S.S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

Memorandum

Date: December 4, 2015

From: Charles B. Andrews

To: Arlene Anderson-Vincent, Natural Resource Manager

Subject: **White Pine Springs – Aquifer Characteristics**

This memorandum describes the characteristics of the water-table aquifer in the vicinity of production well PW-101 at the White Pine Springs Site in Osceola County. This well is located within the Chippewa Creek watershed. The locations of PW-101, the Chippewa Creek Water Management Area and the adjacent Twin Creek Water Management Area are shown on Figure 1. The characteristics that are described include the lithology of the aquifer, water-level conditions in the aquifer, and aquifer parameters (transmissivity and storativity). This information was assembled for consideration by the Michigan Department of Environmental Quality (MDEQ) in connection with the site specific review to be conducted with regard to a proposed increase in the withdrawal capacity of PW-101.

Extensive site-specific aquifer data are available in the vicinity of PW-101 from the hydrogeologic investigations which have been conducted by Nestlé Waters North America Inc. (NWNA). Thirty-nine groundwater monitoring wells and 54 drive points have been installed, and a stream-gaging system was established. Monitoring of groundwater levels and surface water flows and levels began in 2000 and continue to date. A nine-day aquifer test was conducted at PW-101 in June 2001.

Lithologic Characteristics of Water-Table Aquifer

The geologic deposits in the vicinity of PW-101 are mapped as glacial outwash and postglacial alluvium, end moraines of coarse-textured glacial till, undifferentiated coarse-textured glacial till, and fine-textured glacial till (Farrand and Bell, 1982). The deposits at PW-101 consist of 195 feet of fine to coarse grained sand with minor silt and gravel lenses overlying a thick clay unit. Similar lithologies were observed in the borings for nearby monitoring wells. The water table aquifer consists of the saturated portion of the fine to coarse grained sand unit. The water table at PW-101 averages approximately 35 feet below ground surface, thus the water table aquifer has a saturated thickness of approximately 160 feet.

Groundwater Flow in the Water-Table Aquifer

Groundwater flow in the water-table aquifer in the vicinity of PW-101 is generally toward the south. A water-table map developed from groundwater level measurements taken on August 7, 2012 is shown on Figure 2. This water-table map is representative of water-table conditions that have been observed since monitoring began in the vicinity of PW-101. Also shown on Figure 2 are hydrographs of two representative monitoring wells, MW-107d and MW-110d, showing water level fluctuations during the period 2001 through October 2015. Water levels at both of these monitoring wells fluctuated over a range of about three feet during this 15-year period. The hydraulic gradient between MW-107d and MW-110d, which are located about 2,300 feet apart, has been relatively constant during this time period at about 0.0058 feet/feet (range of 0.0057 to 0.0059). The water level differences between MW-107d and MW-110d during the 15-year monitoring period are shown on the upper insert graph on Figure 2. The groundwater flow rate in the water-table aquifer, based on this estimate of the hydraulic gradient and an aquifer transmissivity of 8,100 ft^2/day (discussed later in this memorandum), is about 1,300 gpm per mile width of the aquifer.

Aquifer Parameters

Estimates of aquifer parameters in the vicinity of PW-101 were made from data collected during the aquifer test conducted at PW-101 in 2001 and a groundwater model developed for the region. The groundwater model is described in detail in Appendix A[1]. For the aquifer test, PW-101 was pumped at a constant rate of 400 gpm for eight days and then at a constant rate of 700 gpm for an additional day. Water levels were measured and drawdowns computed at 32 monitoring wells and the pumped well. Background data for this test, the drawdowns measured during the test, and analyses of the drawdown data are contained in the spreadsheet that accompanies this memorandum.

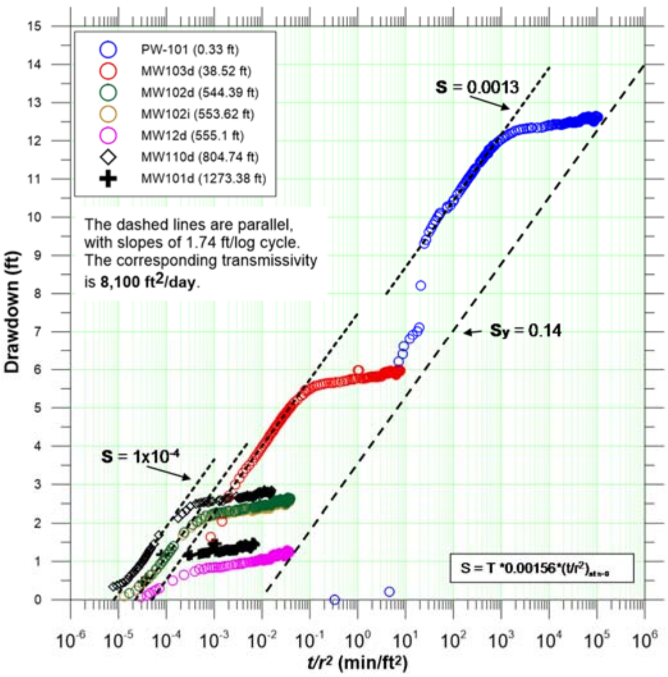
The drawdowns observed during the pumping test indicated that the water-table aquifer in the immediate vicinity of PW-101 is relatively uniform as the drawdown responses at monitoring wells closely matched a Theis-type response in early-time and a Neuman-type response in latter time as drainage occurred at the water table (Theis, 1935; Neuman, 1974). The aquifer transmissivity, as derived by the Cooper-Jacob analysis method (Cooper and Jacob, 1946) from the aquifer test drawdown data, is approximately 8,100 ft^2/day. The relevant storage parameter is the specific yield as the storativity in a water table aquifer is approximately equal to the specific yield. The specific yield estimate derived from a Neuman analysis is 0.14, which is consistent with the expected specific yield of a fine to coarse grained sand but at the lower end of the expected range McWhorter and Sunada, 1977).

Analysis of early-time drawdown data from an aquifer test in an unconfined aquifer provides estimates of the storage coefficient, as in the early part of the test water is produced as the result of releases of water due to the compressibility of the aquifer matrix and the compressibility of water. Only at latter time during an aquifer test does drainage at the water table occur, and as a result storativity estimates made using data from early in the aquifer test will not provide an

[1] Appendix A contains references to the "White-Cedar-Osceola" area or project. The name has since been changed to "White Pine Springs".

accurate estimate of the true storativity (specific yield) of an unconfined aquifer (Neuman, 1974). Based on early time drawdown data, the storativity (storage coefficient) is estimated to be about $1x10^{-4}$ and as noted above based on late time drawdown data the storativity (specific yield) is estimated to be no less than 0.14.

The uniformity of aquifer properties in the vicinity of PW-101 is illustrated on the graph to the right which is a plot of drawdown versus scaled time[2] for many of the monitoring wells in the vicinity of PW-101 during the eight day 400 gpm aquifer test. With a graph of this type, the drawdowns in many monitoring wells can be easily compared on a single plot. On this graph, the slopes of early time drawdown data from nearby monitoring wells are similar, indicating that the transmissivity at these nearby monitoring wells is similar. As noted on the graph, the estimated transmissivity is 8,100 ft2/day as derived by the Cooper-Jacob analysis method (Cooper and Jacob, 1946).



The straight lines fitted to the drawdown data on the graph above intercept the x-axis at different x-values; this indicates that the effective storativity is variable. The effective storativity is estimated using the formula shown in the lower right corner of the graph above which is a function of the x-intercept. The effective storativity is estimated as $1x10^{-4}$ from early time drawdown data from MW-110d, 0.0013 from early time drawdown data from PW-101 and MW-103d, and late time drawdown data from PW-101 and MW-12d suggest a specific yield of 0.14. The test was not run long enough to provide a definitive estimate of specific yield, but the available data indicate that it is not less than 0.14.

The spreadsheet that accompanies this memorandum contains all of the drawdown data and contains an analysis of aquifer transmissivity using the Cooper-Jacob method. In addition, the spreadsheet contains the results of an analysis of specific yield using the Neuman method.

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[2] Time is scaled by the inverse of the squared distance from a monitoring well to PW-101.

References

Cooper, H.H. and C.E. Jacob, 1946. A generalized graphical method for evaluating formation constants and summarizing well field history, Am. Geophys. Union Trans., vol. 27, pp. 526-534.

Farrand, W. and D. Bell, 1982. Quaternary Geology of Southern Michigan. Department of Geological Sciences, University of Michigan.

McWhorter, D. and D. Sunada, 1977. Ground-Water Hydrology and Hydraulics. Water Resources Publications. Fort Collins, Co.

Neuman, S.P., 1974. Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response, Water Resources Research, vol. 10, no. 2, pp. 303-312.

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.

Figures

Figure 1 Location of PW-101 and Twin Creek and Chippewa Creek Water Management Areas

Figure 2 White Pine Springs Groundwater Levels – August 7, 2012

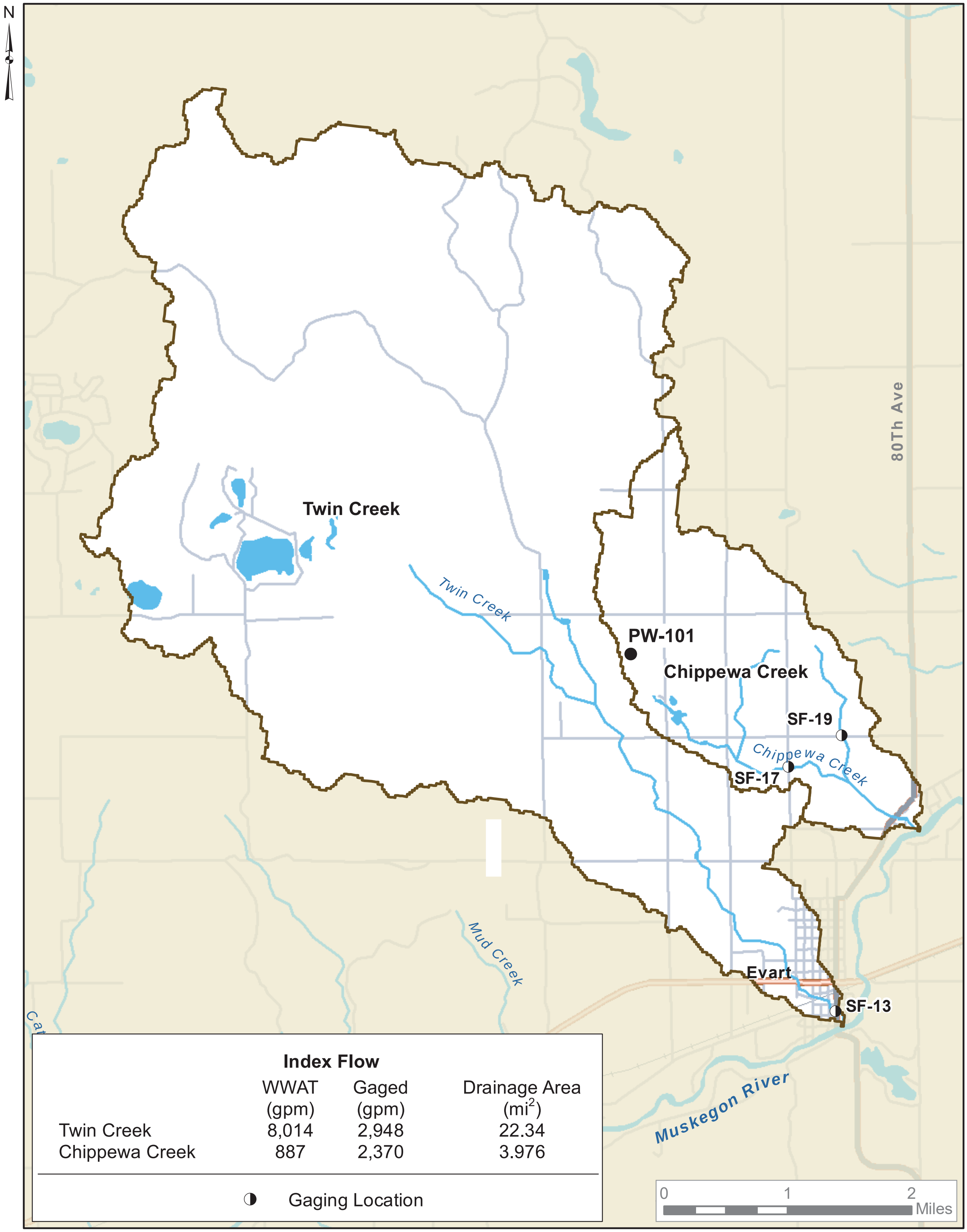
Appendices

Appendix A – Groundwater Flow Model

Appendix B – Curriculum Vitae of Charles B. Andrews

Accompanying Files

Spreadsheet -- “Summary of PW-101 Aquifer Test June 2001.xls”



Index Flow

	WWAT (gpm)	Gaged (gpm)	Drainage Area (mi^2)
Twin Creek	8,014	2,948	22.34
Chippewa Creek	887	2,370	3.976

◑ Gaging Location

Figure 1 Location of PW-101 and Twin Creek and Chippewa Creek Water Management Areas

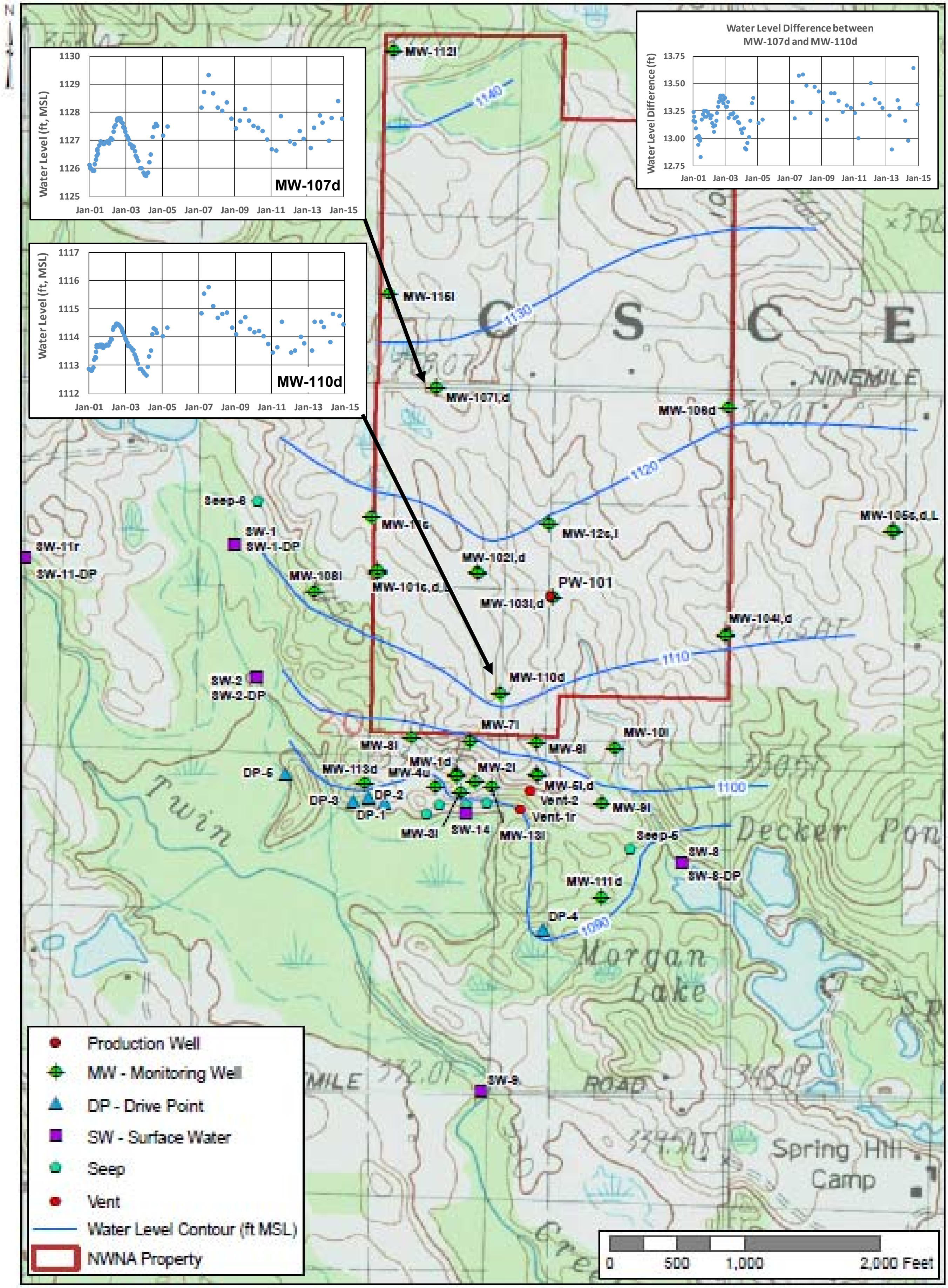


Figure 2 White Pine Springs Groundwater Levels – August 7, 2012

Appendix A

Groundwater Flow Model

Groundwater Flow Model

Prepared For:

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Table of Contents

Page

List of Figures ii

List of Tables ii

Groundwater Flow Model 1

Geologic Setting 1
Finite-Difference Grid 2
Recharge 3
Rivers, Creeks, and Ponds 3
Springs 5
Wetlands 5
Groundwater Use 5
Parameters 6
Horizontal Hydraulic Conductivity 6
Vertical Hydraulic Conductivity 6
Conductance 6
Storage Parameters 6

Groundwater Model Calibration 7

Model Sensitivity 11

Groundwater Basins 13

Stream Flow Reductions 14

References 15

Figures

Tables

List of Figures

Figure A-1	Regional Study Area
Figure A-2	Regional Water Levels from Water Well Records
Figure A-3	Regional Geologic Zones and Cross Section Traces
Figure A-4	Regional Groundwater Model Grid
Figure A-5	Recharge Zones in Model Area
Figure A-6	Springs and Streams in the Vicinity of Production Well PW-101
Figure A-7	Calculated Steady-State Water Levels in Vicinity of Production Well PW-101
Figure A-8	Calculated Steady-State Regional Water Levels
Figure A-9	Comparison of Calculated and Observed Drawdowns During Aquifer Test of PW-101
Figure A-10	Comparison of Calculated and Observed Drawdowns During Aquifer Test of TW-1, TW-2 and TW-3
Figure A-11	Twin Creek and Chippewa Creek Watersheds and Groundwater Basins
Figure A-12	Calculated Steady-State Drawdowns with a Withdrawal of 150gpm

List of Tables

Table A-1	Steady-State Calibration Targets and Residuals

REPORT

Groundwater Flow Model

A groundwater flow model was constructed for the White-Cedar-Osceola area. The study area for this analysis, which is also referred to as the model area, encompasses a 50-square-mile area that includes the recharge areas and discharge areas for groundwater that flows in the vicinity of production well PW-101 (Figure A-1). The model area was defined on the basis of surface watershed boundaries and the reasonableness of the model area was verified by developing a groundwater level map of the area (Figure A-2). Water level data were obtained from static-water level measurements from the Michigan Department of Environmental Quality's (DEQ) Statewide Groundwater Database for water supply wells in Osceola County. The groundwater level map shows that groundwater flow is approximately parallel to watershed boundaries, indicating that it is appropriate to use watershed boundaries in defining an area that includes both the recharge and discharge areas for groundwater in the vicinity of well PW-101.

The southern boundary of the model area is the Muskegon River, a regional groundwater discharge area (Figure A-1). The eastern and northern boundaries of the model area follow watershed boundaries. The southern part of the western boundary is along a ridge east of Cat Creek, a tributary of the Muskegon River, and the rest of the western boundary corresponds to the western extent of the Twin Creek watershed. The western portion of the northern boundary corresponds with the northern boundary of the Twin Creek watershed and the remainder of the northern boundary corresponds with the boundaries of the watersheds of several small tributaries of the Muskegon River. The eastern boundary of the model area is a small-unnamed tributary of the Muskegon River that enters the river approximately 2.5 miles northeast of Evart. Beyond the model area to the northwest is the watershed of the Pine River, a tributary of the Manistee River. To the north of the model area is the watershed of the Middle Branch River, a tributary of the Muskegon River.

In the northwestern half of the model area, which is at an elevation of greater than about 1150 feet above MSL, there are no perennial streams. Perennial streams are limited to Twin Creek, Chippewa Creek and a few other unnamed creeks near the Muskegon River with headwater elevations at about 1150 feet above MSL or less. Numerous springs and seeps occur in the headwaters of each of these drainages. Most of the northwestern portion of the model area is forested and is a part of the Pere Marquette State Forest.

The groundwater flow model was developed using MODFLOW-2000, a finite difference flow simulation code developed by the USGS (Harbaugh et al., 2000). The input data sets for the model were prepared using Groundwater Vistas (Rumbaugh, 2002). The groundwater model was calibrated to average annual groundwater conditions based upon data generally collected between October 2000 and September 2003.

Geologic Setting

The glacial deposits near the site have been mapped as glacial outwash and postglacial alluvium, end moraines of coarse-textured glacial till, undifferentiated coarse-textured glacial till, and fine-textured glacial till (Farrand and Bell, 1982). The character and extent of the glacial deposits were evaluated further for this study by means of lithologic information from water supply wells in Osceola County, in combination with monitoring wells constructed at the site, and topographic features.

In the vicinity of the White-Cedar-Osceola Project area, the more permeable glacial deposits generally occur within about 150 feet of the water table based on the borings advanced in the vicinity of the site and geologic logs of nearby supply wells. Below these permeable deposits, a clay of glaciolacustrine or glacial origin exists that appears to be areally extensive at elevations of about 900 to 980 feet above MSL. Other permeable glacial fill deposits occur below this clay unit; however, this clay forms the base of the modeled aquifer system.

Seeps and springs in the area generally occur along the edge of the contact between coarse-textured glacial till and the glacial outwash sand and gravel unit mapped by Farrand and Bell (1982). Lithologic data from water well logs in Osceola County were obtained from the Michigan DEQ's Statewide Groundwater Database. These lithologic data, in combination with site well logs, were reviewed to more clearly identify geologic characteristics in the White-Cedar-Osceola model area. Four geologic units were identified within the model area as shown in Figure A-3. These geologic units were defined based upon site-specific and regional geologic and hydrogeologic information including lithologic, geologic, and hydrologic data, and topographic morphology. The data set was limited by the variability inherent in the lithologic descriptions provided in the driller's logs; however, general lithologic trends could be identified on a regional scale.

Finite-Difference Grid

The finite-difference model grid encompasses an area of approximately 50 square miles that represents the shallow aquifers within the Twin Creek-Chippewa Creek sub-basin of the Muskegon River, as shown on Figure A-4. The model grid extends for approximately 8 miles in a north-south direction and eight miles in an east-west direction. The model grid is aligned north-south.

The model grid has 176 columns and 174 rows. Row and column spacing is variable. In the vicinity of the proposed production well and the major springs, the grid cells are approximately 50-foot squares. Elsewhere, grid cells have a maximum size of 500 feet by 500 feet. The grid spacing is sufficiently fine to allow an accurate calculation of changes in groundwater levels and groundwater discharges to surface water from withdrawing groundwater from the site for bottling.

The finite-difference grid has five layers to represent the glacial deposits in the shallow aquifers of the Twin Creek-Chippewa Creek sub-basin of the Muskegon River. The model layers have, with the exception of the upper model layer, uniform thickness throughout the model domain, as it was determined that the known geologic information can be incorporated in the model with this structure. The upper layer was defined as all saturated deposits above an elevation of 1060 feet above MSL. The saturated thickness of this layer is as great as 140 feet in the northwest portion of the model area. The other model layers were defined as follows:

- Layer 2 – thickness of 30 feet from 1030 feet to 1060 feet MSL;
- Layer 3 – thickness of 30 feet from 1000 to 1030 feet MSL;
- Layer 4 –thickness of 40 feet from 960 to 1000 feet MSL; and
- Layer 5 –thickness of 60 feet from 900 to 960 feet MSL.

Recharge

The groundwater recharge rate for the model area was estimated through model calibration. In the model calibration process, two different recharge distributions were investigated; a uniform recharge distribution and a non-uniform recharge distribution in which the groundwater recharge was specified as a function of soil type and forest cover according to the method developed by Holtschlag (1997). Recharge rates in the non-uniform distribution were specified for ten different combinations of soil type and forest cover:

- Open water – Zone 1;
- Upland areas with no forest cover – Zone 2;
- Upland areas with soils developed on coarse-grained till with no forest cover – Zone 3;
- Upland areas with soils developed on outwash sands with no forest cover –Zone 4;
- Upland areas with deciduous forest – Zone 5;
- Upland areas with soils developed on coarse-grained till with deciduous forest –Zone 6;
- Upland areas with soils developed on outwash sands with deciduous forest—Zone 7;
- Upland areas with coniferous forest – Zone 8;
- Upland areas with soils developed on coarse-grained till with coniferous forest –Zone 9; and
- Upland areas with soils developed on outwash sands with coniferous forest—Zone 10.

The areal extent of soil types and forest cover was specified on the basis of digital land-cover data from the Geographic Data Library, Michigan Center for Information Technology, State of Michigan. The distribution of the various recharge zones are shown on Figure A-5.

The average recharge over the model area was initially specified as 10.4 inches per year. In the immediate vicinity of the production well, in the model version with non-uniform recharge distribution, the recharge rate was specified as 8.4 inches. In the model calibration process for the model version with non-uniform recharge distribution the recharge rates in the ten model zones were adjusted by a constant factor.

Rivers, Creeks, and Ponds

Twin Creek, Chippewa Creek and other tributaries to the Muskegon River, which are shown on Figure A-1 as perennial streams, were simulated using the MODFLOW Drain package with the exception noted below. The Drain Package simulates only the discharge of groundwater to a surface-water body, and not the seepage of water from a surface-water body to the water table. The Drain Package is appropriate for simulating surface-water bodies that do not lose significant amounts of water to the groundwater table by seepage.

The Muskegon River was simulated using the MODFLOW River Package. The River Package simulates both the discharge of groundwater to a surface-water body and the seepage of water from a surface-water body to the water table. Twin Creek in the vicinity of the Evart municipal wells was also simulated with the River Package.

The ponds located along Twin Creek and in the headwaters of Chippewa Creek were also simulated with the Drain Package. These ponds are all located within groundwater discharge areas and the Drain Package is an appropriate means of simulating changes in groundwater inflow into the ponds as the result of groundwater production. When the ponds are simulated with the Drain Package, the groundwater model does not explicitly calculate the change in pond levels that occurs as the result of changes in groundwater discharge to the ponds. For these ponds, the calculated changes in groundwater inflow are sufficiently small that ponds levels are not quantifiably altered as the result of changes in groundwater inflow. All of the ponds that were simulated with the Drain Package are man-made impoundments with outlet control structures that control the water level in the ponds, and it is the nature of these control structures that they are the primary controls on pond levels.

Four input parameters are required in using the MODFLOW Drain and River packages: the water level in the stream or pond, the area of the stream or pond within a model grid cell, the vertical hydraulic conductivity of the deposits at the base of the stream or pond, and the thickness of the deposits. For simplicity, the latter two parameters were lumped into a single parameter referred to as the normalized conductance. The normalized conductance is defined as the vertical hydraulic conductivity of the stream or pond bed deposits divided by the thickness of the deposits. The normalized conductances were determined in the model calibration process with the procedures described in the next section.

The surface elevations of the creeks and ponds in the vicinity of the White-Cedar-Osceola Project were defined on the basis of a topographic map prepared with 2-foot contour intervals. The elevations of the Muskegon River and creeks outside of the vicinity of the youth camp were specified on the basis of digital elevation model (DEM) data from the Michigan Geographic Information Library (2003). DEM data are arrays of regularly spaced elevation values referenced to a geographic coordinate system. The grid cells are spaced at regular intervals along south-to-north profiles that are ordered from west to east. The DEM data used in the groundwater model were the 7.5-minute, 30-meter data for the Evart and Sears 7.5-minute quadrangles (*link no longer valid, deleted*). The area of a stream or pond within a model cell was estimated on the basis of available maps.

Springs

The mapped seeps in White Cedar Springs, Northern and Southern Boomerang Springs, Chippewa Springs, and Decker Springs and the Northern Ridge Spring (Figure A-6) were simulated with the MODFLOW Drain Package. The elevations of the seeps were specified as the average water level measured in an adjacent drive point (for example, the elevation at Seep-1 was specified as the average water level measured in the drive point identified as "Seep-1"), or if there was not a nearby drive point, on the basis of land-surface elevation.

Wetlands

All wetlands within the model area were simulated implicitly. Implicit simulation means that water levels in wetlands were not directly simulated. For wetlands in contact with the regional water table, implicit simulation implies that water levels in the wetlands are directly correlated with the regional water table. This is seldom the case, as most wetlands are underlain by fine-grained materials that limit the hydraulic communication with the underlying regional aquifer. As a result, implicit simulation of wetland water levels tends to over predict the changes in wetland levels that will occur as a result of changes in the regional water table.

In selecting the implicit method for simulating wetland water levels, an analysis was made of the relationship between groundwater levels and water levels in wetlands and an analysis was made of the relationship between spring flow and wetland water levels. An analysis of wetland water levels and seep flow rates at White Cedar Springs, Northern Ridge Spring, and Decker Springs has indicated that there is not a meaningful correlation between wetland water levels and seep flows. Water levels in the wetlands located at the break in slope appear to be controlled by the morphology of the land surface rather than by groundwater discharge rates; therefore, an implicit simulation of these wetlands is appropriate.

The water levels in perched wetlands, which were assumed to be all wetlands located in areas where the wetland water levels are more than 20 feet above the water table, are not a function of the regional water table, as changes in the level of the regional water table do not affect the flux from this type of wetland to the regional water table. Perched wetlands were modeled as a source of recharge to the regional water table that is not affected by the level of the regional water table. All wetlands in the vicinity of the White-Cedar-Osceola Project, except for those in or adjacent to the valleys of Twin and Chippewa Creeks, are perched wetlands.

Groundwater Use

Groundwater production by the City of Evart was simulated in the groundwater model as occurring at a steady-state rate of approximately 1,500 gpm, which was the reported groundwater production rate for the city in 2001. The production was specified as occurring at the location of the eight municipal wells that are currently in operation. Seven of these wells are located adjacent to Twin Creek and one well is located west of the city along Highway 10 (Figure A-1).

Groundwater production at residential wells and wells used by the youth camp were not simulated in the groundwater model because production from these wells averages less than 5 gpm per individual well. The production rates from these wells are sufficiently small that they do not have a quantifiable effect on groundwater flow conditions, and much of the water that is produced from these wells is returned to the subsurface via infiltration from septic tanks.

Parameters

Horizontal Hydraulic Conductivity

A uniform horizontal hydraulic conductivity distribution was specified initially within each mapped geologic unit. To begin the calibration process, hydraulic conductivity was specified as 50 feet per day in the undifferentiated sands, 150 feet per day in the coarse-grained gravel and sand, 10 feet per day in the Eastern fine-grained sediments and 5 feet per day in fine-grained sediments of Twin and Chippewa creeks. Outside of the valley of the Muskegon River in model layer 5, a horizontal hydraulic conductivity of one foot per day was specified. The initial values were estimated on the basis of the lithologic characteristics of the materials.

Vertical Hydraulic Conductivity

A uniform vertical hydraulic conductivity distribution was also specified initially within each mapped geologic unit. To begin the calibration process, a vertical hydraulic conductivity of 1 foot per day was specified throughout the model domain. This initial value was chosen to represent the effective vertical hydraulic conductivity of fine-grained lenses within the subsurface environment.

Conductance

The normalized conductance for the streams, ponds, and seeps simulated with either the Drain Package or the River Package was initially specified as one per day, a typical value for the normalized conductance of stream bed deposits.

Storage Parameters

A steady-state simulation does not require the specification of any storage parameters. In simulating the aquifer tests, a specific yield of 0.15 and a storage coefficient of 10^{-5} were specified initially in each model layer. These values are consistent with storage parameters estimated from aquifer tests conducted at PW-101 and at the test wells TW-1, TW-2 and TW-3.

Groundwater Model Calibration

The groundwater model was calibrated using the automated computer program "PEST - Model Independent Parameter Estimation" (PEST) (Doherty, 2002). A groundwater model is deemed calibrated when the difference between model outputs and field observations, referred to as calibration targets, has been reduced to a minimum in the weighted least squares sense [i.e., the sum of squared differences between model outputs and measurements, termed the objective function or PHI (Φ)]. Model calibration is an iterative process that seeks to reduce PHI by determining the sensitivity of the model parameters to the calibration data. When the calibration process can no longer reduce PHI (i.e., $\Phi = \Phi_{min}$), the parameters are considered optimal with respect to the measured data set and may be used to make predictions under conditions comparable to the calibration conditions. The computer program PEST automates the procedure of determining the minimum value of PHI.

The first step in the model calibration process is the identification of measured hydrologic data that can be used as calibration targets. Two sets of formal calibration targets were identified: average water levels in monitoring wells at the site, and average measured stream flows and spring flows. A total of 42 monitoring-well targets; 9 stream-flow targets and 5 spring targets were used in the model calibration process. These calibration targets are listed on Table 1. In addition, water levels at eighteen residential wells distributed widely over the model area were utilized in the model calibration process.

The monitoring well water-level targets were based on average water levels during the period January 2001 through December 2002. The stream-flow and spring-flow targets were also based on average base flows between January 2001 and December 2002. An evaluation of stream-flow data from the Muskegon River at Evart, for the baseline period 1971 to 2000 and the period January 2001 through December 2002, indicated that stream flows during the latter period were about nine percent smaller than the average annual flows during the baseline period (average flow during period 1971 to 2000 was 1132 ft^3 per second, and flow during 2001 to 2002 was 1028 ft^3 per second). This indicates that the model was calibrated to water levels and flows that are slightly below the normal or average value.

All calibration targets that were identified represent average, baseline hydrologic conditions. As a result, the calibration process consisted of the development of a groundwater model to simulate average, baseline conditions. This type of model is commonly referred to as a steady-state model. In this steady-state groundwater model, the variable parameters are the distribution of hydraulic conductivity, the magnitude of hydraulic conductivities, and the recharge rate.

The second step in the model calibration process is the selection of model parameters that can be varied in the model calibration process. In setting up the PEST input files for the model, a very flexible approach was adapted such that the sensitivity of a large number of parameters could be investigated and, in theory, a large number of parameters could be estimated. The parameters and parameter groups that were specified in the PEST input files were the following:

- Horizontal and vertical hydraulic conductivities – Seventeen zones were defined in the PEST input files in which the horizontal and vertical hydraulic conductivities could be estimated. Zones were specified for each of the major geologic units in each of the model layers, with the following exceptions. In model layer 5 one zone was specified that encompassed all areas outside of the valley of the Muskegon River, and only one zone was specified for the coarse-grained gravel and sand unit and this zone was specified in both model layers 4 and 5. In addition, two sets of zones were defined for the fine-grained sediments of Twin and Chippewa creeks – a set of zones for the area adjacent to the East Branch of Twin Creek and a set of zones for everywhere else.
- Normalized Conductance – Twenty-seven zones in which the normalized conductance could be estimated were defined in the PEST input files. One zone was specified for each mapped seep, major stream reach, and major ponds.
- Recharge – one recharge parameter was defined in the PEST input files. This parameter was the recharge rate when the model was calibrated for a uniform recharge distribution and was a multiplier for the initial recharge estimates derived from the Holtschlag (1997) method when the model was calibrated for a non-uniform recharge distribution.

The third step in the model calibration process is the identification of conditioning information on model parameters. Two types of conditioning information were identified: estimates of aquifer transmissivity from an aquifer test conducted at the production well, and geologic information. The transmissivity of the glacial aquifer at well PW-101 is estimated from the aquifer test to be about 8,000 ft^2/day. This information was incorporated in the calibration process as a constraint on the estimated transmissivity in the vicinity of the tested well. The known geologic information was incorporated into the calibration processes by the use of the geologic zones shown on Figure A-3 in the calibration process.

The fourth step in the calibration process is automated calibration using the computer program PEST. The result of this step is the calibrated groundwater model. In this step, the groundwater model was calibrated using both a uniform and non-uniform recharge distributions. The model calibrated equally well to both distribution, and since the uniform recharge distribution is based on fewer assumptions, a uniform recharge distribution was used to develop the final calibrated model. The hydraulic conductivities estimated by this process were the following:

- Undifferentiated sands -- layer 1 – horizontal hydraulic conductivity (K_h) of 47 feet per day and vertical hydraulic conductivity (K_v) of 3 f33t per day; layer 2 – K_h of 30 feet per day and K_v of 0.4 feet per day; layer 3 – K_h of 25 feet per day and K_v of 0.4 feet per day; layer 4 – K_h of 140 feet per day and K_v ranging from 10^{-3} feet per day to 0.1 foot per day; and layer 5 – K_h of 50 feet per day near the Muskegon River and K_h of 1 foot per day elsewhere with K_v of one foot per day.

- Eastern Fine Grained Sediments -- K_h of 15 feet per day layers 1 through 4, this unit not defined in layer 5; K_v of one foot per day.
- Coarse-grained gravel and sand -- K_h of 150 feet per day in layers 4 and 5, this unit not defined in other layers; K_v of one foot per day.
- Fine-grained sediments of Twin and Chippewa Creeks (with exception of area near East Branch of Twin Creek) -- layer 1 - K_h of 28 feet per day and K_v of $3x10^{-2}$ feet per day; layer 2 - K_h of 15 feet per day and K_v of $3x10^{-2}$ feet per day, layers 3 and 4 – K_h of 10 feet per day and K_v of 0.1 foot per day. This unit is not defined in layer 5.
- Fine-grained sediments near the East Branch of Twin Creek – K_h of 1 foot per day and K_v of 1 foot per day everywhere.

The recharge rate was calibrated at 14 inches per year. This calibrated recharge rate is approximately 25 percent greater than the rate estimated using the Holtschlag method that is based on regional conditions. The calibrated recharge rate is consistent with the observation that much of the model area has poorly developed surface drainages indicating that surface-water runoff is insignificant over much of the model area. In addition, the calibrated recharge rate is consistent with the observed base flows of Twin Creek and Chippewa Creek.

The calculated steady-state water levels in the calibrated model in the vicinity of production well PW-101 in model layer 2 are shown on Figure A-7 along with calculated residuals for monitoring wells screened in models layers 2 and 3. Calibrated steady-state water levels in the entire model area are shown on Figure A-8. These calculated water levels are similar to the water levels shown on Figure A-2 that were estimated on the basis of drillers' logs from residential wells.

Quantitative evaluation of the model calibration consisted of examining the residuals between the 42 measured and calculated average water levels from the monitoring wells, the residuals from the 9 stream-flow targets, and the residuals from the five spring-flow targets. The residual is defined as the target minus the calculated water level, stream flow or stage. The calculated water levels, stream flows, and spring flows are listed on Table 1 along with the residuals.

The automated calibration process minimized the sum of the square of the residuals for the 42 monitoring wells to 182 ft^2. To quantify the model error for the water levels in the calibrated model with easier-to-understand metrics, three statistics were calculated for the residuals: the mean of the residuals, the mean of the absolute value of the residuals, and the standard deviation of the residuals. The mean of the residuals is 0.3 foot, the mean of the absolute value of the residuals is 1.7 feet, and the standard deviation of the residuals is 2.3 feet. The near-zero value of the mean residuals demonstrates that there is no systematic bias in the calibration. The absolute mean residual of 1.7 feet is considered acceptable since the observed water-level measurements applied as calibration targets have a total range of 40 feet. The standard deviation of 2.3 feet is also acceptable given the range of water-level values.

As shown on Table 1, there is good agreement between the stream-flow targets and the calibrated model-calculated stream flows, and there is good agreement between spring flow targets and measured spring flows.

The calibrated model was used to simulate the eight-day aquifer test conducted at production well PW-101 between June 12 and June 20, 2001. During this test, the well was pumped at a relatively constant rate of 400 gpm, and water levels were measured in nearby monitoring wells. In simulating this test, a specific yield of 0.15 and a storage coefficient of 5×10^{-4} were specified in all geologic zones. Simulated drawdowns reasonably match measured water levels in nearby monitoring wells as shown on Figure A-9.

The calibrated model was also used to simulate the 7-day pumping test conducted at wells TW-1, TW-2 and TW-3 from August 23 to August 30, 2001. TW-1 was started first at a rate of 200 gpm, followed one hour later by TW-2 at a rate of 227 gpm, followed one hour later by TW-3 at a rate of 296 gpm. Pumping continued for seven days. Flows at the weirs were measured during the test, and significant changes in flow were observed. The calculated changes in water levels in monitoring wells and flow at the weirs closely match observed changes as shown on Figure A-10.

Model Sensitivity

Model calibration is a process of determining the sensitivity of model results to changes in model parameters and using this information in an iterative manner to produce a model in which there is good correspondence between observed and calculated values. The parameter estimation program used in this study, PEST, calculates sensitivities to parameters during model calibration, and PEST uses these sensitivities in its search for optimal solutions. The sensitivities to parameters are calculated by the method of perturbation: a base run of the model is made and the sum of squares of the residuals is computed and then one of the parameters is changed by a fractional amount and the model is rerun and the sum of squares of the residuals is recomputed. The difference in the sum of squares of the residuals between the two runs is a measure of the sensitivity to that parameter. The program PEST works by computing sensitivity to each parameter, and then uses the information on the sensitivities to adjust parameter values to minimize the sum of squares of the residuals.

The sensitivity of the model results to 44 parameters was computed by PEST. This indicated that the model results are only sensitive to very few of the model parameters. The parameters to which the model was most sensitive and the relative sensitivity of the model results to these parameters, are listed below

Parameter	Relative Sensitivity
Horizontal Hydraulic Conductivity – Undifferentiated Sands -Layer 4	1.0
Horizontal Hydraulic Conductivity – Undifferentiated Sands -Layer 2	0.30
Horizontal Hydraulic Conductivity – Undifferentiated Sands -Layer 3	0.26
Horizontal Hydraulic Conductivity – Fine-Grained Sediments of Twin and Chippewa Creeks –Layer 3	0.17
Horizontal Hydraulic Conductivity – Undifferentiated Sands near the Muskegon River – Layer 5	0.13
Horizontal Hydraulic Conductivity – Undifferentiated Sands -Layer 1	0.11
Recharge Rate	0.10
Horizontal Hydraulic Conductivity – Fine-Grained Sediments of Twin and Chippewa Creeks –Layer 2	0.10

The relative sensitivity is a measure of the change that occurs in the computed sum of squares of the residuals for a fractional change in the value of the parameter. A larger relative sensitivity indicates that a fractional change in the given parameter will result in a larger change in model outputs. Therefore, the relative sensitivities are a useful measure of the effect different model parameters have on model results.

The model is most sensitive to the hydraulic conductivity of the undifferentiated sands in model layers 2 through 4. The transmissivity of these sands, as estimated from the aquifer test of PW-101, is about 8,000 ft^2/day. The transmissivity of these sands in the model, which represents the thickness-weighted hydraulic conductivities of layers 1 through 4, is 8,070 ft^2/day. The close correspondence between the estimated transmissivity and the model transmissivity for these sands and the fact that the hydraulic conductivities of these sands are the more sensitive model parameters, provide strong evidence that the parameters in the calibrated groundwater model are consistent with observed conditions.

The model is also relatively sensitive to recharge. In the groundwater model, recharge equals discharge from the model, and since discharge from the model to Twin Creek and Chippewa Creek are targets in the model calibration process, it is expected that recharge would be a sensitive parameter. Since good estimates of stream flows are available, the calibration process provides a reliable estimate of recharge.

Groundwater Basins

The calibrated groundwater model was used to calculate the groundwater basins upgradient of gaging location SF-9 on Twin Creek and upgradient of SF-17 on Chippewa Creek (Figure A-11). The groundwater basins include those areas upstream of SF-9 and SF-17 where the groundwater component of stream flow originates as precipitation infiltrating into the subsurface. The groundwater basins were calculated using the computer program MODPATH (Pollock, 1994). With this program, water particles were traced from the water table at the center of every grid node in the model domain to the locations where they discharge to a surface water body or well. The groundwater basin upgradient of SF-9, as shown on Figure A-11, was defined to include the starting locations of all particles that discharge to Twin Creek upstream of SF-9. Likewise, the groundwater basin upgradient of SF-17, as shown on Figure A-11, was defined to include the starting locations of all particles that discharge to Chippewa Creek upstream of SF-17.

The groundwater basin upgradient of SF-9 on Twin Creek differs markedly from the surface watershed upstream of SF-9 as shown on Figure A-11. The area of the groundwater basin is 7.2 square miles whereas the area of the surface watershed is 17 square miles. This groundwater basin is smaller than the surface watershed, in part, because there are no perennial streams in much of the watershed and as a result groundwater flow is toward the Muskegon River and other watersheds rather than towards Twin Creek. Because the groundwater basin upgradient of SF-9 is much smaller than the surface watershed, the base flow at SF-9 is smaller than is predicted using generalized techniques that are based on the area of the surface watershed.

The groundwater basin upgradient of SF-17 on Chippewa Creek also differs markedly from the surface watershed upstream of SF-17 as shown on Figure A-11. In this case, the area of the groundwater basin is much larger than the area of the surface watershed (2.8 square miles and 5.6 square miles, respectively). Because the groundwater basin upgradient of SF-17 is much larger than the surface watershed, the base flow at SF-17 is larger than is predicted using generalized techniques that are based on the area of the surface watershed.

Stream Flow Reductions

The effect of the withdrawal of 150 gpm at a steady rate from production well PW-101 was simulated with the calibrated groundwater model by specifying a pumping well at the location of PW-101. The well was specified as screened adjacent to model layers 2, 3 and 4 and pumping was assigned to the layers proportional to their transmissivities. The effect of the withdrawal on stream flows was calculated by subtracting the calculated stream flows in the calibrated model from those in the calibrated model with pumping. The stream flow reductions occur as the result of a decline in the water levels in the aquifer. The calculated water level changes (drawdowns) that occur in the aquifer as the result of a withdrawal of 150 gpm are shown on Figure A-12. Water level declines of more than a foot occur within one-half mile of PW-101.

The total calculated change in streamflow as the result of pumping is a reduction of 150 gpm in the flow of the Muskegon River downstream of Evart. The streamflow reductions are manifested as decreased groundwater discharge to tributaries of the Muskegon River and decreased groundwater discharge to the river. The majority of the reductions occur as the result of decreased groundwater discharge, and thus decreased streamflows, to Twin Creek and Chippewa Creek. The calculated changes in streamflow at selected locations along these streams are the following:

Stream	Segment Number[1]	Gaging Station	Base Flow[2] (gpm)	Model Calculated Base Flow (gpm)	Calculated Base Flow with Pumping (gpm)	Change in Flow (gpm)
Twin Creek	700	SF-1	711	715	693	22
	387	SF-9	2962	2670	2602	68
	mouth	SF-13	3073	2973	2902	71
Chippewa Creek	703	SF-16	996	1009	974	35
	702	SF-17	2051	1965	1914	51
	mouth	SF-20	2800	2849	2789	60

Notes:
1. Stream segment as defined and numbered in 1:100,000 scale, National Hydrography Dataset.
2. Methods used to estimate base flow and index flow are described in Appendix C.

The calculated streamflow reduction at the mouth of Twin Creek at the Muskegon River is 71 gpm and the reduction at the mouth of Chippewa Creek is 60 gpm. Thus the total calculated streamflow reduction for these two streams is 131 gpm. The remainder of the streamflow reduction, approximately 19 gpm, occurs to other small tributaries of the Muskegon River and is the result of decreased groundwater discharge to the Muskegon River itself.

References

Doherty, J. 2002. PEST - Model Independent Parameter Estimation, Version 5.5, Watermark Numerical Computing, Queensland, Australia. February 2002.

Farrand, W., and D. Bell. 1982. Quaternary Geology of Southern Michigan. Department of Geological Sciences, University of Michigan.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald. 2000. *MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model--User Guide to Modularization Concepts and the Ground-Water Flow Process*. U.S. Geological Survey. Open-File Report 00-92.

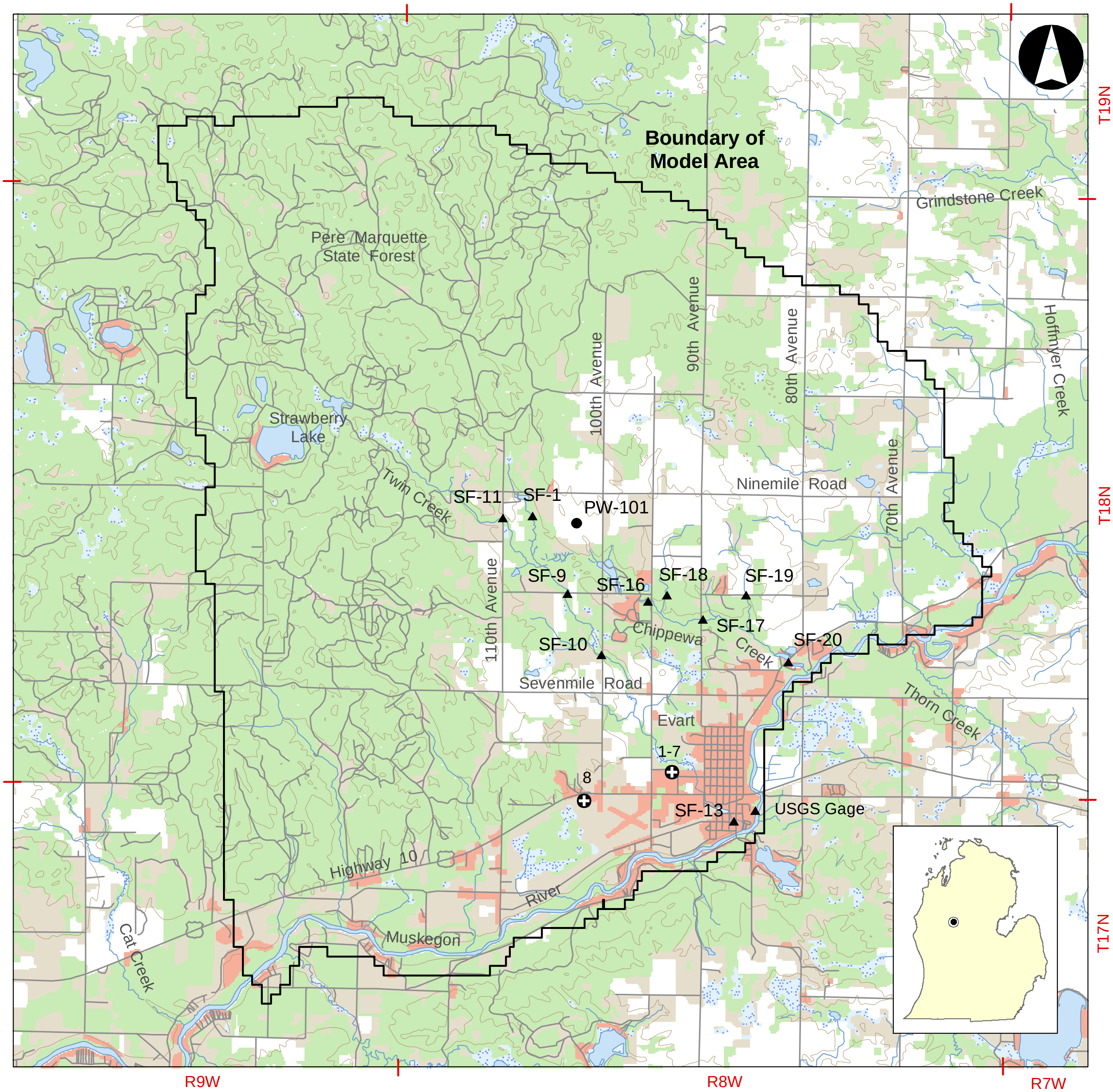
Holtschlag, D.J. 1997. A Generalized Estimate of Ground-Water-Recharge Rates in the Lower Peninsula of Michigan. U.S. Geological Survey Water-Supply Paper 2437.

Michigan Geographic Data Library. 2003. Digital Elevation Models (DEM) for Osceola County, Michigan. Downloaded from *(The link provided was broken and has been removed)*.

Pollock, D.W. 1994. User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, The U.S. Geological Survey Finite-Difference Ground-Water Flow Model. U.S. Geological Survey, Open-File Report 94-464.

Rumbaugh, J. 2002. Groundwater Vistas (Version 3.17). Environmental Simulations Inc., Reinholds, PA.

FIGURES



PW-101 ● Production well

8 ⊕ Evart municipal wells and well number

SF-10 ▲ Stream gaging location

0 7,500 15,000 Feet

Figure A-1 Regional Study Area

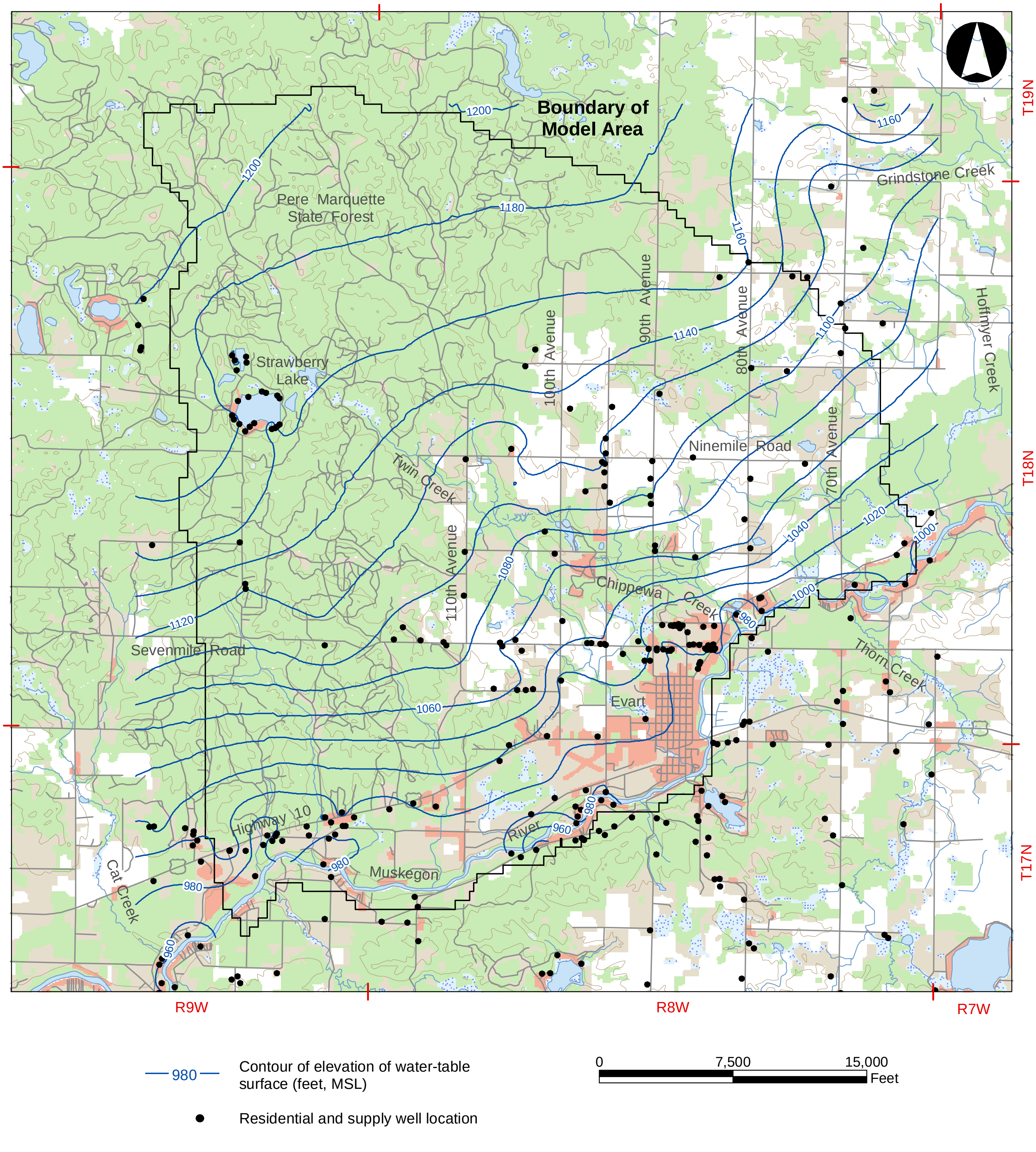
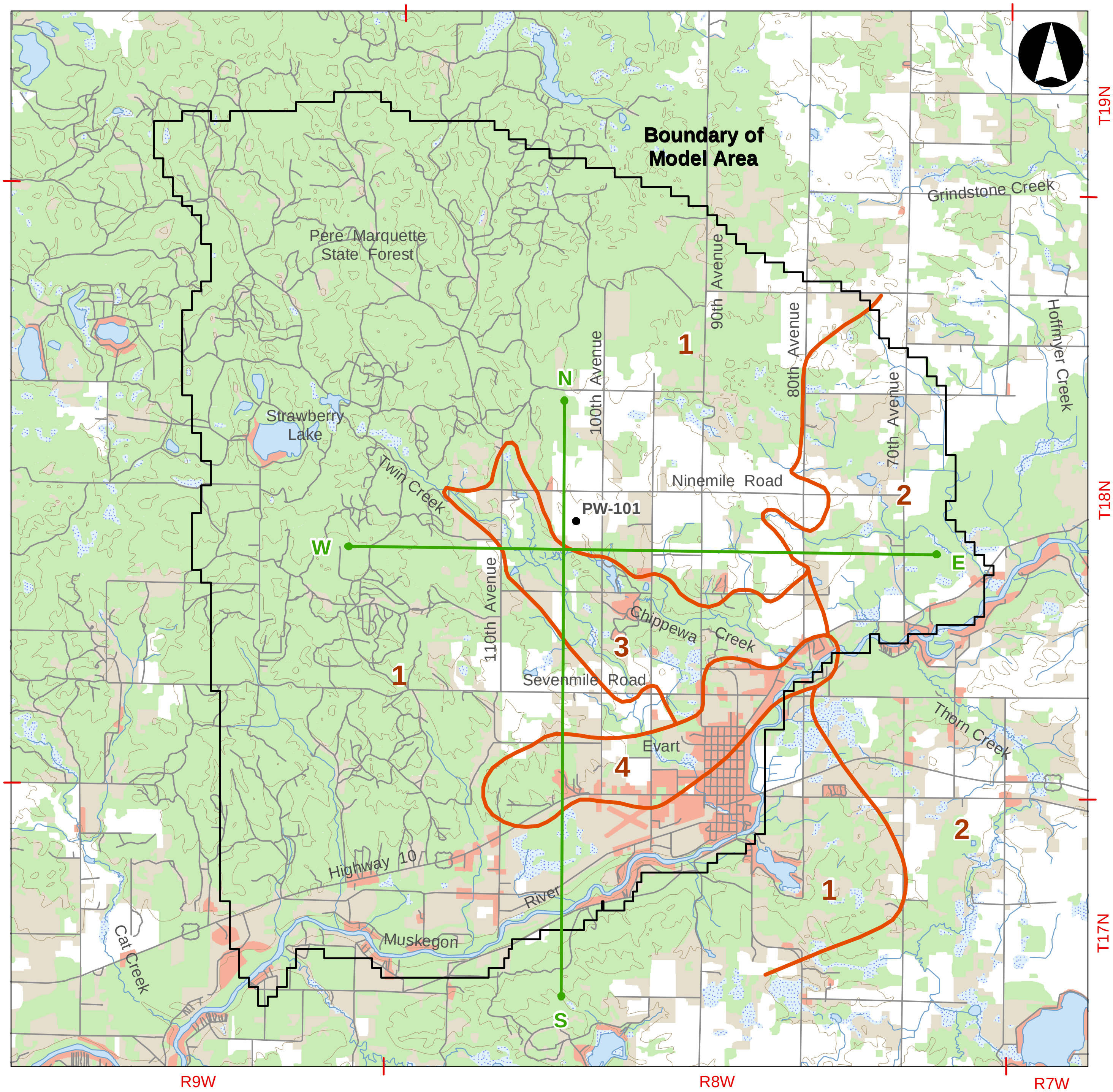


Figure A-2 Regional Water Levels from Water Well Records



1 Undifferentiated Sands

2 Eastern Fine-grained Sediments

3 Fine-grained Sediments of Twin and Chippewa creeks

4 Coarse-grained Sand and Gravel

Geologic cross section trace

0 7,500 15,000 Feet

Figure A-3 Regional Geologic Zones and Cross Section Traces

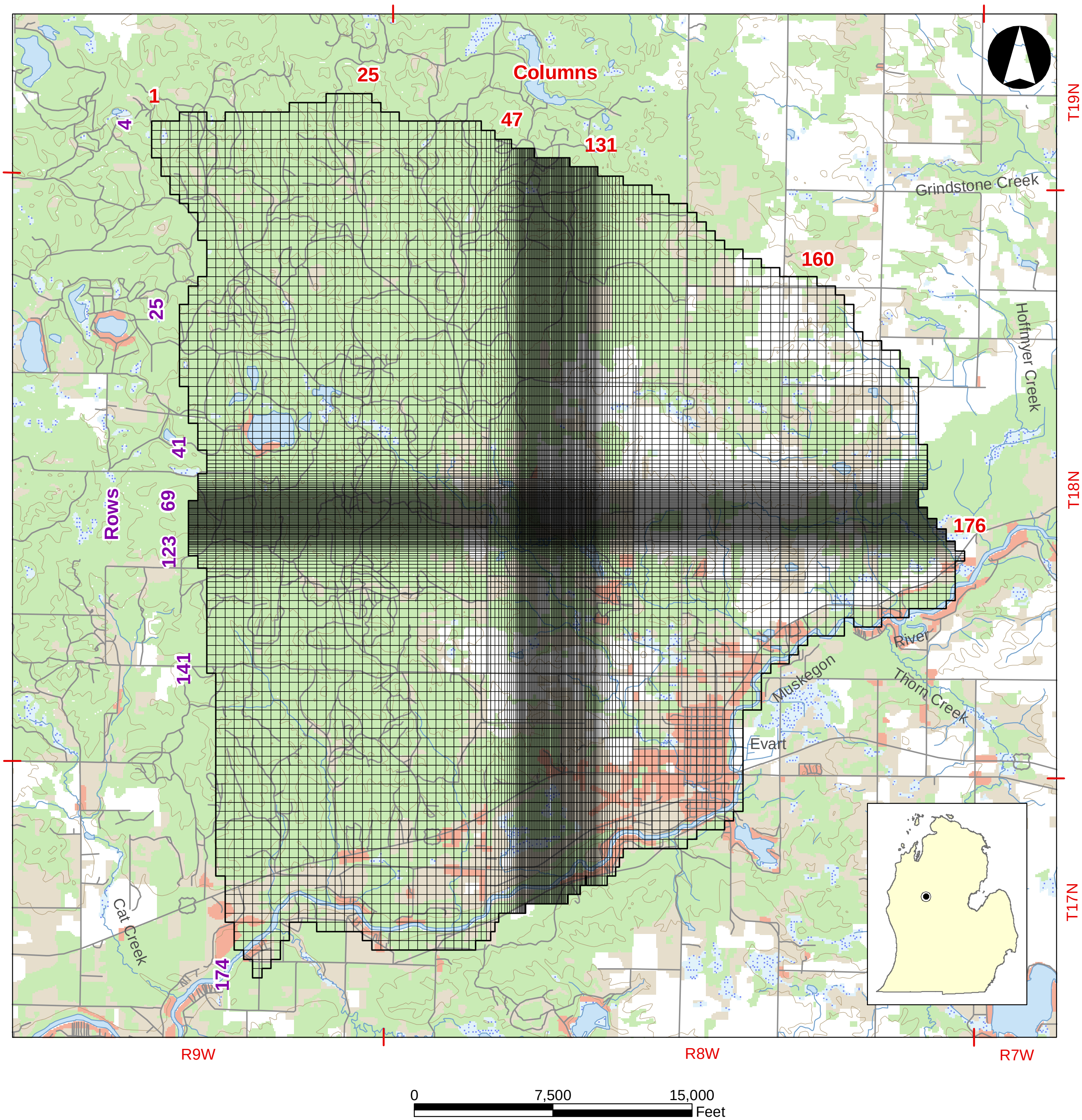


Figure A-4 Regional Groundwater Model Grid

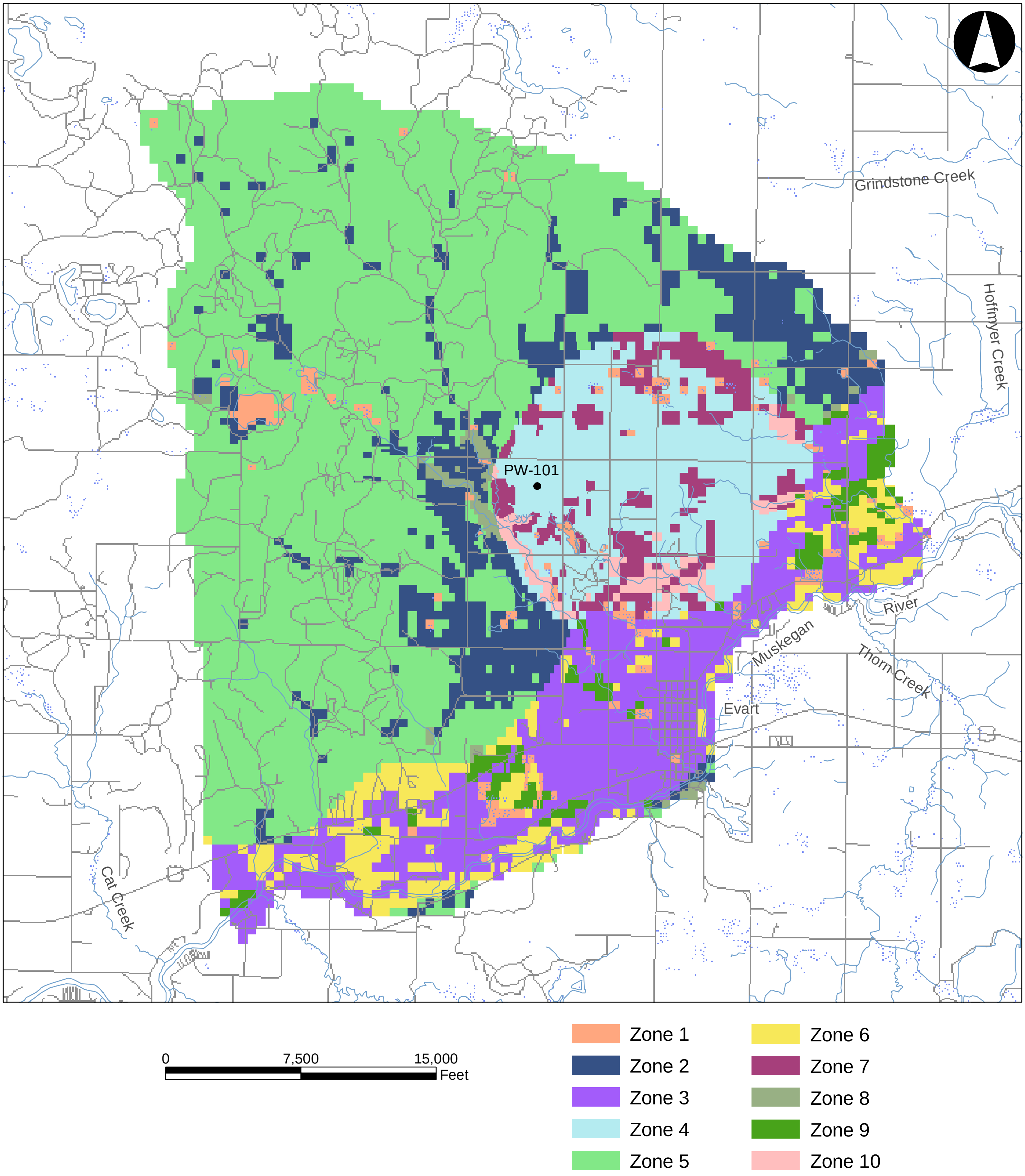


Figure A-5 Recharge Zones in Model Area

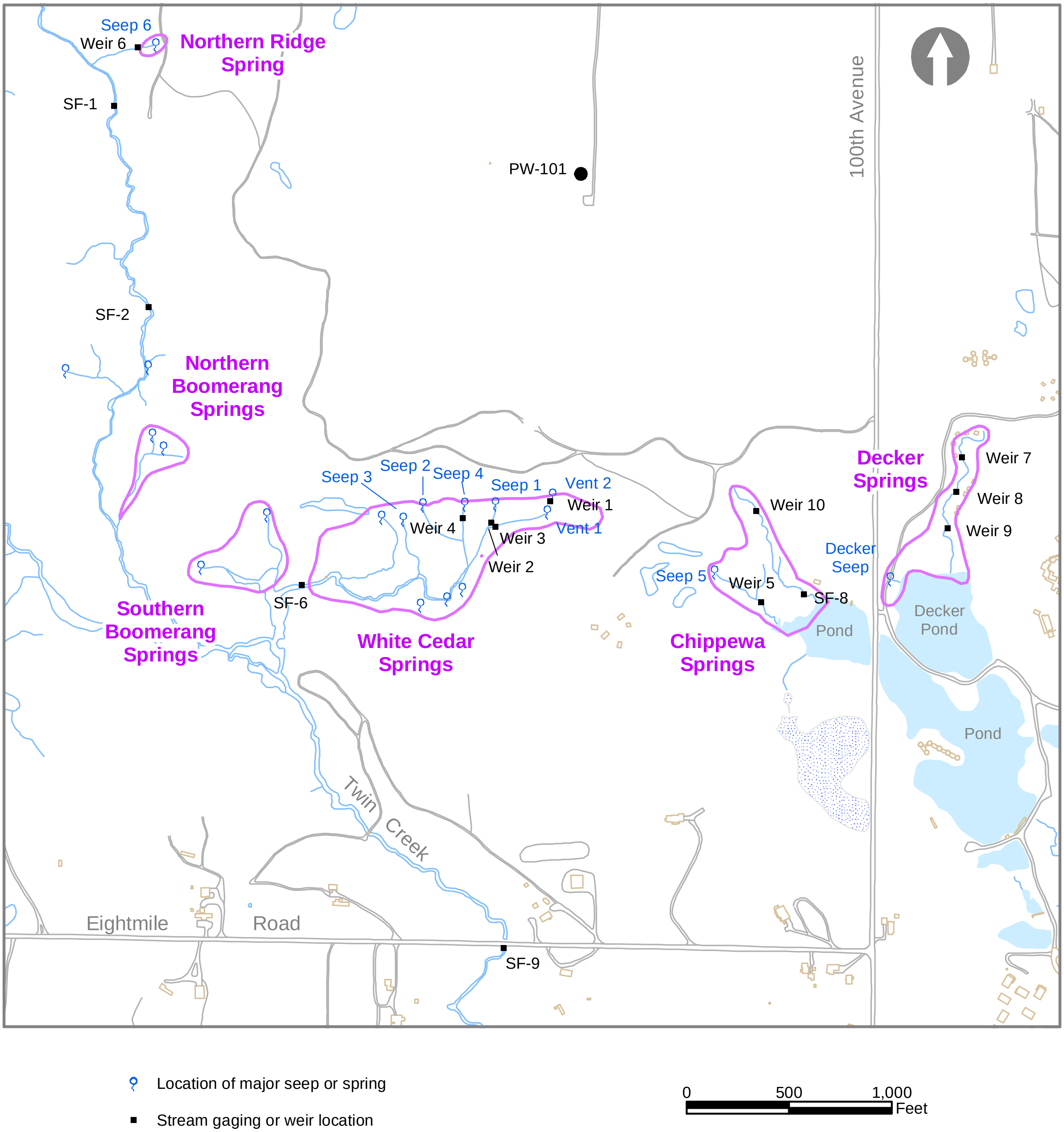


Figure A-6 Springs and Streams in the Vicinity of Production Well PW-101

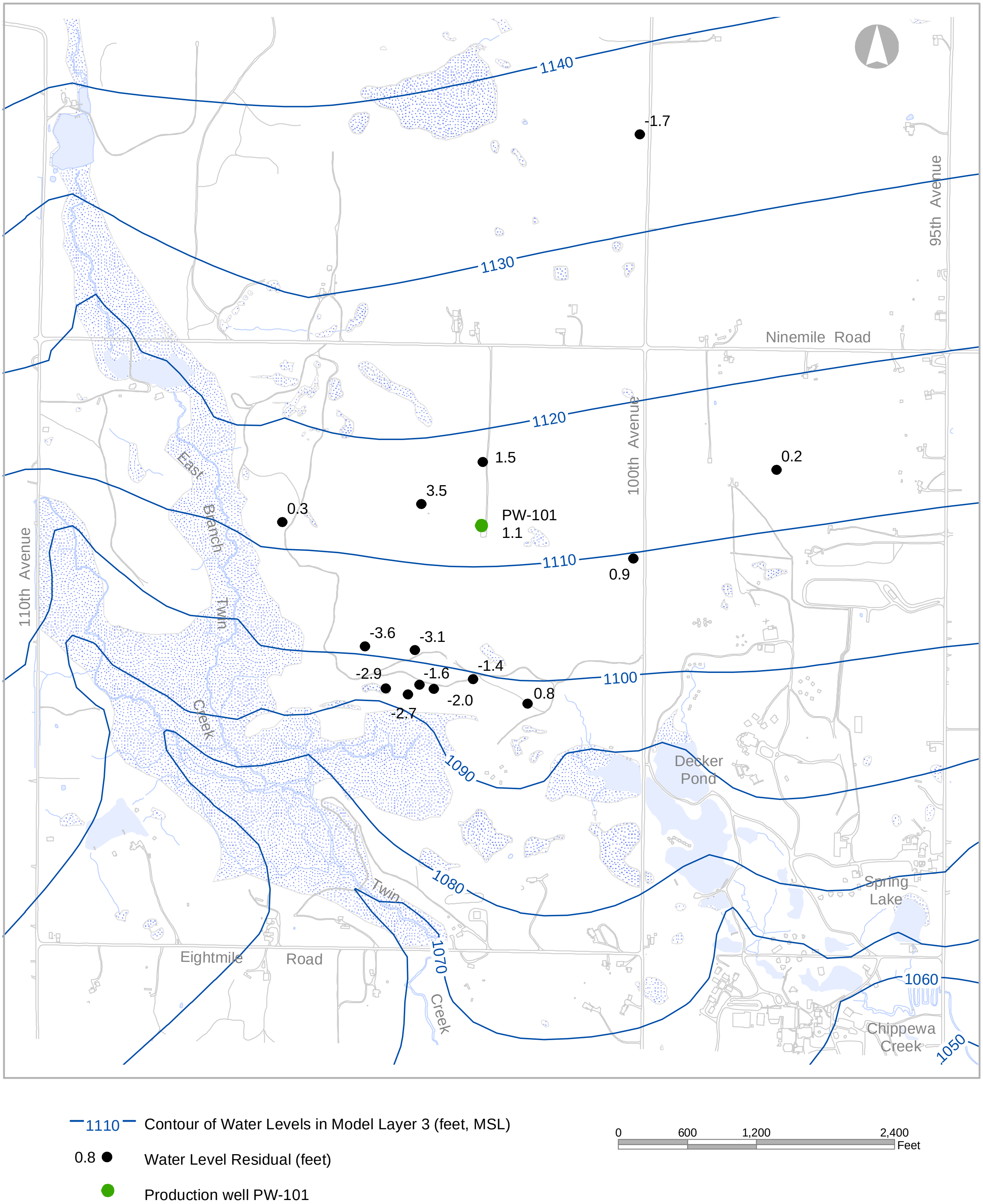


Figure A-7 Calculated Steady-State Water Levels in Vicinity of Production Well PW-101

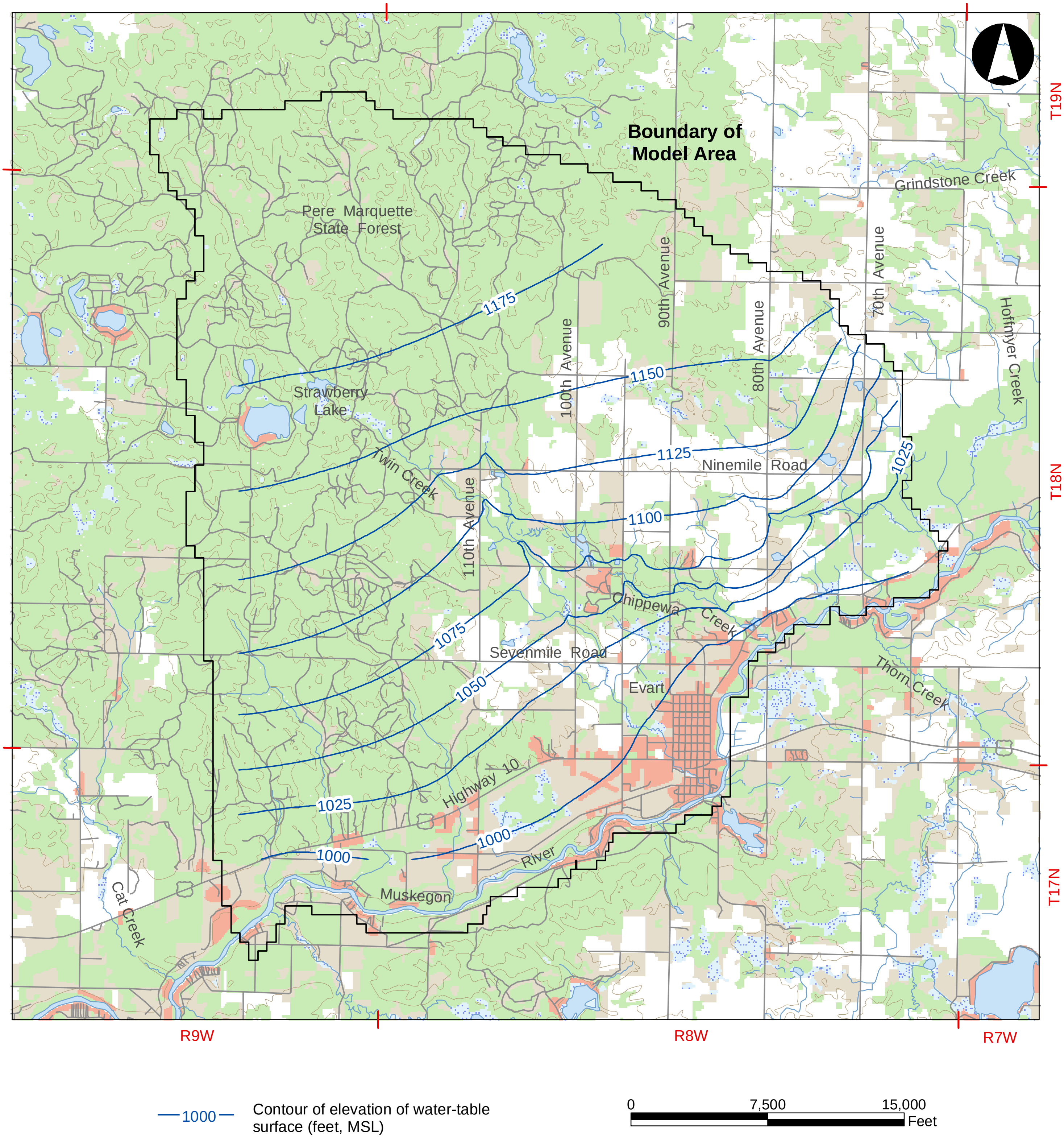
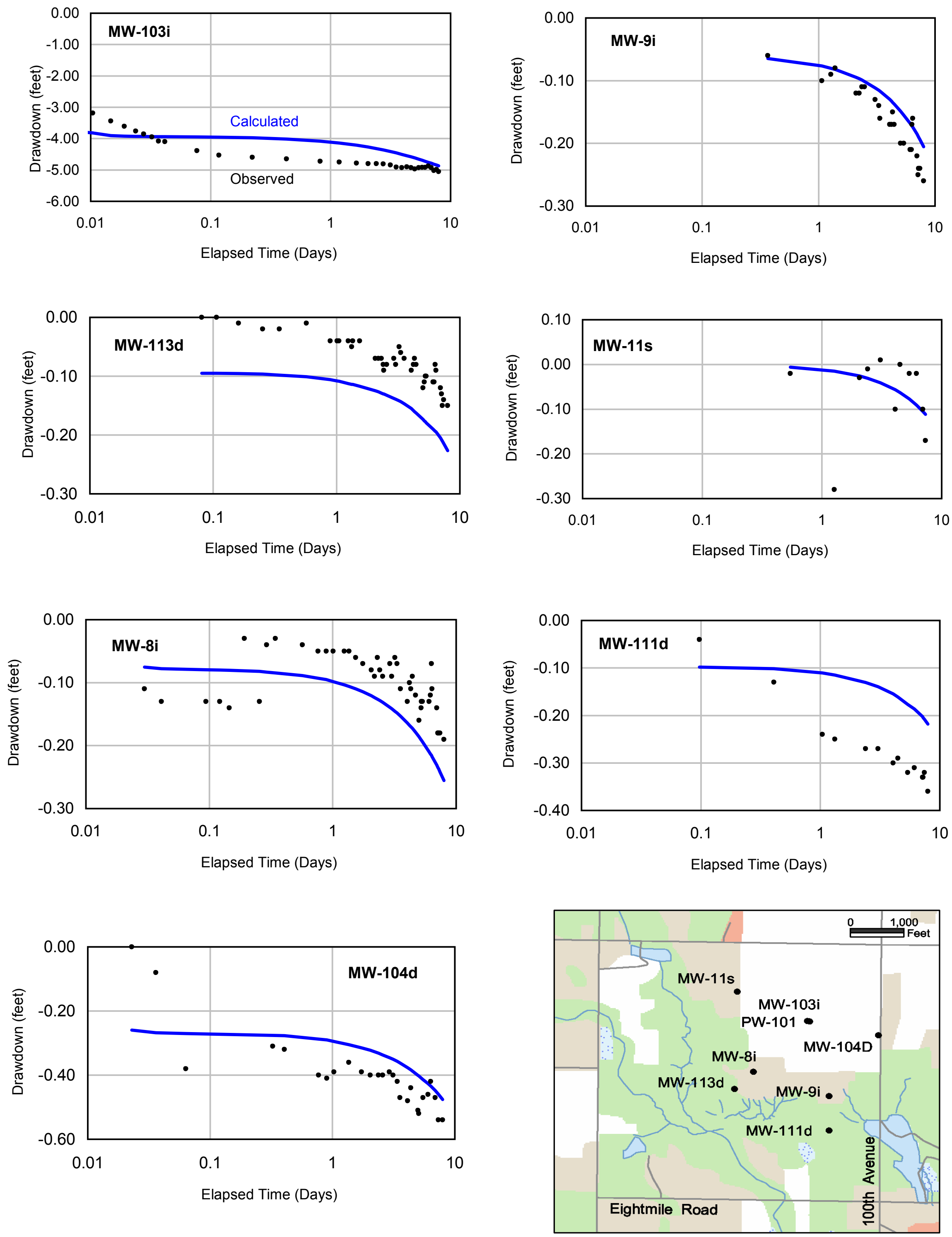
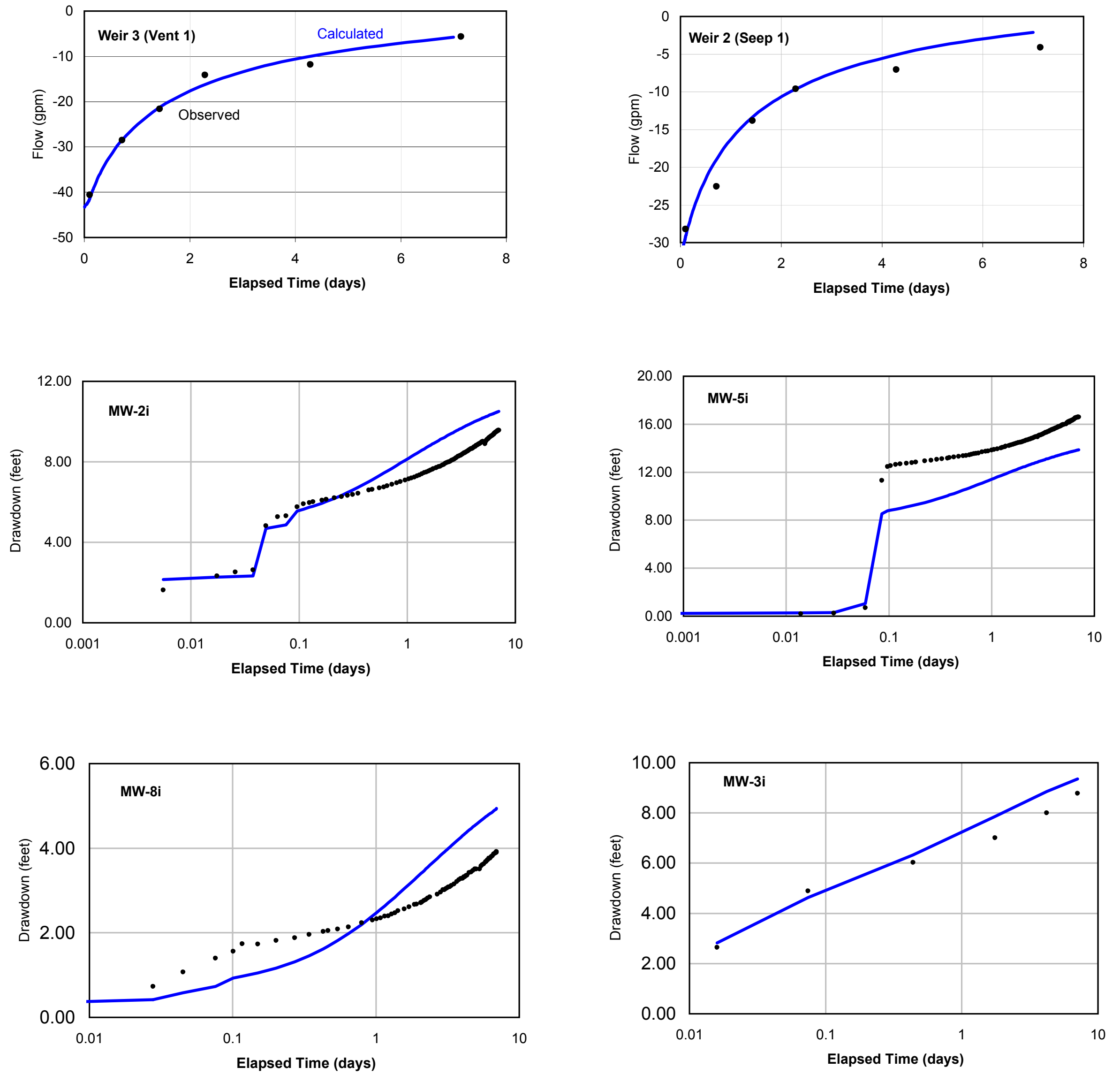


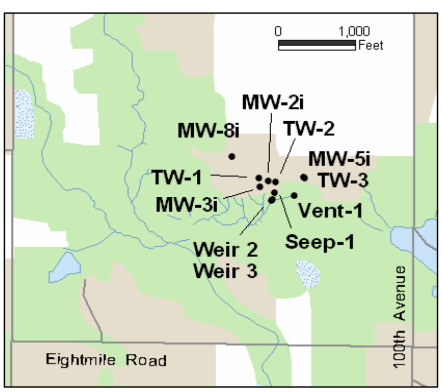
Figure A-8 Calculated Steady-State Regional Water Levels



Note: PW-101 pumped for eight days at a rate of 400 gpm.

Figure A-9 Comparison of Calculated and Observed Drawdowns During Aquifer Test of PW-101





Notes:

TW-1 started first at rate of 200 gpm, followed one hour later by TW-2 at a rate of 227 gpm, followed one hour later by TW-3 at rate of 296 gpm. Pumping continued for seven days.

Figure A-10 Comparison of Calculated and Observed Drawdowns During Aquifer Test of TW-1, TW-2 and TW-3

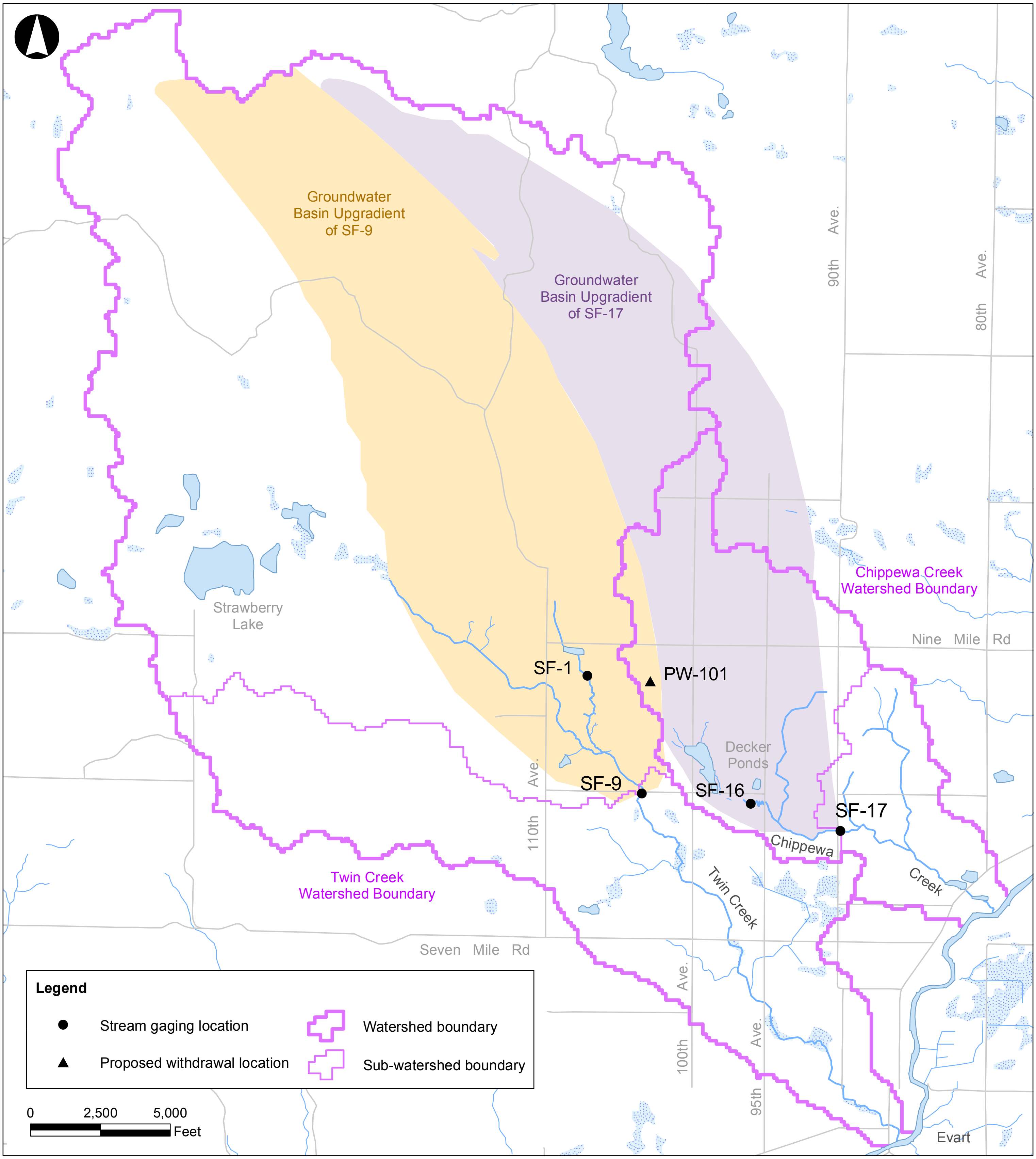


Figure A-11 Twin Creek and Chippewa Creek Watersheds and Groundwater Basins

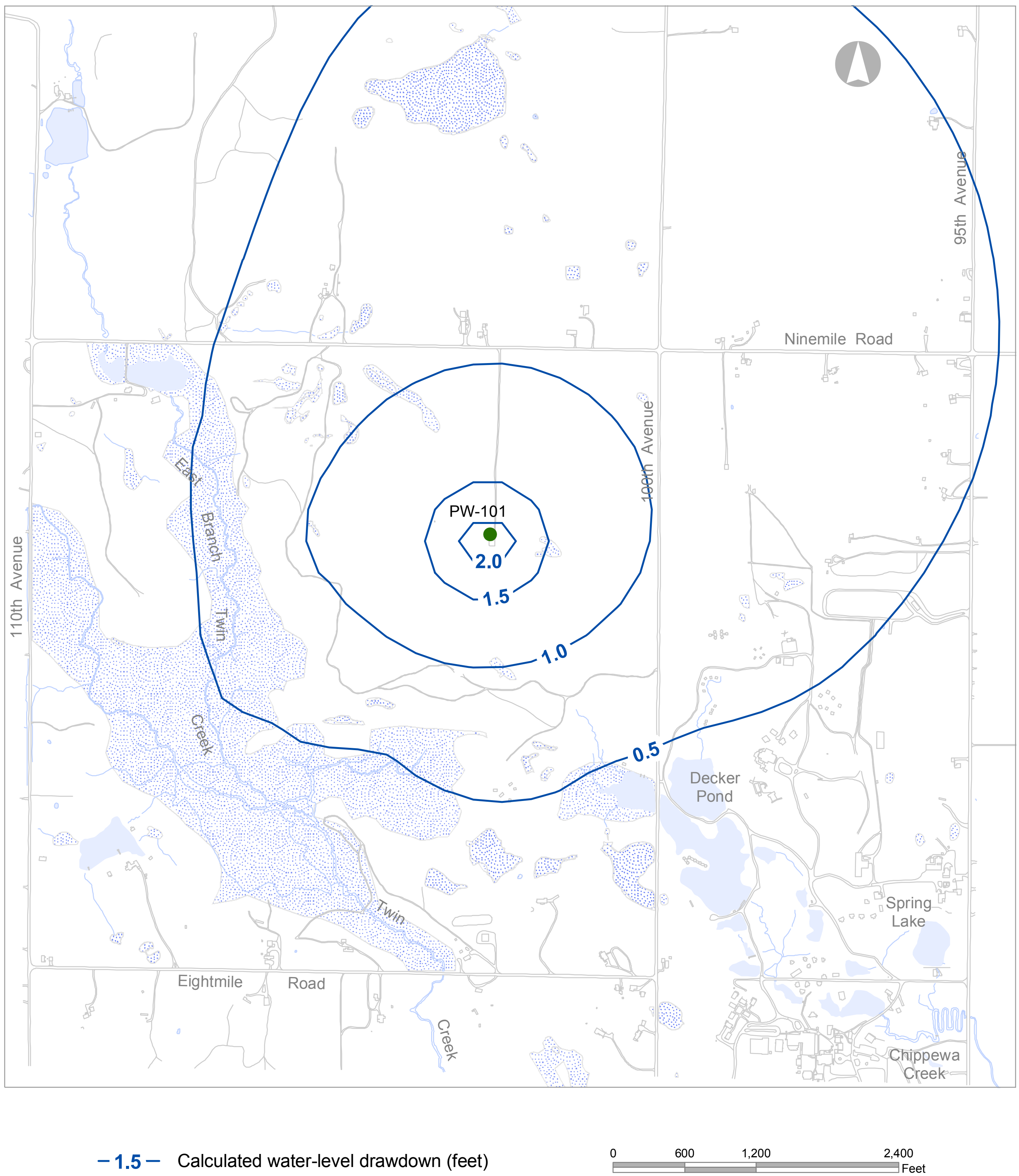


Figure A-12 Calculated Steady-State Drawdown with a Withdrawal of 150 gpm

TABLES

Table A-1 Steady-State Calibration Targets and Residuals

Water Level Targets (feet)

Well	Measured	Calculated	Residual
MW-1d	1098.25	1098.21	0.04
MW-1i	1096.6	1097.4	-0.80
MW-1u	1094.09	1097.19	-3.10
MW-2i	1096.12	1098.79	-2.67
MW-3i	1095.05	1097.81	-2.76
MW 4i	1095.13	1097.86	-2.73
MW-5d	1099.11	1098.46	0.65
MW-5i	1098.02	1100.09	-2.07
MW-6i	1100.75	1102.34	-1.59
MW-7i	1098.29	1101.79	-3.50
MW-8i	1097.3	1101.38	-4.08
MW-9i	1098.89	1098.5	0.39
MW-10s	1102.69	1102.37	0.32
MW-11s	1117.79	1117.1	0.69
MW-12i	1119.22	1117.28	1.94
MW-12s	1119.38	1117.21	2.17
MW-13i	1095.64	1098.77	-3.13
MW-101s	1114.25	1113.84	0.41
MW-101d	1122.31	1124.64	-2.33
MW-101L	1106.6	1108.2	-1.60
MW-102i	1118.91	1115.51	3.40
MW-102d	1118.8	1117.68	1.12
MW-103i	1115.72	1112.83	2.89
MW-103d	1116.12	1115.12	1.00
MW-104i	1110.47	1110.24	0.23
MW-104d	1110.47	1111.27	-0.80
MW-105s	1114.61	1114.34	0.27
MW-105d	1114.01	1114.01	0.00
MW105L	1114.46	1113.76	0.70
MW-106d	1120.32	1121.54	-1.22
MW-107i	1127.07	1124.88	2.19
MW-107d	1126.9	1126.87	0.03
MW-108i	1112.59	1112.31	0.28
MW-109d	1128.82	1130.89	-2.07
MW-110d	1113.7	1111.79	1.91
MW-111d	1098.19	1095.53	2.66
MW-113d	1092.05	1097.52	-5.47
MW-114i	1133.59	1133.1	0.49
PW-101	1114.34	1113.65	0.68
TW-1	1096.42	1098.93	-2.51
TW-2	1097.56	1098.83	-1.27
TW-3	1098.04	1099.95	-1.91

Stream Flow Targets (gpm)

Stream	Monitoring Location	Measured	Calculated	Residual
East Branch	SF-1	711	715	-4
	SF-2	737	737	0
Twin Creek	SF-11	650	642	8
	SF-9	2692	2670	22
	mouth (SF-13)	3073	3035	38
Chippewa Creek	SF-16	996	1009	-10
	SF-18	646	586	60
	SF-19	186	253	-67
	mouth (SF-20)	2800	2849	-49
Northern Ridge Spring	Weir 6	7	6	1
White Cedar Springs	Weir 2	28	27	1
	Weir 3	42	41	1
	Weir 4	37	33	4
Chippewa Springs	Weir 5 and SF-8	165	165	0

Appendix B

Curriculum Vitae of Charles B. Andrews

CHARLES B. ANDREWS

Groundwater Hydrologist

AREAS OF EXPERTISE

- Simulation of Groundwater Flow/ Contaminant Fate and Transport
- Water Resource and Water Rights Evaluations
- Contaminated Site Investigation and Remediation
- Expert Testimony
- Peer Review

SUMMARY OF QUALIFICATIONS

Dr. Andrews is nationally known for his creative solutions to difficult water resource problems. His areas of expertise include the assessment and remediation of contaminated sites; formulation of water-resource projects; assessment of surface-water and groundwater flow and quality conditions at hazardous waste sites; design of water remediation systems; and development of new and modification of off-the-shelf numerical simulation models for adaptation to specific field projects. He has provided technical guidance to significant water-rights litigation.

Dr. Andrews is a frequently requested member of groundwater advisory panels for the evaluation of state-of-the-art hydrology and for pioneering research and evaluation of contaminant transport in the subsurface. He is the author and co-author of numerous publications on modeling of groundwater flow and transport of chemical constituents, and the use of analytical models in identifying appropriate remediation alternatives for a site.

YEARS OF EXPERIENCE: 30+

EDUCATION

PhD, Geology, University of Wisconsin, Madison, 1978
MS, Geology, University of Wisconsin, Madison, 1976
MS, Water Resources, University of Wisconsin, Madison, 1974
BA, Geology, Carleton College, 1973
American University of Beirut, Beirut, Lebanon, 1971-1972

REGISTRATIONS

Registered Geologist:
Alabama No. 1175
California No. 3853
Georgia No. PG001689
Illinois No. 196001360
Mississippi No. 859
Washington No. 2841

PROFESSIONAL HISTORY

S.S. Papadopulos & Associates, Inc.
Principal, 1984 to present
President, 1994–2012
Woodward - Clyde Consultants
Hydrogeologist and head of Groundwater Section, 1980–1984
Northern Cheyenne Indian Tribe
Scientist, 1978-1980
Wisconsin State Government
Dept. of Justice and Department of Natural Resources, Consultant, 1977-1978
University of Wisconsin, Madison
Dept. of Geology & Geophysics, Research Assistant, 1975-1978
Dept. of Water Resources, Researcher, 1974-1975

REPRESENTATIVE EXPERIENCE

S.S. Papadopulos & Associates, Inc., Bethesda, MD

- **Agricultural Issues,** Wisconsin -- Working with large irrigated farm operators and dairy CAFO's to develop crop rotation and nutrient management plans to minimize potential for nitrogen contamination of groundwater. For one project involving the conversion of 4,000 acres from pine plantation to irrigated agriculture developed a detailed nitrogen balance of the expected agricultural practices and a groundwater transport model. Subsequently used these tools to develop cropping and nutrient application schedules that minimize potential for nitrogen contamination of groundwater. These evaluations were incorporated into an environmental impact statement for the project. He has made several presentations to state regulatory agency and growers associations on this work.
- **Onondaga Lake,** Syracuse, New York — Headed the groundwater modeling effort for design of remedial alternatives for this reputed-to-be the most contaminated lake in the U.S. Remediation costs projected to cost several hundreds of millions of dollars. Interacted frequently with and made many presentations to the New York State Department of Environmental Conservation. This work is ongoing.

- **Large Industrial Site,** Georgia — Conducted a detailed field and laboratory evaluation of the leachability of PCBs from contaminated soils at this site. Developed innovative methods to distinguish dissolved- and particulate-phase PCBs in leachate from batch tests.
- **Confidential Client,** Michigan — Conducted a detailed laboratory evaluation of analytical methods used to analyze for phenols in water samples. Determined that certain analytical methods were prone to false-positive readings due to reactions with dissolved natural organic matter during the analytical procedure. Identified the probable reaction pathways for the reactions that create phenols from the dissolved organic matter.
- **Williams Companies** — Participated as a technical expert for a major pipeline company in a year-long Consent Decree negotiations with US DOJ on soil and groundwater contamination issues at 30 compressor station sites. Developed a comprehensive framework, which was incorporated in the Consent Decree, for efficient, cost-effective investigation and remediation of compressor stations. Subsequent to Consent Decree provided, and continue to provide, technical oversight for site investigation and remediation.
- **Major Bottled-Water Company,** Michigan — Provide on-going groundwater consulting services for the identification and development of spring water sources. This work involves development of groundwater models to determine potential production rates, optimal pumping rates and locations, and environmental effects of water production. Developed long-term monitoring plans and was an expert witness in litigation related to development and operation of spring water sources.
- **Professional Review and Services,** miscellaneous U.S. sites — Served as Chair of External Peer Review Panel for Frenchman Flat CAU at the Nevada Test Site, 2010. Served on a review panel for Hanford (Washington)'s site-wide groundwater flow and transport model, 1989–2001. Developed a groundwater model of the A- and M- areas at the Savannah River Site (South Carolina), 1985–1986.
- **Multiple Contamination Sites,** Eastern U.S. — Directed a study to evaluate the mobility and fate of polychlorinated biphenyl compounds (PCBs) in the subsurface for over 30 contaminated sites. These studies involved laboratory and field experiments to investigate the interactions between PCBs and the subsurface materials, and to investigate the potential degradation of PCBs in the subsurface. Long-term monitoring was selected as the appropriate remedial action at all the sites.
- **New Mexico Attorney General: Hueco Bolson and the Mesilla Basins,** New Mexico — Evaluated the long-term availability of groundwater and the associated water-quality problems of these large regional aquifers in southern New Mexico. Served as an expert witness in litigation involving the proposed development of large water supplies from these basins.
- **Industrial Sites,** California and New Jersey — Managed remediation activities, including remedial investigations, feasibility studies, remedial design and implementation, for industrial sites that are extensively contaminated with arsenic and associated heavy metals. Several of these investigations involved the evaluation of geochemical parameters that govern arsenic mobility in the subsurface and groundwater/surface-water interactions.

Woodward-Clyde Consultants, San Francisco and Walnut Creek, California

Senior Project Manager of the 15-person Ground-Water Group: Responsible for water-resource business development, technical review of all water-resource projects, and staff administration. Served as Project Manager and Hydrology Task Leader on projects such as the development of groundwater flow models of Madison Aquifer in Wyoming and the San Juan Basin in New Mexico; analysis of reservoir-induced seismicity at the Aswan Dam; and development of a groundwater model and remediation plan for a 12,000-acre site having 200 major source areas. Responsible for developing the firm's state-of-the-practice capabilities in quantitative hydrology.

Northern Cheyenne Indian Tribe, Lame Deer, Montana

Directed and helped establish a comprehensive surface-water and groundwater monitoring program, and established and managed the tribal computer system. Trained tribal members in the operation and management of the hydrologic monitoring system and the computer system. Participated in numerous administrative and legislative proceedings as an advocate for tribal management of the reservation's natural resources.

Wisconsin Department of Justice and Department of Natural Resources, Madison, Wisconsin

Served as an expert witness for several judicial and administrative proceedings on cases involving groundwater contamination and wetland drainage.

University of Wisconsin, Department of Geology and Geophysics, Madison, Wisconsin

Researched the impacts of heated-water seepage from a power plant cooling lake. Developed a finite-element computer code to simulate water and heat transfer in shallow unconfined aquifers, and designed and maintained an extensive field monitoring program to collect the data needed for model verification.

University of Wisconsin, Department of Water Resources, Madison, Wisconsin

Conducted research that was funded by the U.S. Environmental Protection Agency-Denver, on the impact of oil shale development to the groundwater and surface-water resources of northwestern Colorado.

APPOINTMENTS

American Chemical Society
National Ground Water Association
American Association for the Advancement of Science
Geological Society of America

PUBLICATIONS & PRESENTATIONS

Andrews, C., 2011. How Much Modeling is Enough? Presentation at MODFLOW and More 2011: Integrated Hydrologic Modeling. International Groundwater Modeling Center (IGWMC), Colorado School of Mines, Maxwell, P., Hill, and Zheng, eds.

Andrews, C., 2011. Urban Recharge Myth: Case Study of Montgomery County, Maryland. Presentation at the 2011 Ground Water Summit and 2011 Ground Water Protection Council Spring Meeting. National Ground Water Association, Baltimore, MD.

Root, R.A., D. Vlassopoulos, N.A. Rivera, M.T. Rafferty, C. Andrews, and P.A. O'Day, 2009. Speciation and Natural Attenuation of Arsenic and Iron in a Tidally Influenced Shallow Aquifer: *Geochimica et Cosmochimica Acta, Science Direct*.

Johnson, T., C. Andrews, and M. Hennessey, 2009. Development of Chloride Profiles to Estimate Groundwater Discharge for Cap Design in Onondaga Lake. Presentation at the Fifth International Conference on Remediation of Contaminated Sediments, Jacksonville, FL, February 2-5, 2009.

Barth, G., and C. Andrews, 2009. Practical Problems, Practical Solutions. Presentation at the National Groundwater Association's Annual Groundwater Summit, Tucson, AZ, April 19–23, 2009.

Spiliotopoulos, A., and C.B. Andrews, 2007. Analysis of Aquifer Test Data – MODFLOW and PEST. in *Groundwater and Wells*.(3rd ed.). Sterrett, R.J., ed. Johnson Screens, New Brighton, MN, 812 p.

Andrews, Charles, 2008. One Hydrogeology — A New Paradigm for Model Construction: Modeling with Google Earth. Presentation at MODFLOW and More 2008: Ground Water and Public Policy Conference, May 18-21, 2008, Golden, CO.

Andrews, C.B., 2008. Review of "Effective Groundwater Model Calibration: With Analysis of Data, Sensitivities, Predictions, and Uncertainty": *Ground Water*, v. 46, no. 1, p. 5.

Karanovic, M., C.J. Neville, and C.B. Andrews, 2007. BIOSCREEN-AT: BIOSCREEN with an Exact Analytical Solution: *Ground Water*, v. 45, no. 2, pp. 242-245.

Andrews, C.B., and G. Swenson, 2006. Simulation of Brine Movement into Onondaga Lake. Presentation at MODFLOW and More 2006: Managing Ground-Water Systems. International Ground Water Modeling Center, Colorado School of Mines Golden, CO, May 22-24, 2006. Vol. 2, pp. 480-483.

Neville, C.J., and C.B. Andrews, 2006. Containment Criterion for Contaminant Isolation by Cutoff Walls: *Ground Water,* v. 44, no. 5, September-October, pp. 682-686.

Spiliotopoulos, A.A., and C.B. Andrews, 2006. Analysis of Aquifer Test Data – MODFLOW and PEST. Presentation at MODFLOW and More 2006: Managing Ground-Water Systems. International Ground Water Modeling Center, Colorado School of Mines, Golden, CO, May 22–24, 2006. Vol. 2, pp. 569-573.

Vlassopoulos, D., N. Rivera, P.A. O'Day, M.T. Rafferty, and C.B. Andrews, 2005. Arsenic Removal by Zerovalent Iron: A Field Study of Rates, Mechanisms, and Long-Term Performance. in *Advances in Arsenic Research: Integration of Experimental and Observational Studies and Implications for Mitigation*. O'Day, P., D. Vlassopoulos, X. Meng, and L. Benning, eds. ACS Symposium Series, v. 915. Washington, DC: American Chemical Society, pp. 344-360.

Andrews, C., and C. Neville, 2003. Ground Water Flow in a Desert Basin: Challenges of Simulating Transport of Dissolved Chromium. *Ground Water,* v. 41, no. 2, pp. 219-226.

Rafferty, M.T., C.B. Andrews, D. Vlassopoulos, D. Sorel, and K.M. Binard, 2003. Remediation of an Arsenic Contaminated Site. Presentation at the 226th American Chemical Society National Meeting, September 7–11, 2003, New York City, NY.

Vlassopoulos, D., C.B. Andrews, M. Rafferty, P.A. O'Day, and N.A. Rivera Jr., 2003. In Situ Arsenic Removal by Zero Valent Iron: An Accelerated Pilot Test Simulating Long-Term Permeable Reactive Barrier Performance. Presentation at the 226th American Chemical Society National Meeting, September 7-11, 2003, New York City, NY.

Sorel, D., C.J. Neville, M.T. Rafferty, K. Chiang, and C.B. Andrews, 2002. Hydraulic Containment Using Phytoremediation and a Barrier Wall to Prevent Arsenic Migration. In *Proceedings of the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds, May 20-23, 2002, Monterey, California*. Gavaskar, A.R., and A.S.C. Chen, editors. Battelle Press.

Vlassopoulos, D., J. Pochatila, A. Lundquist, C.B. Andrews, M.T. Rafferty, K. Chiang, D. Sorel, and N.P. Nikolaidis, 2002. An Elemental Iron Reactor for Arsenic Removal from Groundwater. in *Proceedings of the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds,* May 20-23, 2002, Monterey, CA. Gavaskar, A., and A.S.C. Chen, eds. Battelle Press.

Andrews, C., and C. Neville, 2001. Groundwater Flow in a Desert Basin: Complexity and Controversy. Proceedings of MODFLOW 2001 and Other Modeling Odysseys, September 11–14, 2001, International Groundwater Modeling Center, Colorado School of Mines, Golden, CO, pp.770–775.

Andrews, C.B, 2000. The Great American Experiment: Pump-and-Treat for Groundwater Cleanup. Proceedings of the International Symposium on Groundwater Contamination, Japanese Association of Groundwater Hydrology, Tokyo, Japan. June 26, 2000.

Andrews, C.B, 2000. The Meaning of Success in Assessing Groundwater Remediation. Presentation at the Western Pacific Geophysics Meeting, June 27–30, 2000, Tokyo, Japan. in *Eos*, v. 81, no. 22, May 30, 2000.

Andrews, C.B., and D. Vlassopoulos, 2000. Modeling the Migration of Arsenic in Groundwater: Understanding the Processes. Geological Society of America, Annual Meeting, October 2000, Reno, NV. in *Geological Society of America Abstracts with Programs,* A406-7.

Vlassopoulos, D., and C.B. Andrews, 2000. The Intertwined Fate of Iron and Arsenic in Contaminated Groundwater Entering a Tidal Marsh, San Francisco Bay. Invited Speaker Presentation at the National Ground Water Association *Theis 2000 Conference on Iron in Groundwater*, September 15–18, 2000, Jackson Hole, WY.

Lolcama, J.L., and C.B. Andrews, 1999. Catastrophic Flooding of a Quarry in Karstified Dolomite (Abstract). Presentation at the NGWA National Convention and Exposition, December 3-6, 1999, Nashville, TN. in *Ground Water Supply Issues in the Next Century, 1999 Abstract Book*. Nashville, TN: National Groundwater Association.

Vlassopoulos, D., C. Andrews, R. Hennet, and S. Macko, 1999. Natural Immobilization of Arsenic in the Shallow Groundwater of a Tidal Marsh, San Francisco Bay. Presentation at the American Geophysical Union 1999 Spring Meeting, May 31–June 4, Boston, MA.

Andrews, C.B, 1998. MTBE: A Long-Term Threat to Ground Water Quality: *Ground Water*, v. 36, no. 5, pp. 705-706.

Hennet, R., D.A. Carleton, S.A. Macko, and C.B. Andrews, 1997. Environmental Applications of Carbon, Nitrogen, and Sulfur Stable Isotope Data: Case Studies (abstract). Invited Speaker Presentation at the Geological Society of America Annual Meeting, Salt Lake City, UT, November 1997.

Zhang, Y., C. Zheng, C.J. Neville, and C.B. Andrews, 1996. *ModIME User's Guide: An Integrated Modeling Environment for MODFLOW, PATH3D, and MT3D.* Version 1.1. Bethesda, MD: S.S. Papadopulos & Associates, Inc.

Larson, S.P., C.B. Andrews, and C.J. Neville, 1995. Parameter Estimation in Groundwater Modeling: Research, Development, and Application (abstract). American Geophysical Union (AGU) Spring Meeting, Baltimore, May 30–June 2, 1995, Hydrology Sessions. S145, Abstract H51C-02 0835h.

Andrews C.B. (co-author), 1994. Chapter 3—Performance of Conventional Pump-and-Treat Systems, and Chapter 5—Characterizing Sites for Ground Water Cleanup. in *Alternative Ground Water Cleanup*. Washington, DC: National Academy Press.

Hennet, R.J.-C., and C.B. Andrews, 1993. PCB Congeners as Tracers for Colloid Transport in the Subsurface—A Conceptual Approach. in *Manipulation of Groundwater Colloids for Environmental Restoration*. Ann Arbor, MI: Lewis Publishers, pp. 241-246.

Zheng, C., G.D. Bennett, and C.B. Andrews, 1992. Reply to the Preceding "Discussion by Robert D. McCaleb of 'Analysis of Ground-Water Remedial Alternatives at a Superfund Site' ": *Ground Water*, v. 30, no. 3, pp. 440-442.

Zheng, C., G.D. Bennett, and C.B. Andrews, 1991. Analysis of Ground-Water Remedial Alternatives at a Superfund Site: *Ground Water*, v. 29, no. 6, pp. 838-848.

Andrews C.B. (co-author), 1990. Chapter 5—Experience with Contaminant Flow Models in the Regulatory System. in *Ground Water Models: Scientific and Regulatory Applications*. Washington, DC: National Academy Press.

Andrews, C.B., D.L. Hathaway, and S.S. Papadopulos, 1990. Modeling the Migration and Fate of Polychlorinated Biphenyls in the Subsurface. in Proceedings of the PCB Forum, Second International Conference for the Remediation of PCB Contamination, April 2–3, 1990, Houston, TX, pp. 64-82.

Hathaway, D., and C. Andrews, 1990. Fate and Transport Modeling of Organic Compounds from a Gasoline Spill. in *Proceedings of Petroleum Hydrocarbons and Organic Chemicals in Ground Water; Prevention, Detection, and Restoration*, National Water Well Association and American Petroleum Institute, Houston, TX, October 31–November 2, 1990. *Ground Water Management*, v. 4, pp. 563–576.

Stephenson, D.E., G.M. Duffield, D.R. Russ, C.B. Andrews, and E.C. Phillips, 1989. Practical Use of Models in Ground Water Assessment and Protection Programs at the Savannah River Site: Three Case Histories. Presentation at the Joint USA/USSR Conference on Hydrogeology, Moscow, USSR, June 30–July 11, 1989.

Andrews, C.B., and S.P. Larson, 1988. Evolution of Water Quality in the Lower Rio Grande Valley, New Mexico. *Eos*, v. 69, no. 16, p. 357.

Larson, S.P., C.B. Andrews, M.D. Howland, and D.T. Feinstein, 1987. Three-Dimensional Modeling Analysis of Groundwater Pumping Schemes for Containment of Shallow Groundwater Contamination. Presentation at *Solving Ground Water Problems with Models*, Association of Ground Water Scientists and Engineers, Denver, CO, February 10–12, 1987. in *Solving Ground Water Problems with Models: An Intensive Three-Day Conference and Exposition Devoted Exclusively to Ground Water Modeling*. Vol. 1. Dublin, OH: National Water Well Association, pp. 517–536. February 11.

Looney, B.B., R.A. Field, G.B. Merrell, G. Duffield, and C.B. Andrews, 1987. Analyses of the Validity of Analytical Models Used for Assessment of Forty-Five Waste Site Areas: Subsurface Flow and Chemical Transport. in *Solving Ground Water Problems with Models*. Dublin, OH: National Water Well Association, pp. 954-982.

Stephenson, D.E., B.B. Looney, C.B. Andrews, and D.R. Buss, 1987. Three-Dimensional Simulation of Groundwater Flow and Transport of Chemical and Low-Level Radioactive Constituents within Two Production Areas of the Savannah River Plant. in Proceedings of the 9th Annual Low-Level Radioactive Waste Conference, U.S. Department of Energy, Washington, DC, pp. 472-481.

Auerbach, S.I., C. Andrews, D. Eyman, D.D. Huff, P.A. Palmer, and W.R. Uhte, 1984. Report of the Panel on Land Disposal. in *Disposal of Industrial and Domestic Wastes: Land and Sea Alternatives*. Washington, DC: National Academy Press, pp. 73–100.

Andrews, C.B., 1983. Hydrogeology in North America — 1932 to 1982. in *The Revolution in Earth Sciences: Advances in the Past Half-Century*. Boardman, S., ed. Kendall/Hunt Publishing Company.

Andrews, C.B., 1979. *Impacts of Coal-Fired Power Plants on Local Ground-Water Systems*. Wisconsin Power Plant Impact Study. U.S. Environmental Protection Agency. EPA 600/3-80-079. p. 203.

Andrews, C.B., 1979. *Statement of Dr. Charles Andrews, Hydrologist, Northern Cheyenne Tribe*. Hearings before the Select Committee on Indian Affairs. U.S. Senate, 96th Congress, pp. 412-432.

Andrews, C.B., and M.P. Anderson, 1979. Thermal Alteration of Groundwater Caused by Seepage from a Cooling Lake: *Water Resources Research,* v. 15, no. 3, pp. 595-602.

Andrews, C.B., W. Woessner, and T. Osborne, 1979. The Impacts of Coal Strip Mining on the Hydrogeologic System of the Northern Great Plains — Case Study of Potential Impacts on the Northern Cheyenne Reservation. *Journal of Hydrology,* v. 43, pp. 445-467.

Andrews, C.B., 1978. The Impact of the Use of Heat Pumps on Groundwater Temperatures. *Ground Water*, v. 16, no. 6, pp. 437-443.

Andrews, C.B., and M.P. Anderson, 1978. The Impact of a Power Plant on the Groundwater System of a Wetland. *Ground Water,* v. 16, no. 2, pp. 105-111.

Andrews, C.B., and E. Quigley, 1975. Designing and Maintaining Ponds for Swimming. University of Wisconsin–Madison, Extension Publication G2678, p. 22.

DEPOSITION AND TESTIMONY EXPERIENCE

DEPOSITIONS

2015 Duke Energy Progress, Inc. v. N.C. Department of Environment and Natural Resources, Division of Water Resources. State of North Carolina, Wake County in the Office of Administrative Hearings. Case No. 15 HER 02581. July 31.

2014 Emhart Industries, Inc. vs. New England Container Company, Inc., et al. vs. United States Department of the Air Force, et al. vs. Black & Decker, Inc. United States District Court for the District of Rhode Island. C.A. 06-218S and C.A 11-023S (Consolidated). November 17–18.

2014 Emhart Industries, Inc. vs. New England Container Company, Inc., et al. vs. United States Department of the Air Force, et al. vs. Black & Decker, Inc. United States District Court for the District of Rhode Island. C.A. 06-218-S and C.A 11-023-S (Consolidated). May 28.

2012 Commissioner of the Department of Planning and Natural Resources, Alicia V. Barnes, et al. Century Alumina Company, et al. District Court of the Virgin Islands Division of St. Croix. Civil No. 2005-0062. June 28–29.

2010 United States Virgin Islands Department of Planning and Natural Resources vs. St. Croix Renaissance Group, L.L.L.P., et al. District Court of the Virgin Islands Division of St. Croix. Civil No. 2007/114. October 20.

2010 United States Virgin Islands Department of Planning and Natural Resources v. St. Croix Renaissance Group, L.L.L.P., et al. District Court of the Virgin Islands Division of St. Croix. Civil No. 2007/114. October 22.

2010 New Jersey Department of Environmental Protection, The Commissioner of the New Jersey Department of Environmental Protection and the Administrator of the New Jersey Spill Compensation Fund vs. Essex Chemical Corporation. Superior Court of New Jersey Law Division: Middlesex County. Docket No.: MID-L-5685-07. February 22.

2009 United States of America vs. Norfolk Southern Railway Company. U.S. District Court for the District of South Carolina, Aiken Division. Civil Action No. 1:08-CV-01707-MBS. August 5.

2009 Michigan Citizens for Water Conservation, et al. vs. Nestle Waters North America, Inc. State of Michigan Mecosta County Circuit Court. File No. 01-14563-CE. February 11 and March 6.

2008 The Gillette Company vs. Onebeacon America Insurance Company, et al. Commonwealth of Massachusetts Superior Court. 05-5102-BLS. December 4.

2008 Brian Wayne Meixner et al. vs. Emerson Electric Co. et. al. U.S. District Court for the District of South Carolina, Aiken Division. 06-CV-01359-MBS. April 29.

2007 Glenn Gates and Donna Gates v. Rohm & Haas Company, et al. U.S. District Court for the Eastern District of Pennsylvania. Civil Action No. 2:06-CV-01743-GP. November 16, 19.

2007 Methyl Tertiary Butyl Ether (MTBE) Products Liability Litigation, County of Suffolk and Suffolk County Water Authority vs. Amerada Hess Corporation et al., United Water New York, vs. Amerada Hess Corporation et al. U.S. District Court Southern District of New York. 04 CIV. 5424 and O4 CIV. 2389. November 27, 28.

2007 Kay Ryan Corley, et al. v. Colonial Pipeline Company, et al. Hale County Circuit Court, Alabama. CV-2005-138. September 6–7.

2003 American Home Products Corporation vs. Adriatic Insurance Company. Superior Court of New Jersey Law Division: Hudson County. Docket No. HUD-L-5002-92. April 29.

2003 H. Todd Brinckerhoff, Jr., Harriet B. Haslett and MBM Company I, LLC vs. Shell Oil Company and Motiva Enterprises, LLC. U.S. District Court, Southern District of New York. Civil Action No. 02cv939. March 27.

2003 Bernice Samples et al. vs. Conoco, Inc.; Agrico Chemical Company and Escambia Treating Company, Inc. Circuit Court of the First Judicial Circuit in and for Escambia County, Florida. No. 01-631-CA-01. March 18.

2002 Michigan Citizens for Water Conservation et al. vs. Nestlé Waters North America, Inc. et al. State of Michigan in the Circuit Court for the County of Mecosta. Case No. 01-14563-CE. October 14.

2001 JBG/JER Shady Grove, LLC vs. Eastman Kodak Company. Circuit Court for Montgomery County, Maryland. Civil No. 214877. October 25.

1999 Associated Aviation Underwriters, Inc. vs. Purex Industries, Inc. et al. Superior Court of the State of California for the County of Los Angeles. No. EC021744. August 9.\

1999 Flintkote Company and Genstar Corp. vs. Liberty Mutual Insurance Company et al. Superior Court of New Jersey, Law Division, Bergen County. Docket No. 10288-97. March 26.

1998 GenCorp Inc. vs. Adriatic Insurance. Superior Court of New Jersey. Case No. 5:95CV 2464. September.

1997 C-I-L Corporation of America and Marsulex, Inc. vs. NL Industries, Inc. et al. U.S. District Court, District of New Jersey. Civil Action No. 93-2157 (WHW). January 21.

1995 Freehold-Carthage, Inc. vs. Lumbermans Mutual Casualty et al. vs. Hartford Insurance Company vs. Minnesota Mining and Manufacturing Company. Superior Court of New Jersey. Docket No. L-56812-90.

1995 Hughes Aircraft Company vs. Brian Eustace Beagley et al. Superior Court of the State of California, County of Los Angeles. No. BC062120. February 10.

1993 Martin Marietta Corporation vs. Aetna Casualty & Surety et al. Superior Court of the State of California for the County of Los Angeles. Case No. C610358.

1992 In re: Demand for Arbitration filed by Richard and Susan Ritchie and Exxon Corporation. State of New Jersey, Department of Environmental Protection. Damage Claim No. 86-54-0033. February 29.

TESTIMONY

2015 Emhart Industries, Inc. v. New England Container Company, Inc., et al. and Emhart Industries, Inc. v. United States Department of the Air Force, et al. v. Black & Decker, Inc., et al. United States District Court for the District of Rhode Island. C.A. Nos.: 06-218 S and 11-023 S. June 25.

2014 In the Matter of a Conditional High Capacity Well Approval for Two Potable Wells to be Located in the Town of New Chester, Adams County, Issued to New Chester Dairy, Inc. and Milk Source, Holding, LLC. Case No. DNR-13-011. State of Wisconsin Division of Hearings and Appeals. January 16–17.

2013 In the Matter of a Conditional High Capacity Well Approval for Two Potable Wells to be Located in the Town of Richfield, Adams County, Issued to Milk Source Holding, LLC. Case

Nos. IH-12-03, IH-12-04, IH-12-05, and IH-12-08. State of Wisconsin Division of Hearings and Appeals. June 24, 25 and December 16, 20.

2010 Branham v. Rohm & Hass Company et al. Court of Common Pleas of Philadelphia County. October 12–18.

2010 New Jersey vs. Essex Chemical Corporation. Superior Court of New Jersey Law Division: Middlesex County. Docket No.: MID-L-5685-07. March 19.

2008 Attorney General of the State of Oklahoma and Oklahoma Secretary of the Environment vs. Tyson Foods Inc. et al. U.S. District Court for the Northern District of Oklahoma. 4:05-CV-00329-TCK-SAJ. March 10.

2003 Michigan Citizens for Water Conservation et al. vs. Nestlé Waters North America Inc. et al. State of Michigan in the Circuit Court for the County of Mecosta. 01-14563-CE. June 6.

2003 Michigan Citizens for Water Conservation et al. vs. Nestlé Waters North America Inc. et al. State of Michigan in the Circuit Court for the County of Mecosta. 01-14563-CE. May 21.

2003 Michigan Citizens for Water Conservation et al. vs. Nestlé Waters North America Inc. et al. State of Michigan in the Circuit Court for the County of Mecosta. 01-14563-CE. May 19.

2001 JBG/JER Shady Grove, LLC vs. Eastman Kodak Company. Circuit Court for Montgomery County, Maryland. Civil No. 214877. December 13.

1995 Anderson et al. vs. Pacific Gas and Electric Company. Superior Court of the State of California for the County of San Bernardino. Case No. BCV00300. July.

1995 Hughes Aircraft Company vs. Brian Eustace Beagley et al. Superior Court of the State of California, County of Los Angeles. No. BC062120.

1995 Anderson et al. vs. Pacific Gas and Electric Company. Superior Court of the State of California for the County of San Bernardino. Case No. BCV00300. February 13.