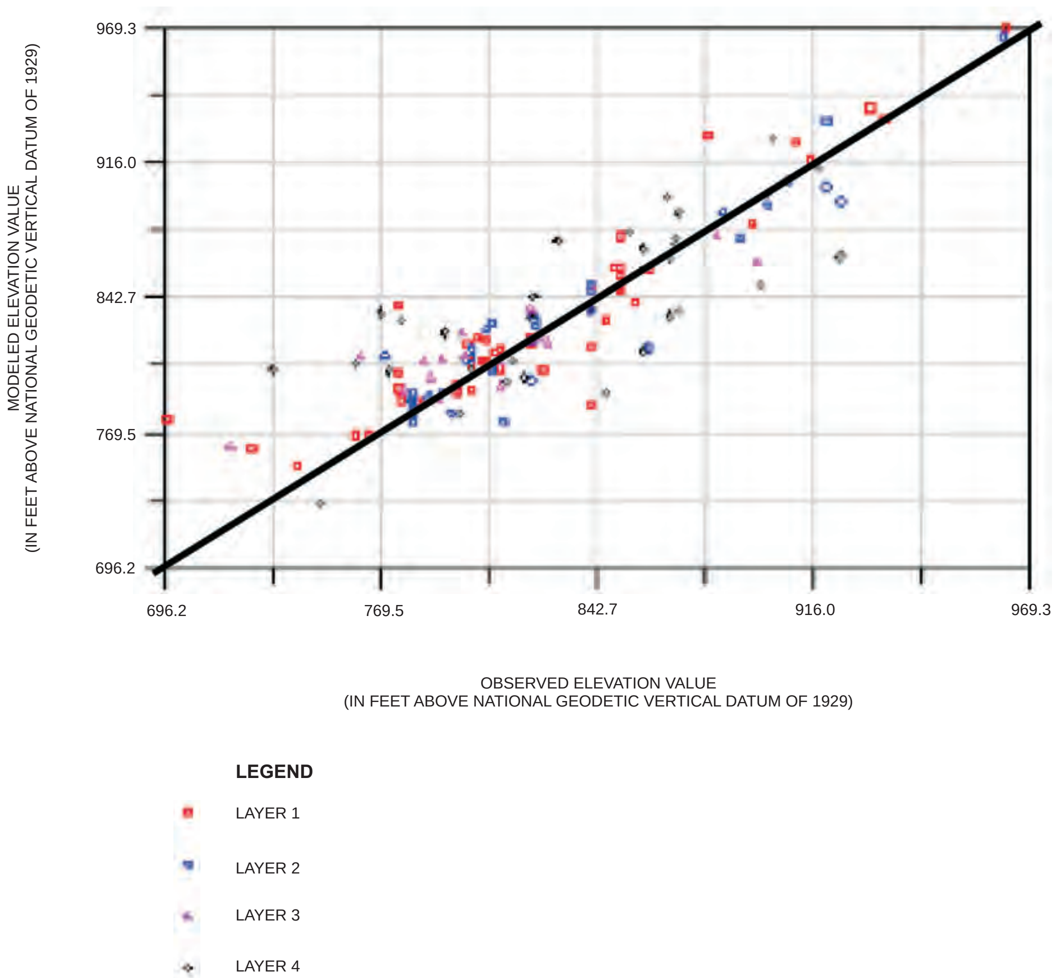
The model produces 52,197 dry cells (less than 4 percent of the total cells) in the upper four layers of the model. The dry cells occur because in some areas the geologic layers being simulated lie above the normal water table and the geologic material is unsaturated. Gonthier (1975) prepared a water table map of Waukesha County that indicated areas where the water table was within the Silurian dolomite bedrock. The dry cells in the model closely match the areas where Gonthier indicated the unconsolidated material was unsaturated.

USES FOR MODEL

The current Troy Valley model contains a great deal of local geologic data and complexity. It provides a reasonable simulation of water flow through the Troy Bedrock Valley aquifer. The model can be used in its current form to estimate the response of the aquifer system to a variety of natural or man-made changes and the effect those changes may have on water levels and discharges to surface water bodies. The model comprises a useful tool for municipalities and other interested or concerned agencies.

Figure 13

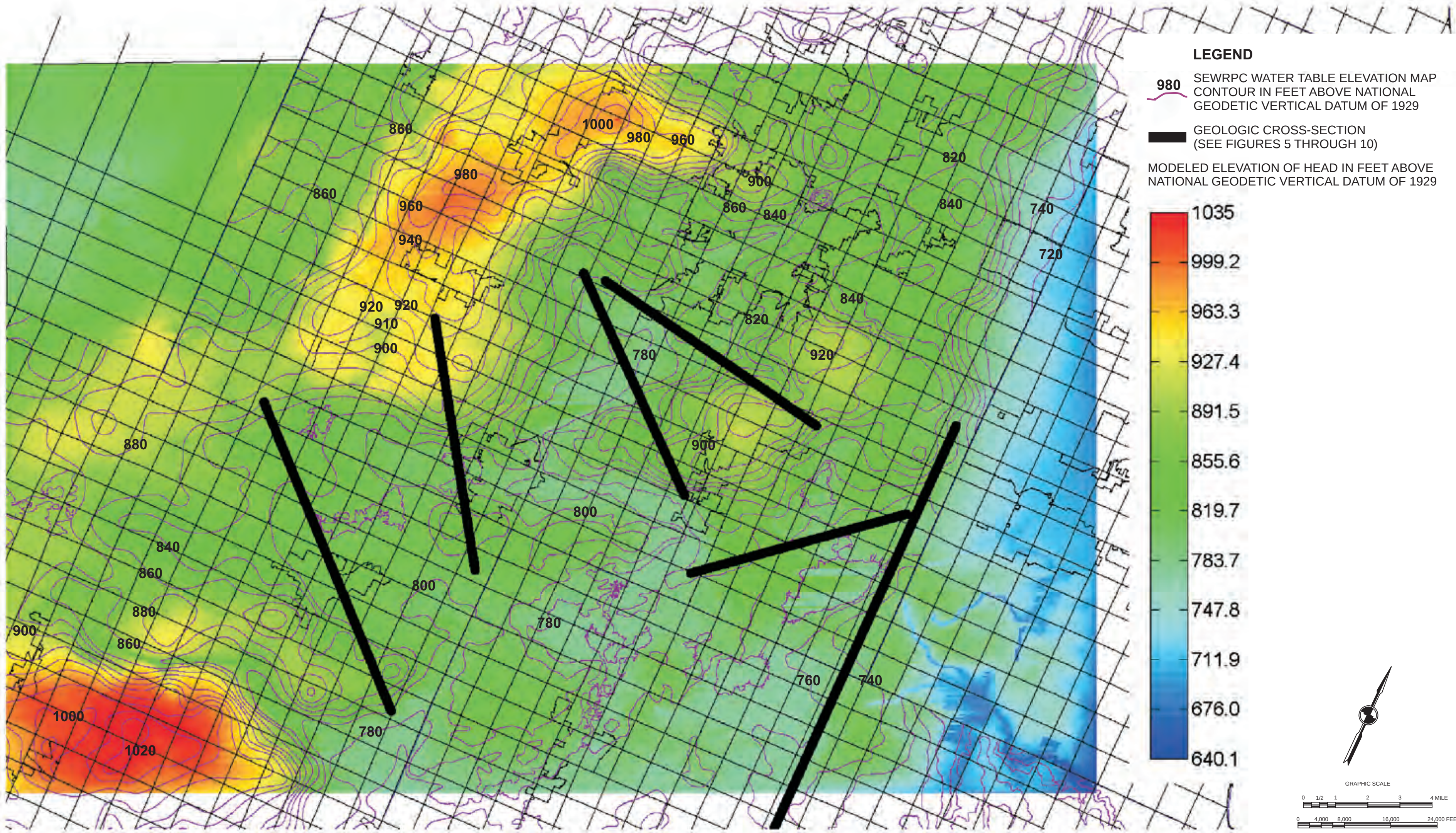
COMPARISON OF MODELED ELEVATIONS OF HEAD TO OBSERVED ELEVATIONS OF HEAD



Source: Ruekert & Mielke, Inc.

Figure 14

COMPARISON OF MODELED ELEVATION HEAD IN LAYER 1 TO SEWRPC WATER TABLE ELEVATION MAP



NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

It must be kept in mind that the geologic conditions in the Troy Bedrock Valley are only known in general terms. While the regional flow system is well described, the bedrock valley aquifer system is more complex than currently known. The model cannot, and does not, account for these unknown complexities, nor does it fully incorporate all of the geologic data available which can vary on scales smaller than the cell size of the model. Some of these variations between the model and the natural system may be significant, particularly on a local scale. In applying the model to estimate the local impacts to a particular water body or specific area it will be essential to consider the degree of geologic complexity necessary to produce a simulation to the degree of desired detail. It may be necessary to revise portions of the model or construct inset models within the larger model to obtain the degree of detail required for specific applications. In many cases it may be necessary to conduct additional testing to obtain the data needed add the degree of local detail desired.

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APPENDICES

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Appendix A

SUMMARY OF PUMPING TEST DATA

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Appendix A: Summary of Pumping Test Data

City	Site Name / Location	Well #/Pump Test	Residual Drawdown T (gpd/ft)	Residual Drawdown K (ft/day)	Distance Drawdown T (gpd/ft)	Distance Drawdown K (ft/day)	Solution	Solution T (gpd/ft)	Solution K (ft/day)	r/B	Storage Coefficient
East Troy	Well 7						Hantush (Leaky w/ Storage)	27,850.00	74.50	0.6	6.000E-04
	SW sec 17 T4NR18E										
Muskego	Well 13	TW-13/C.R. (24)	420,329	12,737.24	535,920	16,240.00	--	--		--	
	NW sec 11 T5NR20E										
	Well 9	TW-9/Step Test	149,300	7,109.52	--	--	--	--		--	
	SE sec 13 T5NR20E	TW-9/C.R. (24)	50,230	2,391.91	263,400	12,542.86	Hantush (Leaky w/ Storage)	15,249.70	726.18	--	2.708E-07
							Moench (Leaky)	24,660.00	1,174.29	0.102	2.654E-04
	Well 7	MW-1, TW Pumping Test					Couper-Jacob	21,262.00			7.0E-04
Mukwonago	YMCA Camp	TB-1/Step Test	38,200	3,820.00	--	--	--	--	--	--	--
	SE sec 24 T5NR18E	TB-2/Step Test	54,620	2,022.96	--	--	--	--	--	--	--
		TB-3/Step Test	31,680	1,320.00	--	--	--	--	--	--	--
	Well 7	TB-3/Step Test	62,645	2,505.80	--	--	--	--	--	--	--
	NE sec 3 T4NR18E	TW-7/C.R. (48)	--	--	--		Hantush (data from OW-1)	39,560.50	--	0.05	1.651E-03
	Well 5	TB-13/Step Test	103,900	4,722.73	107,360	--	--	--	--	--	--
	SW sec 23 T5NR18E				Semi-log Drawdown						
		TB-19/Step Test	50,285	4,880.00	52,800	--	--	--	--	--	--
	Well 6	TB-20/Step Test	155,760	2,225.14	47,925	--	--	--	--	--	--
	SW sec 23 T5NR18E	TB-22/Step Test	135,440	1,693.00	119,160	--	--	--	--	--	--
	Berg	TB-18/Step Test	18,150	550.00	--	--	--	--	--	--	--
	SW sec 23 T5NR18E										
Waukesha	Well 13	TW-13/C.R. (24)	11,643	612.79	--	--	Cooper & Jacob (data from TB-1)	10,213.10	537.53	--	1.285E-04
	SE sec 19 T6NR19E				--		Hantush (data from TB-1)	9,483.11	944.11	0.07	1.415E-04
		PW-13/Step Test	8,337	438.78	--	--	--	--	--	--	--
		PW-13/C.R. (24)									
					Semi-log Drawdown						
		TB-1	9,700		20,800						
		TB-3	6,350		8,250						
		TB-5	5,940		7,920						
	Well 11	TW-11/C.R. (??)	17,900								
	SW sec 20 T6NR19E										
	Well 12	TW-12/C.R. (??)	20,710								
	SW sec 20 T6NR19E										
	SW sec 20 T6NR19E	TB-1/Step Test	10,200				Modified Jacob				
	SW sec 20 T6NR19E	TB-2/Step Test	29,300				Modified Jacob				
	Howell Trust	TB-1/Step Test	2,540	169.33	--	--	--	--	--	--	--
	NW sec 6 T6NR19E				Jacob Equation						
	Lathers	TB-1 Upper/Step Test	13,750	1,840.00	27,400	3,660.00	--	--	--	--	--
	S sec 29 T6NR19E	TB-1 Lower/Step Test	11,310	1,510.00	13,400	1,790.00	--	--	--	--	--
	N sec 32 T6NR19E										
	S sec 29 T6NR19E	TB-3/Step Test	1,320	175.00	5,410	690.00	--	--	--	--	--
	N sec 32 T6NR19E										
	S sec 29 T6NR19E	TB-7/Step Test	23,290	2,329.00	29,400	2,940.00	--	--	--	--	--
	N sec 32 T6NR19E										
	S sec 29 T6NR19E	TB-8/Step Test	19,800	1,237.50	19,500	1,218.75	--	--	--	--	--
	N sec 32 T6NR19E										
	S sec 29 T6NR19E	TB-9/Step Test	20,200	918.18	20,850	947.72	--	--	--	--	--
	N sec 32 T6NR19E										
	S sec 29 T6NR19E	TB-10/Step Test	8,230	685.83	15,150	1,262.50	--	--	--	--	--
	N sec 32 T6NR19E										
	Ransome Farm	TW-2/C.R. (2.5)	2,640	--	1,820	--	--	--	--	--	--
	NE sec 31 T6NR19E										

Appendix A (continued)

City	Site Name / Location	Well #/Pump Test	Residual Drawdown T (gpd/ft)	Residual Drawdown K (ft/day)	Distance Drawdown T (gpd/ft)	Distance Drawdown K (ft/day)	Solution	Solution T (gpd/ft)	Solution K (ft/day)	r/B	Storage Coefficient
Eagle	Wells 3 & 4	TW-3/C.R. (24)	497,400	11,567.44	153,700	3,574.42	Neuman (Uncon. data from OW-3)	165,591.00	3,850.95	--	0.919
	NE sec 33 T5NR17E	TW-4/C.R. (24)	--	--	221,100	3,878.95	Neuman (Uncon. data from OW-1)	82,253.20	1,443.04	--	4.518E-04
	NE sec 33 T5NR17E				Jacob Equation						
Brookfield	Weston Hills	TB-1/Step Test	1,865.00	6.41	3,750	12.89	--	--	--	--	--
	SE sec 32 T7NR20E				Jacob Equation						
New Berlin	Johnson Pit	TB-2/Step Test	22,630	628.61	35,700	991.67	--	--	--	--	--
	SE sec 31 T6NR20E	TB-4/Step Test	10,730	249.53	33,425	777.33	--	--	--	--	--
	SE sec 31 T6NR20E	TB-5/Step Test	2,790	186.00	9,540	636.00	--	--	--	--	--
	SE sec 31 T6NR20E				Jacob Equation						
	Well 11	Marcus-2/Step Test	264,000	26,400.00	15,050	1,505.00	--	--	--	--	--
	SE sec 36 T6NR20E										

Source: Ruekert & Mielke, Inc.

Appendix B

PLOTS OF LAYER ELEVATION, RECHARGE, AND HYDRAULIC CONDUCTIVITY FIELDS

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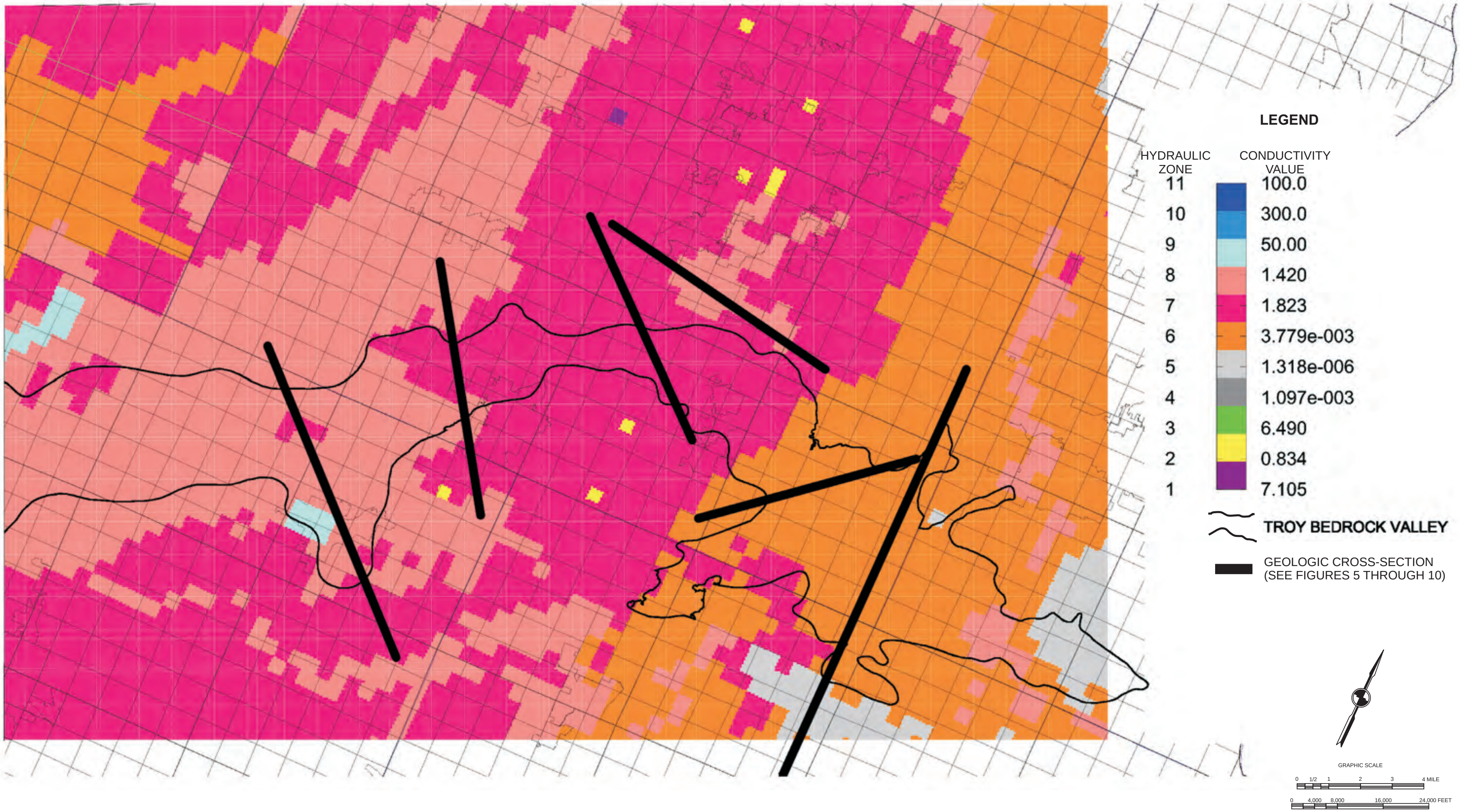
Figure B-1

LAYER 1 HORIZONTAL HYDRAULIC CONDUCTIVITY

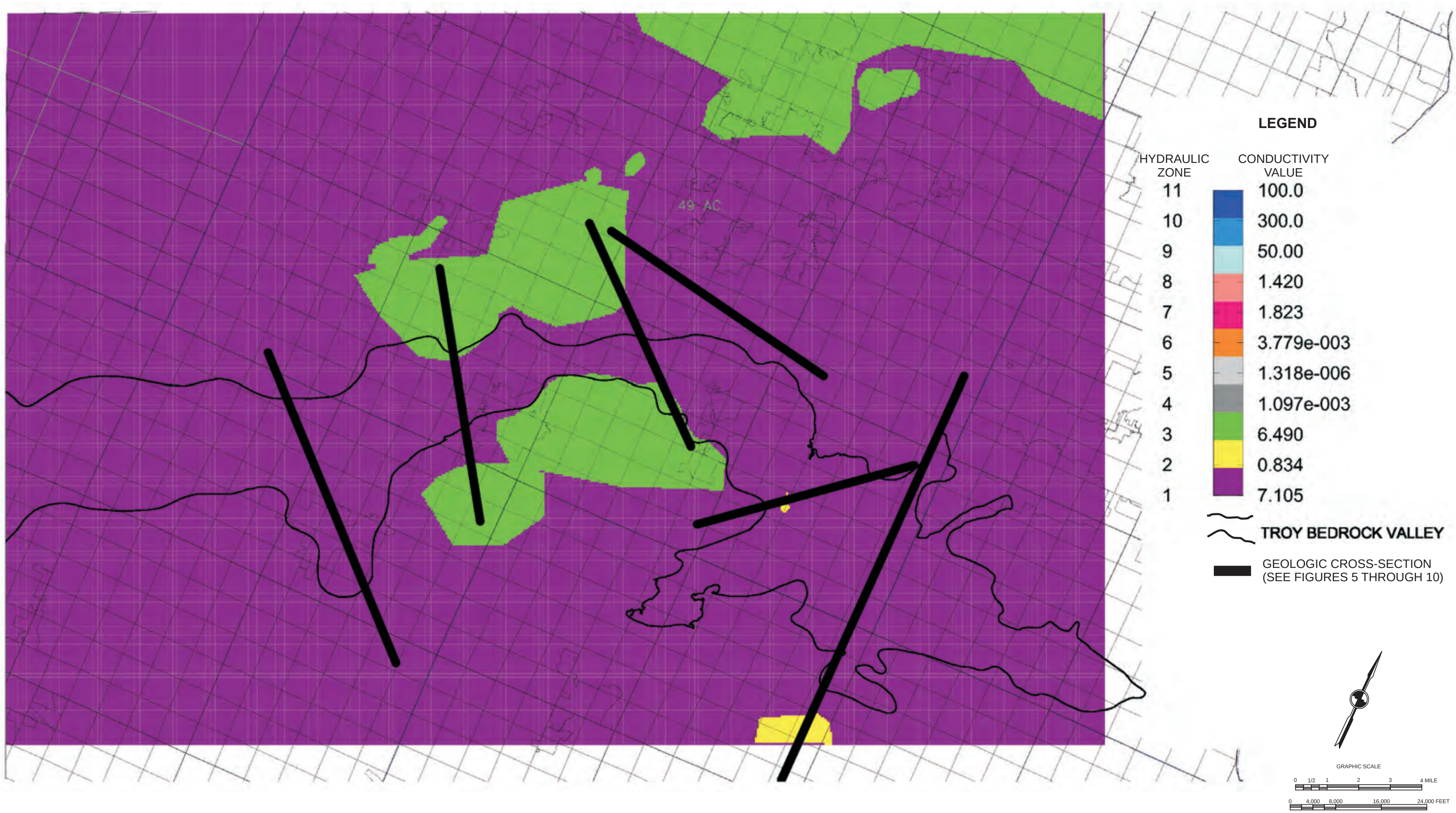


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-2

LAYER 2 HORIZONTAL HYDRAULIC CONDUCTIVITY

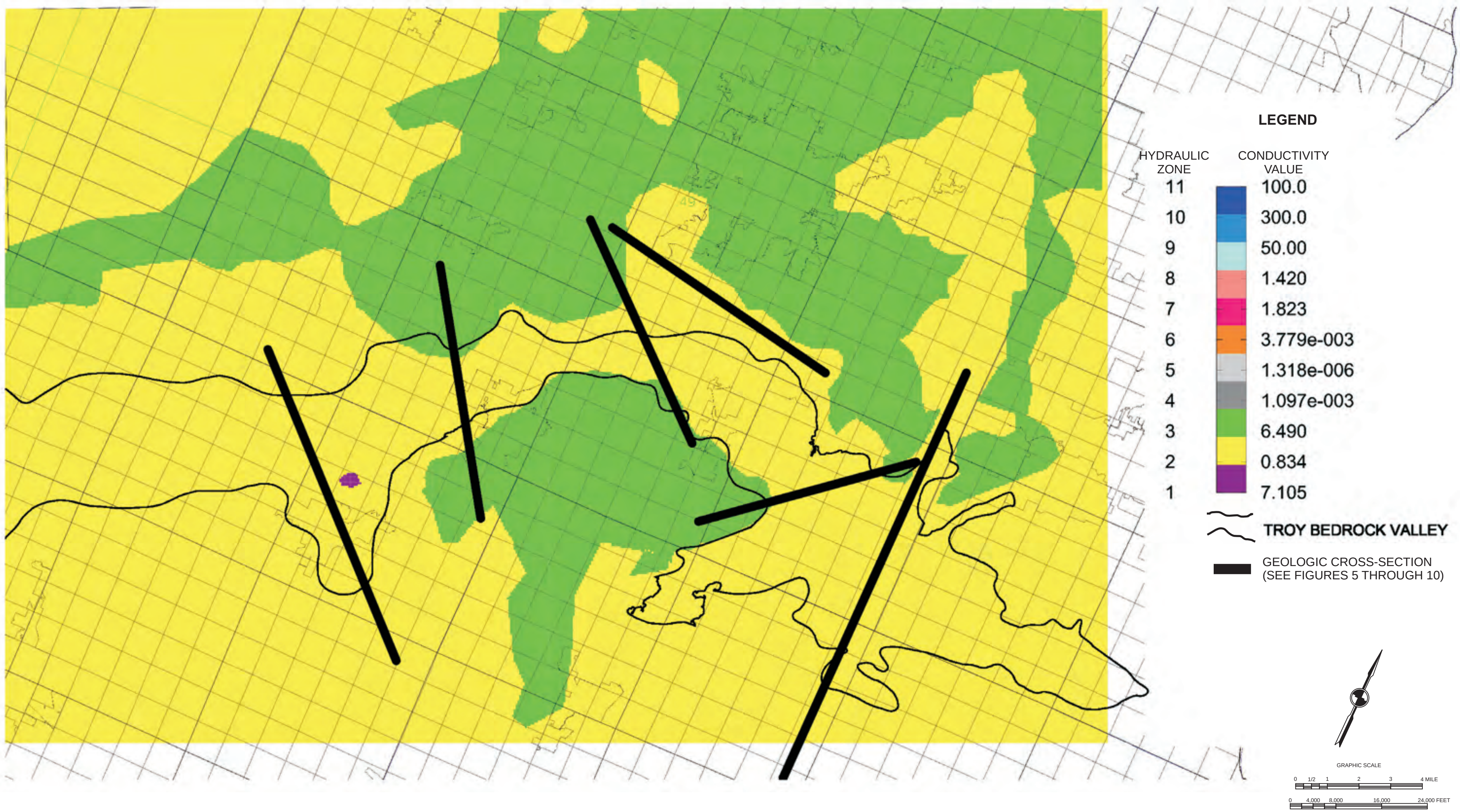


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-3

LAYER 3 HORIZONTAL HYDRAULIC CONDUCTIVITY

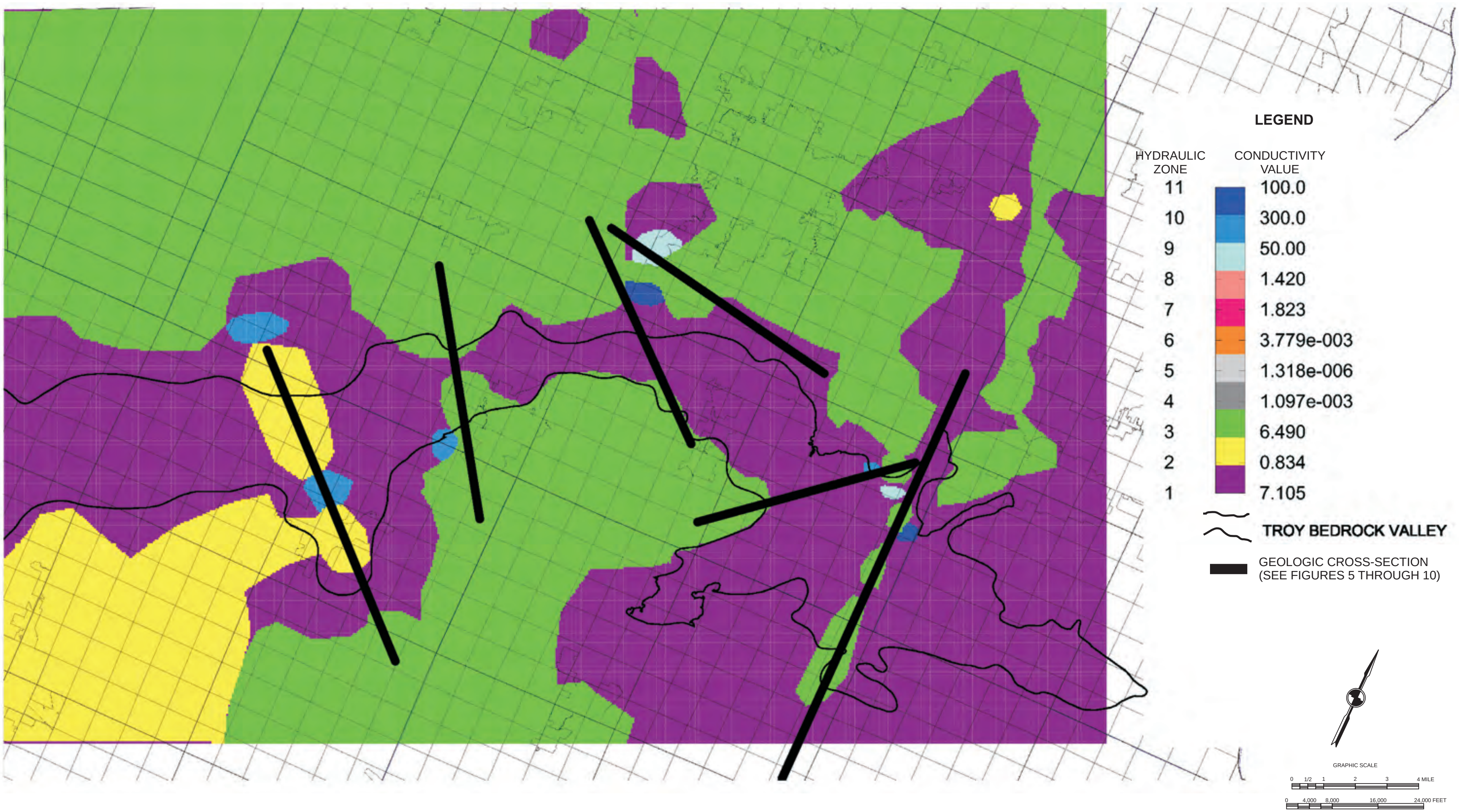


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-4

LAYER 4 HORIZONTAL HYDRAULIC CONDUCTIVITY

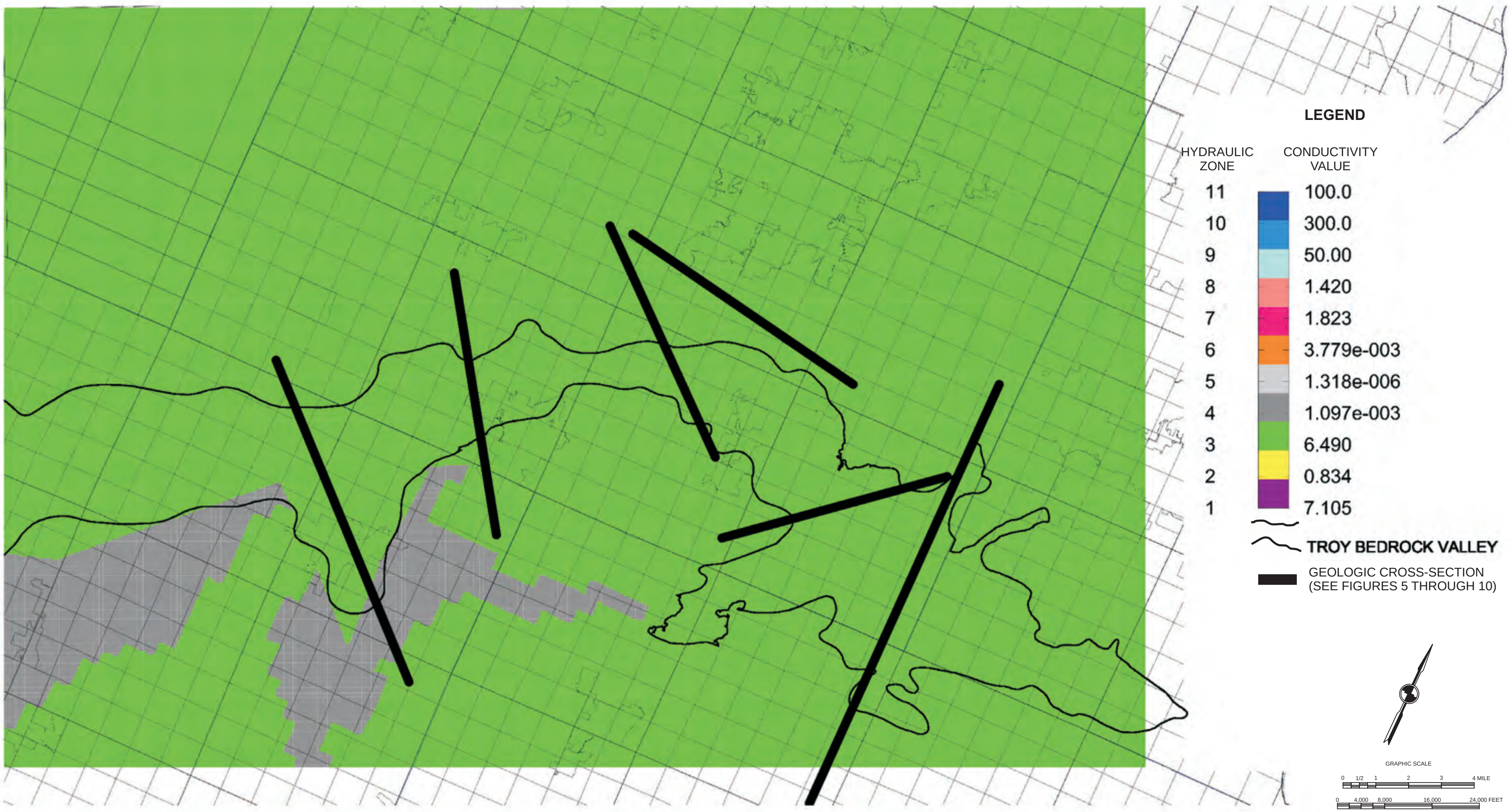


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-5

LAYER 5 HORIZONTAL HYDRAULIC CONDUCTIVITY

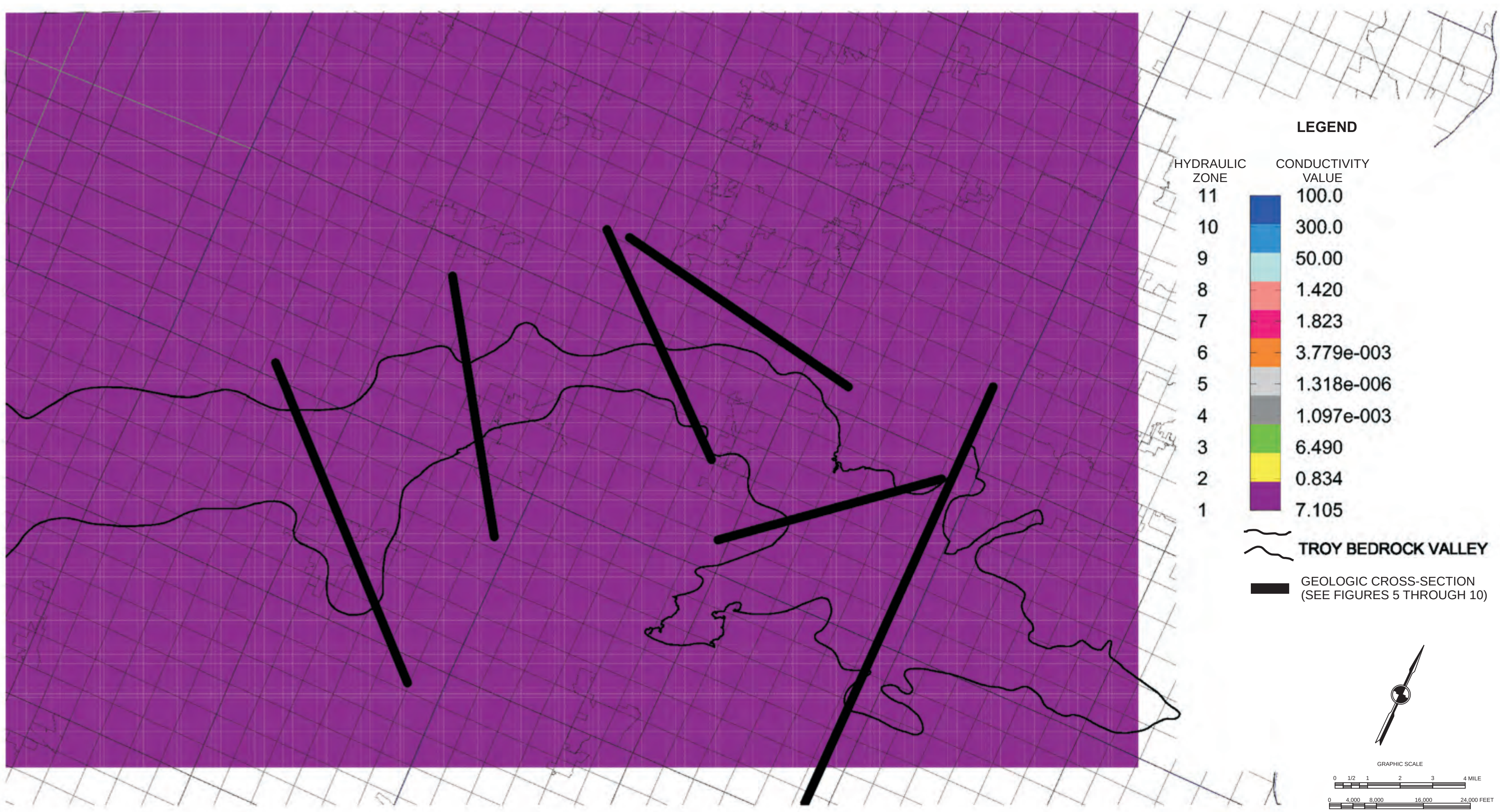


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-6

LAYER 6 HORIZONTAL HYDRAULIC CONDUCTIVITY

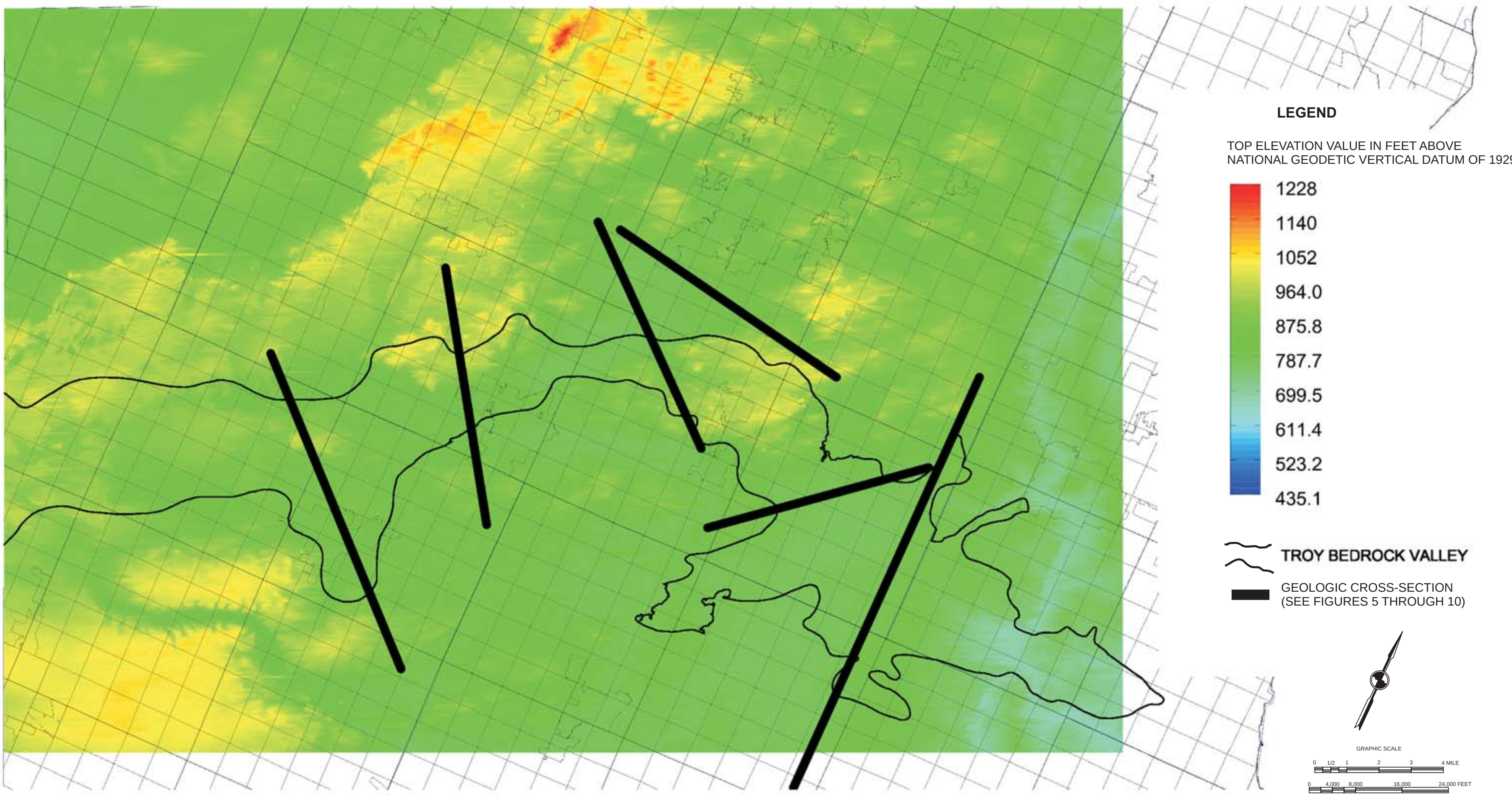


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-7

TOP OF LAYER 1

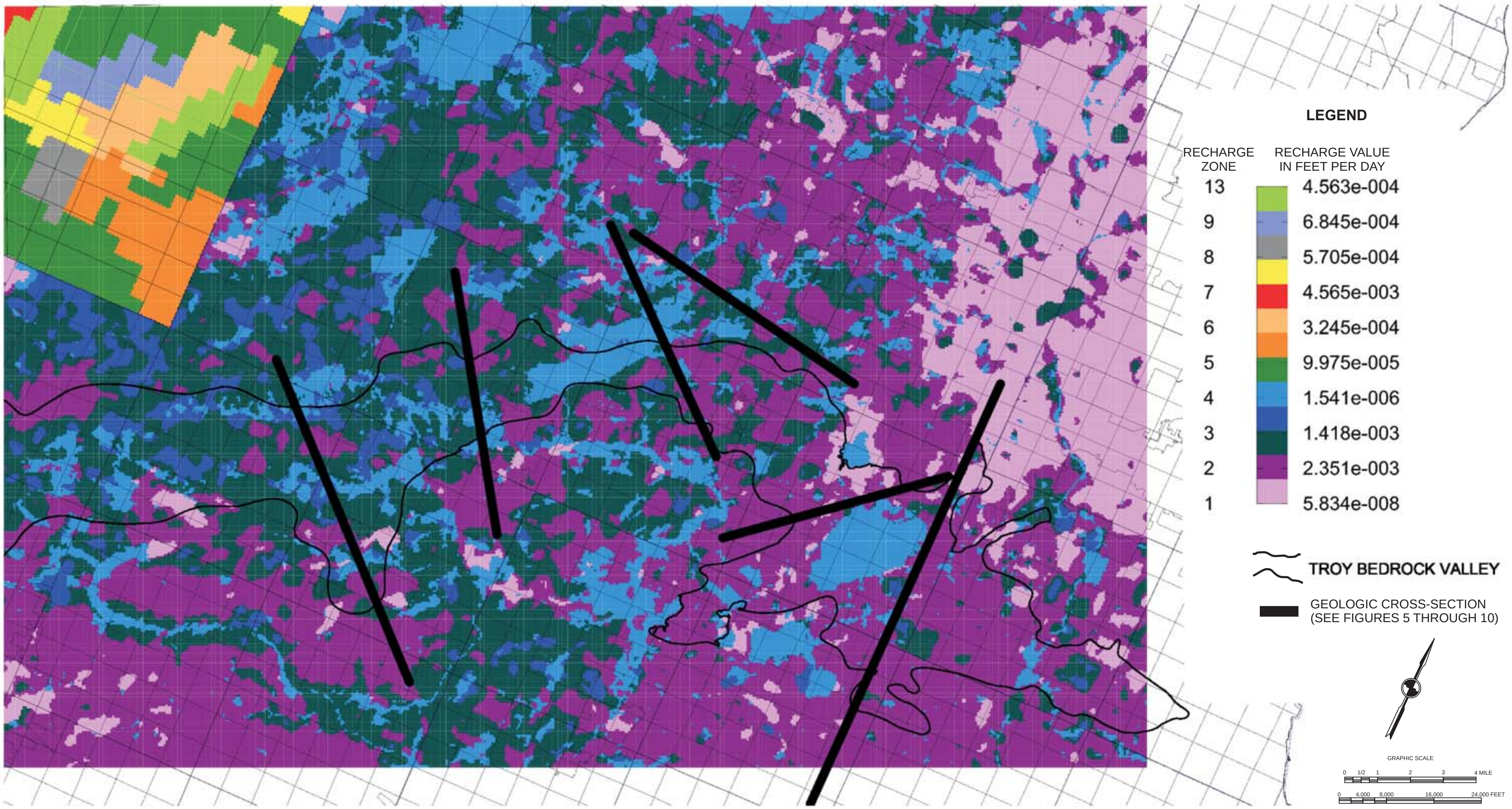


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-8

LAYER 1 RECHARGE

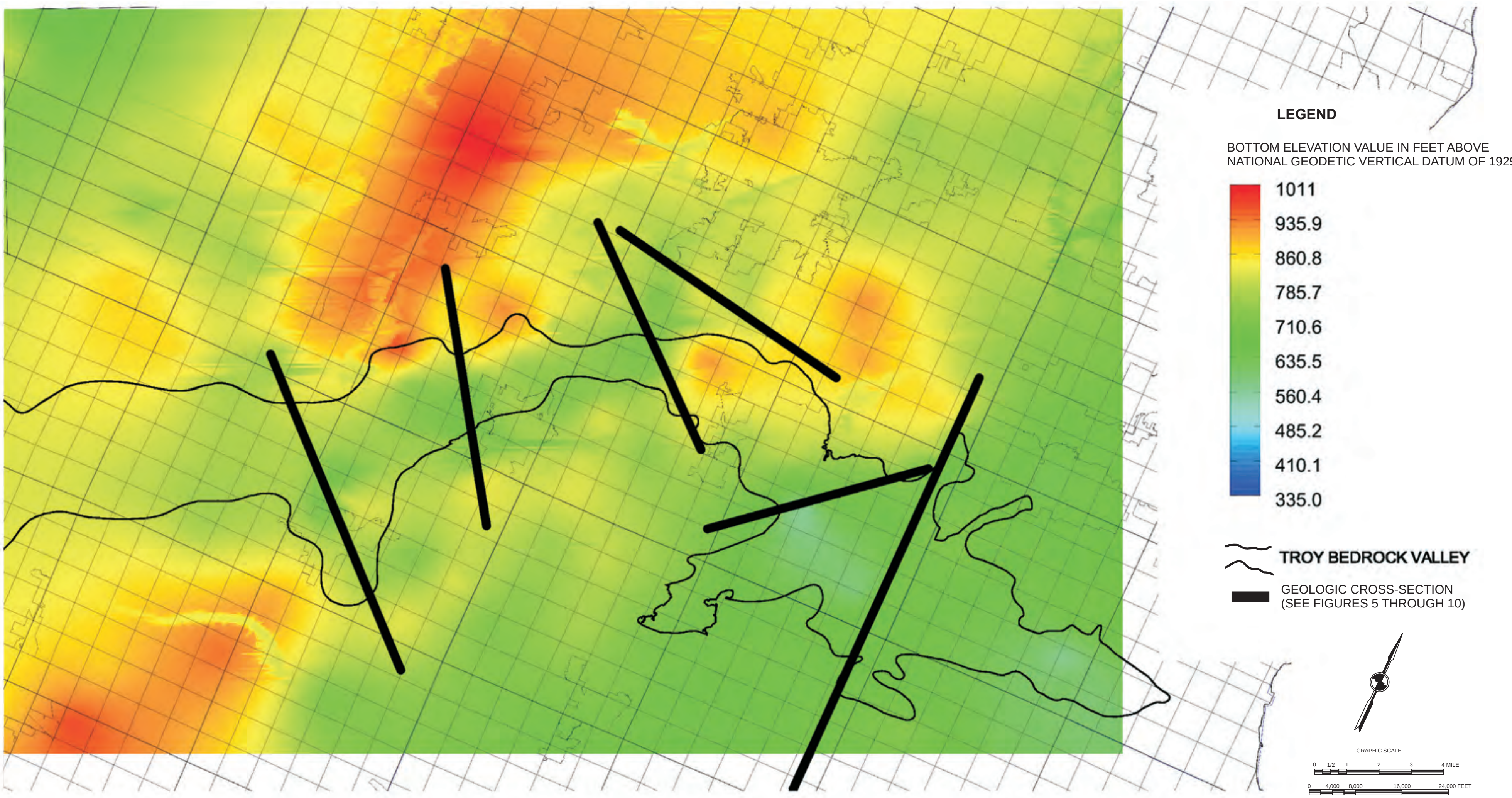


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-9

BOTTOM ELEVATION OF LAYER 1

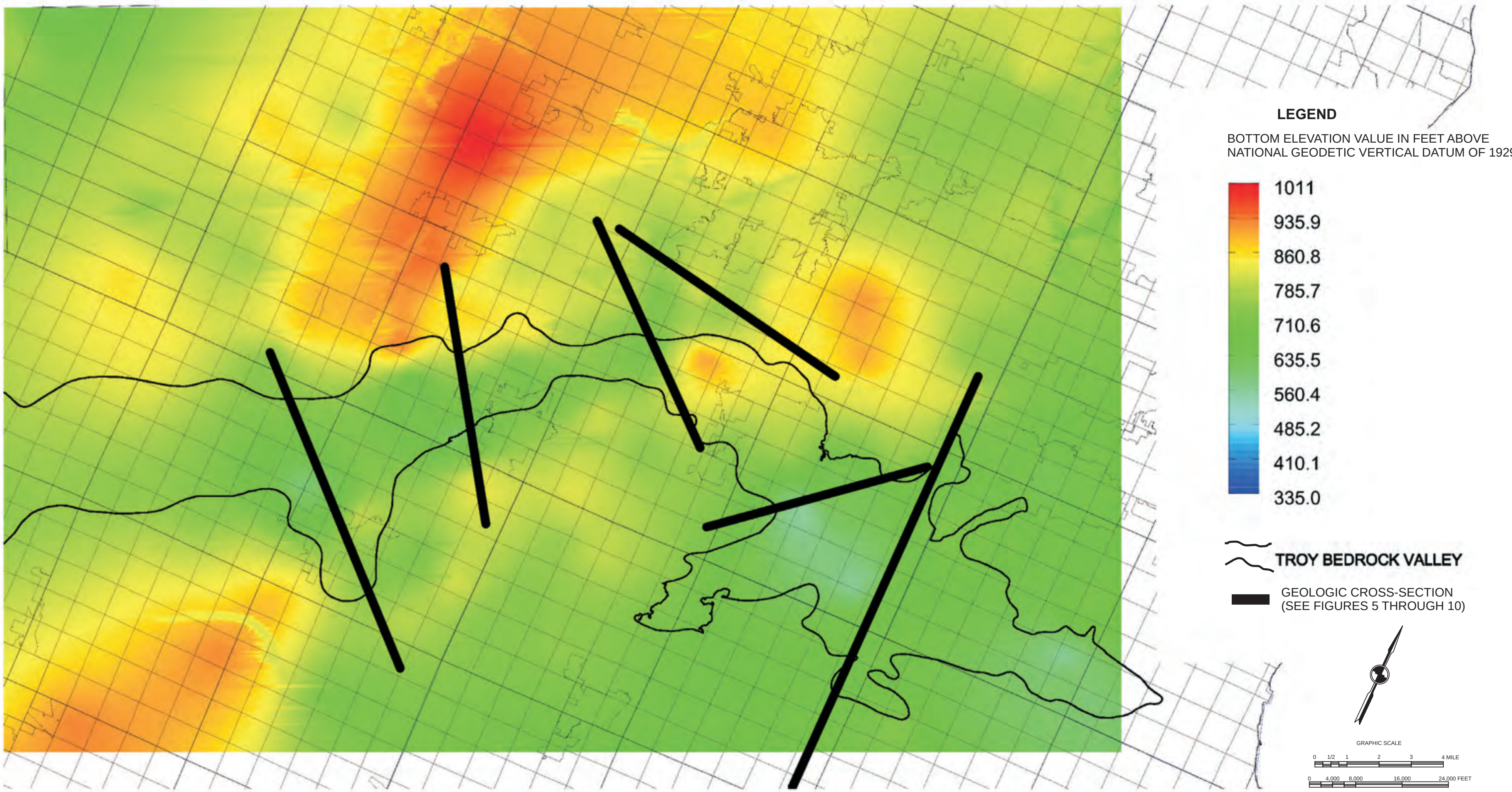


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-10

BOTTOM ELEVATION OF LAYER 2

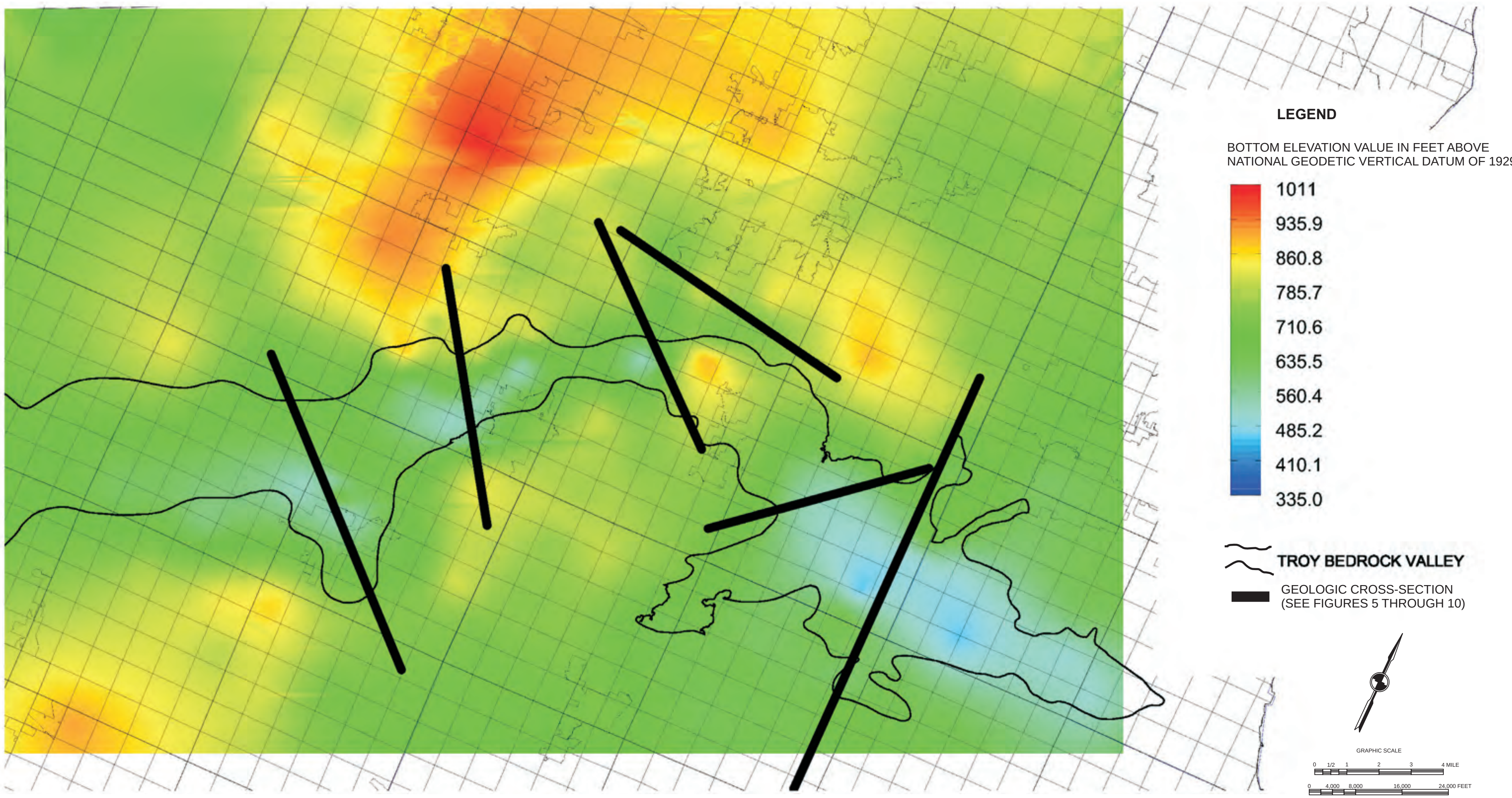


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-11

BOTTOM ELEVATION OF LAYER 3

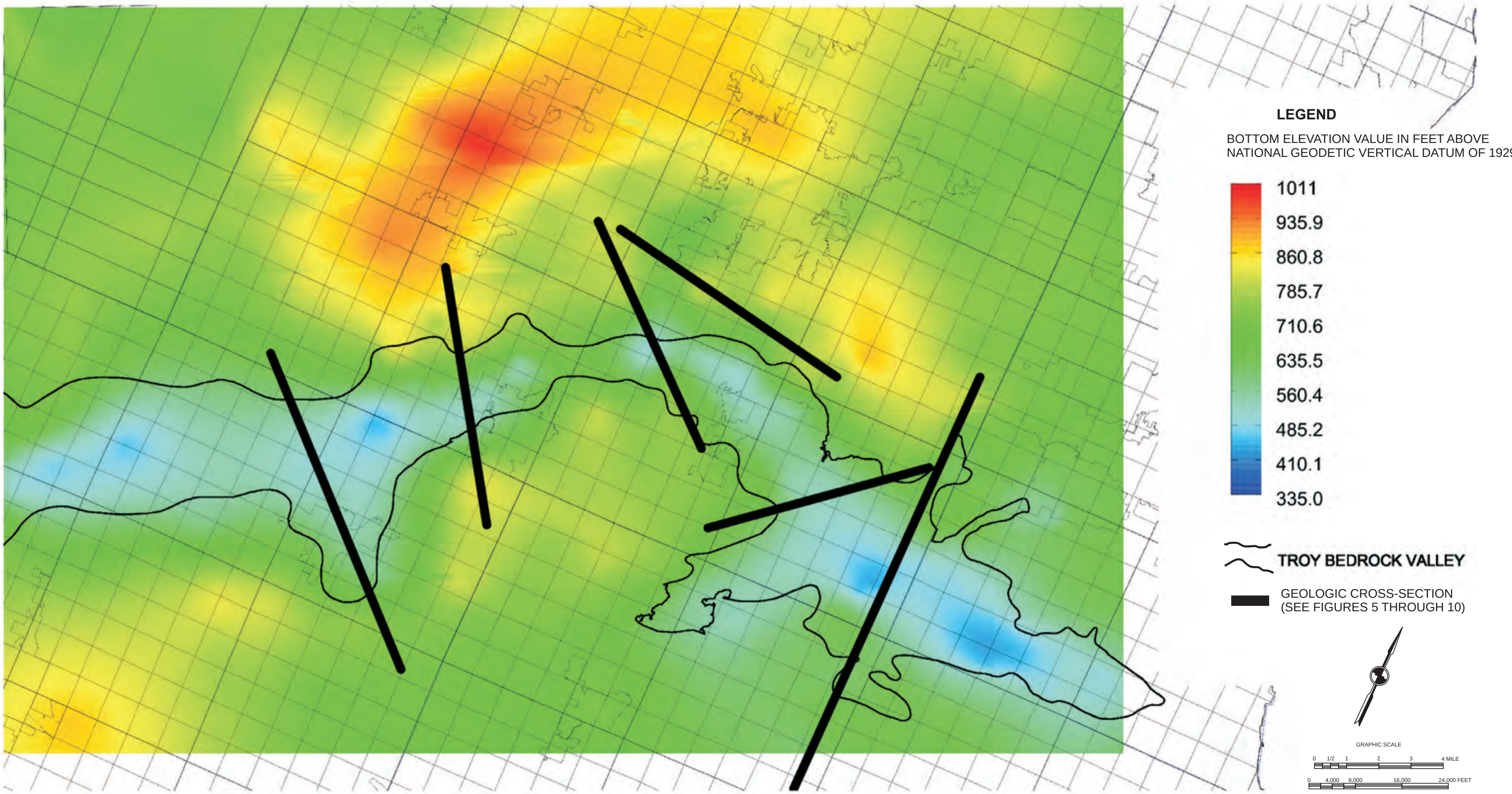


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-12

BOTTOM ELEVATION OF LAYER 4

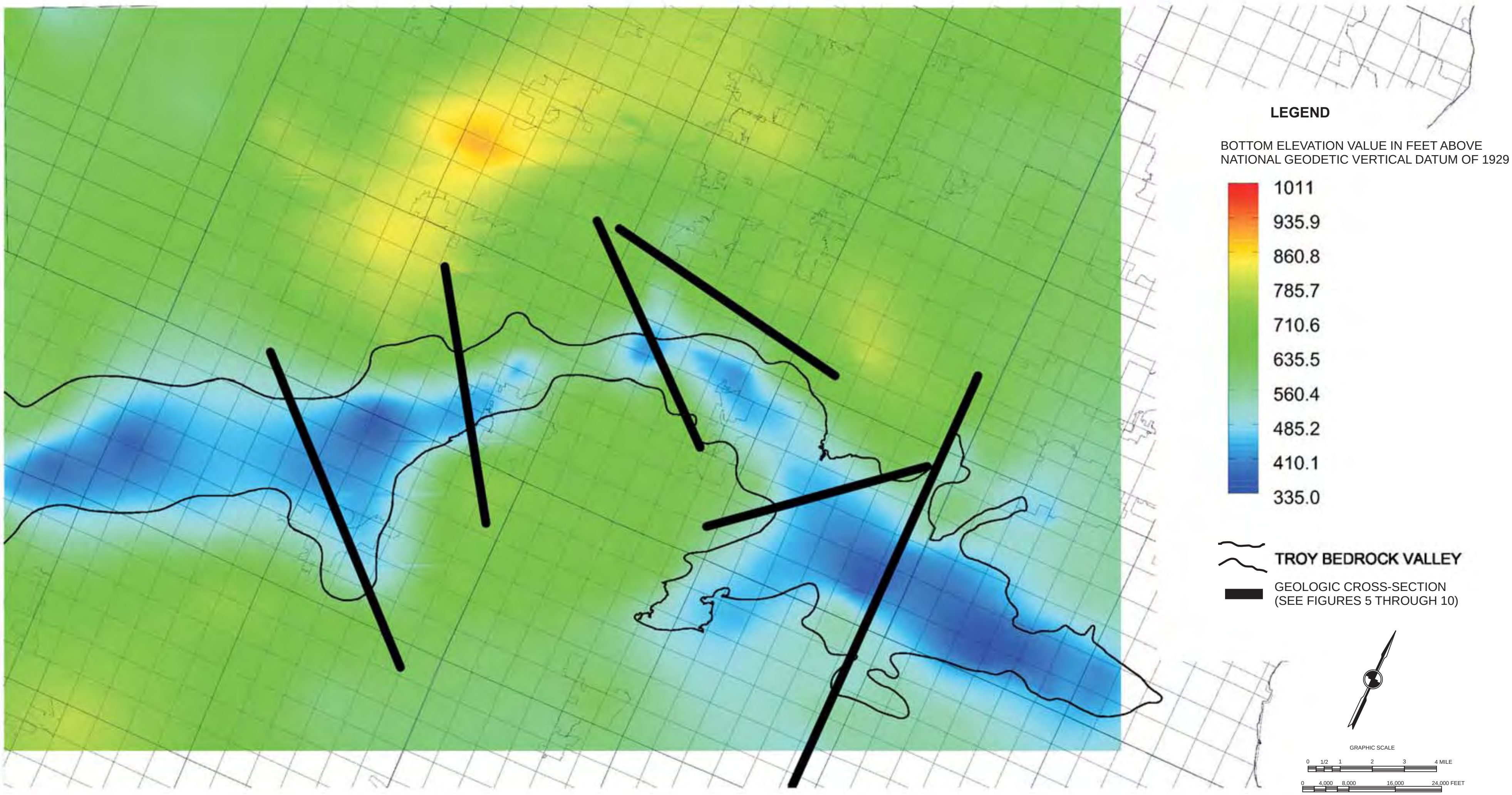


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-13

BOTTOM ELEVATION OF LAYER 5

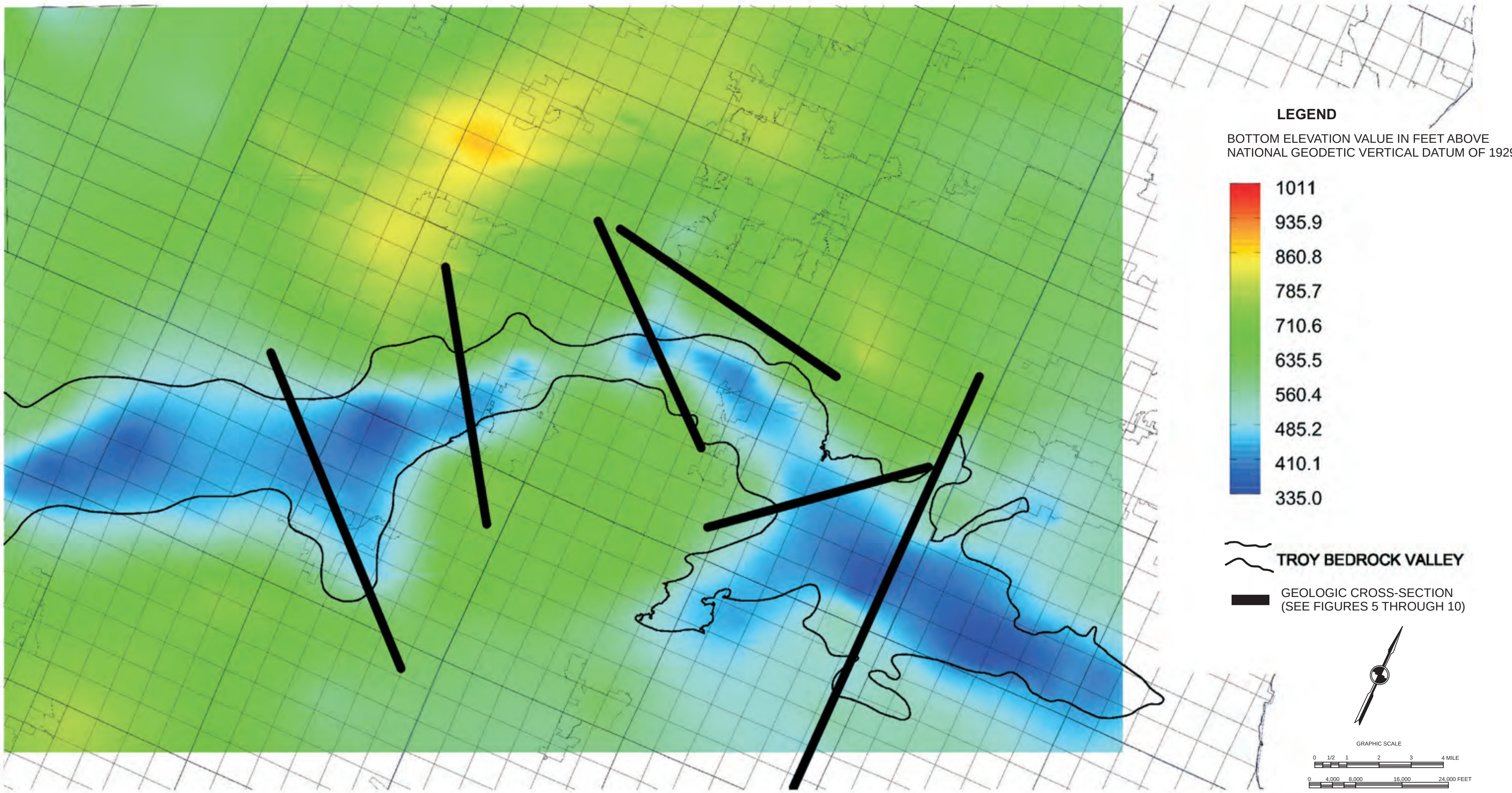


NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.

Figure B-14

BOTTOM ELEVATION OF LAYER 6



NOTE: THE GRID SHOWN IS FROM THE REGIONAL MODEL. THE TROY BEDROCK VALLEY MODEL DOCUMENTED HEREIN CONSISTS OF 400 ROWS AND 600 COLUMNS, AS WELL AS SIX LAYERS INSET INTO THE REGIONAL MODEL

Source: Ruekert & Mielke, Inc.