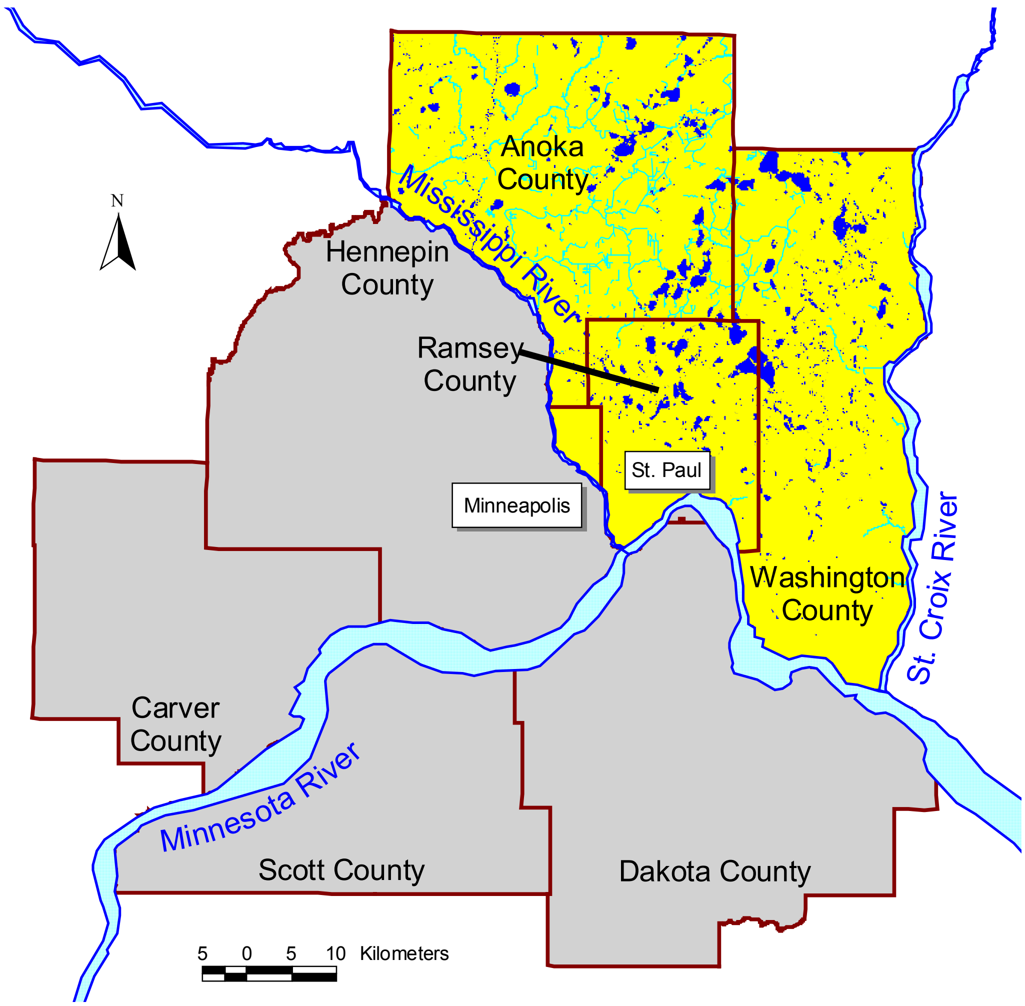
Metropolitan Area Groundwater Model
Project Summary

Northeast Province, Layers 1, 2, and 3 Model

Version 1.00, May 2000

John K. Seaberg and Douglas D. Hansen



Minnesota Pollution Control Agency

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Introduction

This document summarizes the development and construction of one module of the Metropolitan Area Groundwater Model (Metro Model). The Metro Model is actually comprised of four different regional groundwater flow models for the seven-county Twin Cities metropolitan area (Figure 1).

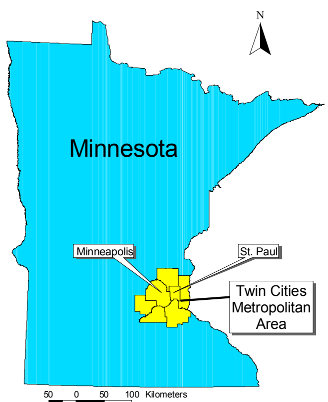


Figure 1. Metro Model Index Map

One of the models is for Layers 3 (Prairie du Chien-Jordan Aquifer), 4 (Franconia-Ironton-Galesville Aquifer), and 5 (Mt. Simon-Hinckley Aquifer), and encompasses the entire metro area. The remaining models are for Layers 1 (Glacial Drift Aquifer), 2 (St. Peter Sandstone Aquifer), and 3 (Prairie du Chien-Jordan Aquifer). The metro area has been divided into three hydrologic provinces for these upper aquifer layers, separated by the Mississippi, Minnesota, and St. Croix Rivers, as shown in Figure 2. These rivers are believed to serve as hydrologic boundaries for the upper three layers.

This report presents a summary of development and construction for the Northeast Province steady-state model of the upper three layers. This includes an area comprised mainly of Anoka, Ramsey, and Washington Counties.

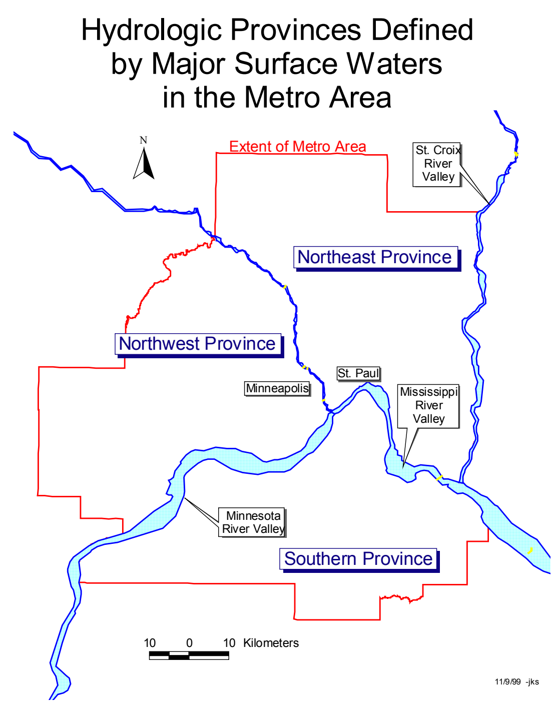


Figure 2. Hydrologic Provinces

This summary has been prepared to provide the user with the basic information required to understand and use the Northeast Province Model. A full documentation log (over 160 pages) chronicling the construction and development of this module of the Metro Model is contained in two documents that are available on request. Also, more detailed information regarding the overall conceptual model may be found in the general report titled Overview of the Twin Cities Metropolitan Groundwater Model, which discusses development of the conceptual model and its application to the Multi-Layer Analytic Element Model (MLAEM), the software used for development of the model. Review of and familiarity with this report provides a more complete context in which to read this summary for the Northeast Province. Refer to that document for more complete descriptions of the conceptual model and its implementation in MLAEM.

The development and construction of the Northeast Province are presented in this document, starting with a summary of the upper hydrostratigraphic units, along with global parameters used in the model. This is followed by a discussion regarding the construction of the polygon mesh used to simulate infiltration and leakage, and how it is tied in to the hydrogeology. The construction phase of the model is completed with a presentation of how surface waters and aquifer inhomogeneities are represented in the model. A discussion of calibration targets and procedures naturally follows, in which water levels and water budget information were used to tie the model to measured conditions. The final portion of this report presents the actual model datasets that are available for use.

Conceptual Model

Hydrostratigraphy

As stated, the Northeast Province model contains the three uppermost aquifer layers. Leaky layers representing aquitards separate these aquifer layers. For reasons that will be discussed later, the regional model does not simulate leaky flow as an output parameter determined by the model on the basis of intrinsic hydraulic properties of the aquitard. Instead, the regional Metro Model represents flow between aquifer layers by specifying the actual flux or leakage rates, which are adjusted during calibration procedures. A brief description of the hydrostratigraphic units is provided in this section. Table 1 summarizes the global aquifer parameters used in model construction. The derivation of these parameters is discussed in the Overview of the Twin Cities Metropolitan Groundwater Model.

Layer 1. This layer represents a buried aquifer comprised of unconsolidated glacial materials throughout the model domain. Groundwater recharge occurs at the top of this layer through infiltration. Water losses from this aquifer occur through discharge to surface water bodies and leakage to the underlying aquifer. The base elevation of this aquifer is globally set to 220 m MSL, and thickness to 40 m. The global hydraulic conductivity value is 21 m/day and the porosity is 0.3.

Leaky Layer 1. This leaky layer represents the lower-most unit(s) with vertical hydraulic resistance underlying the lower-most glacial drift aquifer. This leaky layer represents the effects of one or more of the following: glacial till, Decorah Shale, Platteville Limestone, and the Glenwood Shale.

Layer 2. The St. Peter Sandstone, represented by Layer 2 in the Metro Model, occurs discontinuously in the Northeast Province, owing to post-depositional erosion as illustrated in Figure 3 below. It occurs as the first bedrock in some areas, but is overlain by the Platteville and Glenwood Formations in others, portions of which are overlain by

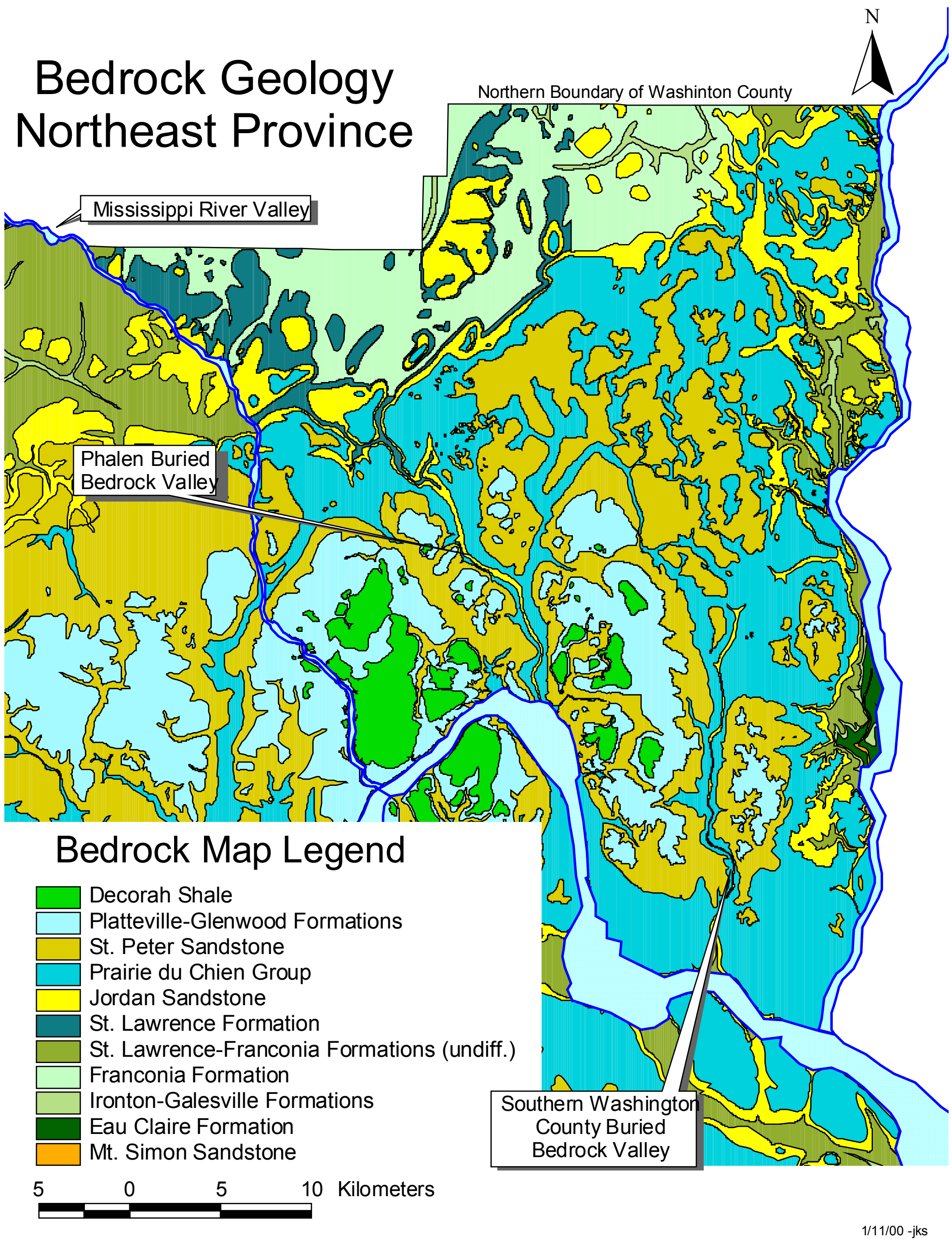


Figure 3. Bedrock Geology, Northeast Province

the Decorah Shale. Recharge rates to this aquifer are influenced by, among other things, the hydraulic properties of the overlying units, which can range from very permeable glacial outwash materials to the tight shale and limestone formations. Layer 2 has been assigned a global hydraulic conductivity value of 3.3 m/day, a porosity of 0.30, with a base elevation of 190 m MSL and a thickness of 29 m.

Leaky Layer 2. This leaky layer represents the base of the St. Peter Sandstone, which may provide significant vertical hydraulic resistance.

Layer 3. Layer 3 represents groundwater flow in the Prairie du Chien-Jordan Aquifer, and treats both formations as one hydrostratigraphic unit of variable areal extent (Figure 3). Recharge to this aquifer occurs as leakage from overlying bedrock units and also from the glacial drift where the formation subcrops beneath it. Discharge occurs to surface water bodies, primarily the major river systems that physically dissect the aquifer. The base of this aquifer is the St. Lawrence Formation, a regional confining unit that we are assuming represents an impermeable base for the model of Layers 1, 2, and 3. The assigned global base elevation is 120 m MSL with a thickness of 60 m. The global value for hydraulic conductivity is 12 m/day and the porosity is 0.090.

Table 1
Global Aquifer Parameters, Northeast Province Layers 1, 2, and 3
Version 1.00

Model Layer	Aquifer	Base Elevation (m MSL)	Thickness (m)	Hydraulic Conductivity (m/day)	Porosity
Layer 1	Glacial Drift	220	40	21	0.30
Layer 2	St. Peter Sandstone	190	29	3.3	0.30
Layer 3	Prairie du Chien-Jordan Aquifer	120	60	12	0.09

Implementation. Because the model is constructed using MLAEM, the aquifers are treated as extending infinitely, when they are actually of very limited extent. However, boundaries are imposed on the system by modeling the major rivers, which act as hydrologic boundaries to the system. Since the actual bedrock layers have variable limited extents, there are areas in the model where the aquifer is erroneously represented as present within a layer. Depending on the location and on the application of the model, this either may be of no consequence, or may require site-specific customization to model the system and to ensure a proper water balance.

The regional model uses only groundwater recharge and leakage rates to maintain the water balance for inter-aquifer flow. Site-specific models will require replacement of these given-strength elements in the area of interest with leaky areal elements that separate the aquifer layers. This will allow the model to properly respond to inter-aquifer stresses, such as pumping, that are imposed on the finite water balance of the system.

Recharge and Discharge Zones

Groundwater recharge for the top three layers in the Northeast Province occurs throughout the interior, originating from infiltration into the glacial drift aquifer. As described in the Overview of the Twin Cities Metropolitan Groundwater Model, the infiltrated water is generally apportioned to the underlying aquifer units proportional to their transmissivities. This ratio method was applied to initial attempts at modeling the layered system and the automated calibration procedures that followed. However, because we cannot account for all existing heterogeneity, this method cannot be expected to produce a well-calibrated model in all areas when it is based on the assumption of homogeneous media. Therefore, manual calibration procedures were employed following automated calibration procedures to provide further improvement of the model fit to measured conditions.

Discharge of groundwater from Layers 1 and 2 occurs via leakage to underlying units, discharge to surface waters, and discharge from seepage faces where the formation is truncated by the erosion of valleys into or through the St. Peter Sandstone. Water is assumed to discharge from Layer 3 to the Mississippi and St. Croix River valleys, which serve as major discharge zones for all three aquifer layers. Additionally, there is a net loss of groundwater owing to extraction from pumping wells.

Model Development and Construction

Polygon Development

Polygons are used to represent infiltration rates and inter-aquifer leakage in MLAEM. There are three different types of variable strength areal elements (VARELs) in MLAEM, each associated with different types of input parameters:

1) **Given-strength** elements are constructed by specifying the actual infiltration or leakage rate for the specified polygon;
2) **Leaky** elements, that separate aquifers specify only the hydraulic resistance (aquitard thickness divided by its vertical hydraulic conductivity); and
3) **Resistance** elements, which have head value (e.g. a surface water elevation), as well as a hydraulic resistance (eg. of a lake bed) specified.

We have chosen to use given-strength VARELs to simulate inter-aquifer flow since it provides the most computationally expedient means to simulate water throughput on a regional basis. The given-strength VARELs will necessitate replacement with leaky or resistance VARELs in order to build local models that can effectively simulate inter-aquifer responses to stresses placed on the system.

Development of the polygon mesh for the Northeast Province will be described very briefly here. Polygon construction is based largely on the theory that infiltration to the top of a layered aquifer system will be distributed to the various layers proportional to their transmissivity values in steady-state conditions. This means that any change in hydraulic properties, such as transmissivity or hydraulic resistance, in any of the layers will result in changes in the leakage distribution to all the layers of the system. Therefore, the polygon mesh that is used to represent various leakage rates must be used to represent all the separating layers between aquifers. A cookie-cutter approach is used to propagate the mesh throughout all the aquifer separating layers.

Great geologic complexity in the Northeast Province poses challenges in developing a polygon mesh. Interpretive license was required to develop a relatively simple regional mesh out of a highly heterogeneous system. The final polygon mesh for the Northeast Province is shown on the following pages overlying the various Geographic Information System (GIS) geologic coverages used in its construction. Discussion is minimal since it is more useful to examine the mesh in context of the hydrogeology.

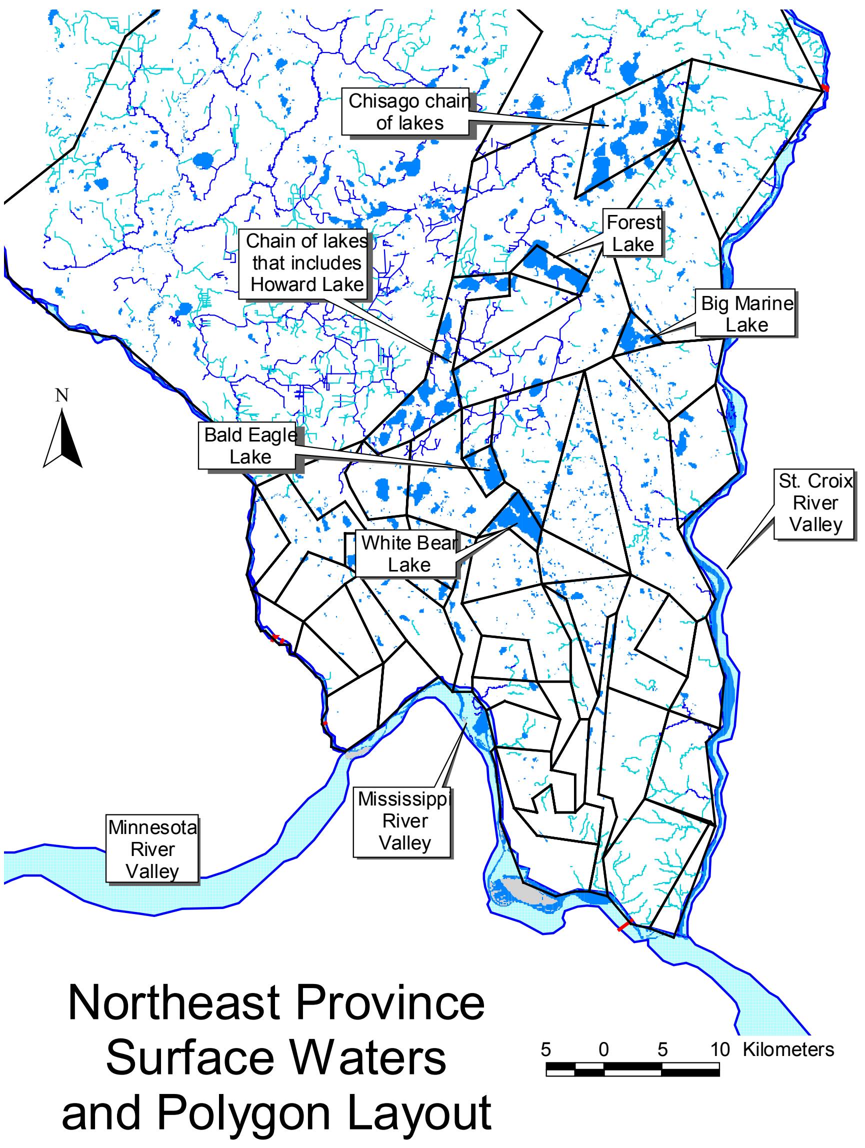


Figure 4. Northeast Province Surface Waters and Polygon Layout

Figure 4 shows the major surface waters of the Northeast Province and includes the final polygon mesh. Note that the following lakes or lake chains are represented as given-strength area elements: 1) the Chisago chain of lakes, 2) Forest Lake, 3) the chain of lakes that includes Howard Lake, 4) Bald Eagle Lake, 5) White Bear Lake, and 6) Big Marine Lake.

Metro Model staff have applied automated database querying and geostatistical techniques to produce sand content maps of the Quaternary glacial drift for different elevation horizon intervals. A detailed description of the procedures used can be found in the Overview of the Twin Cities Metropolitan Groundwater Model. The sand content maps for the four elevation intervals (Interval 1 at 280 – 300 m MSL, Interval 2 at 260 – 280 m MSL, Interval 3 at 240 - 260 m MSL, and Interval 4 at 220 – 240 m MSL) are shown in Figure 5. The naming convention for the intervals is the same as for Metro Model aquifer layers: number 1 is at the top of the sequence, and number 4 is at the bottom. Note that blank areas in the figures occur where either the interval's elevation is above the ground surface or below the bedrock surface.

A potential user of the Metro Model will benefit by being mindful of how the polygon mesh relates to all hydrogeologic features. Many polygon sides are defined by large surface water bodies (Figure 4) or changes in bedrock geology (Figure 7, shown later on page 10), but many were constructed to represent major regional differences in the sand content of glacial materials, either surficial or buried. Note that, although polygon sides generally depict major changes in drift composition, smaller-scale inhomogeneities are not as likely to be defined. Local refinement of this mesh is expected to occur during the construction of site-specific models.

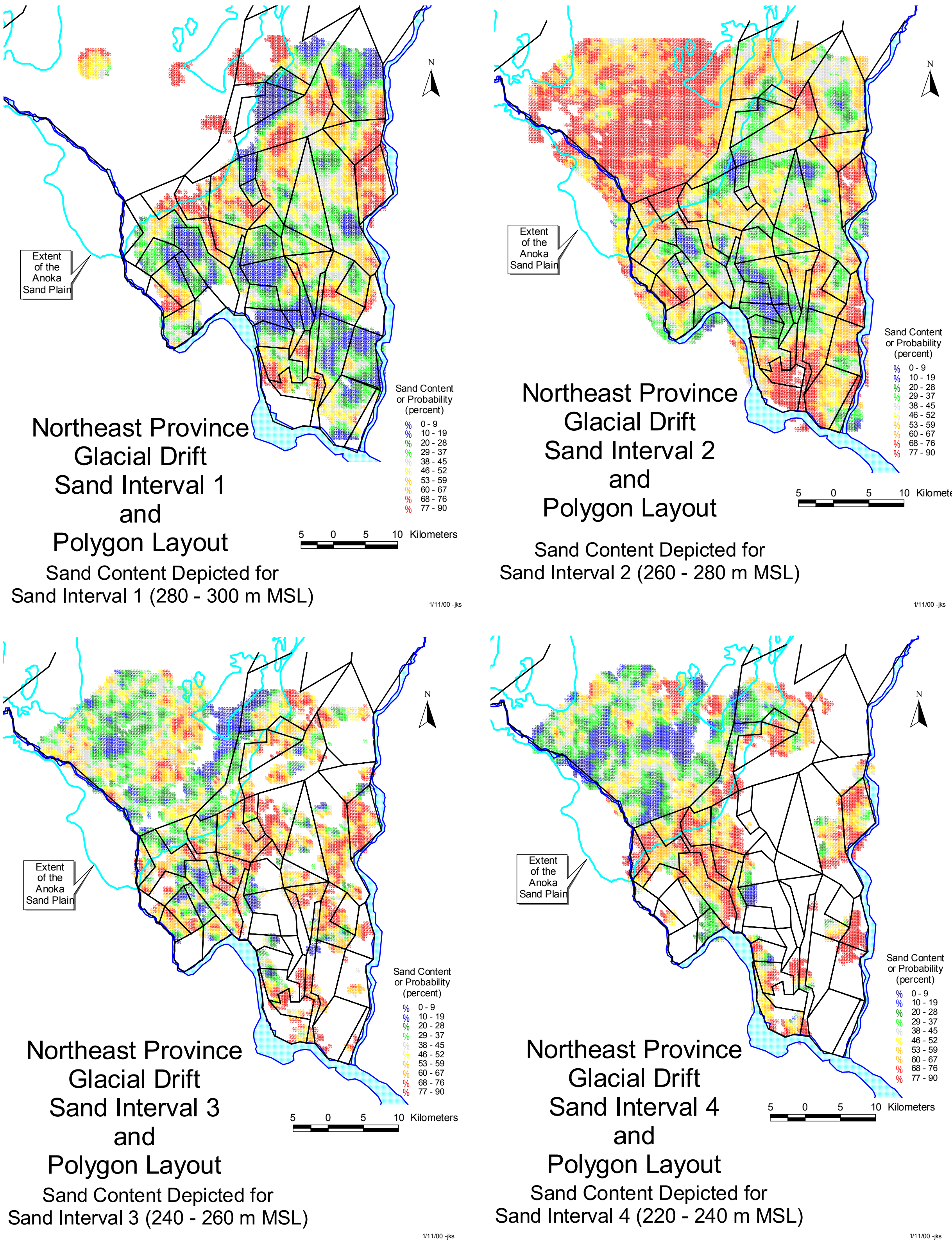


Figure 5. Northeast Province Sand Content of Glacial Drift Intervals 1, 2, 3, and 4

To help define differences in both surface infiltration and aquifer properties, two separate composite coverages were used as shown in Figure 6. The first represents the coverage of Sand Interval 1 overlying Sand Interval 2 that was used as a representation of the surficial glacial materials that impact overall infiltration rates. The second represents Sand Interval 3 overlying Sand Interval 4 as a representation of the nature of the glacial drift aquifer.

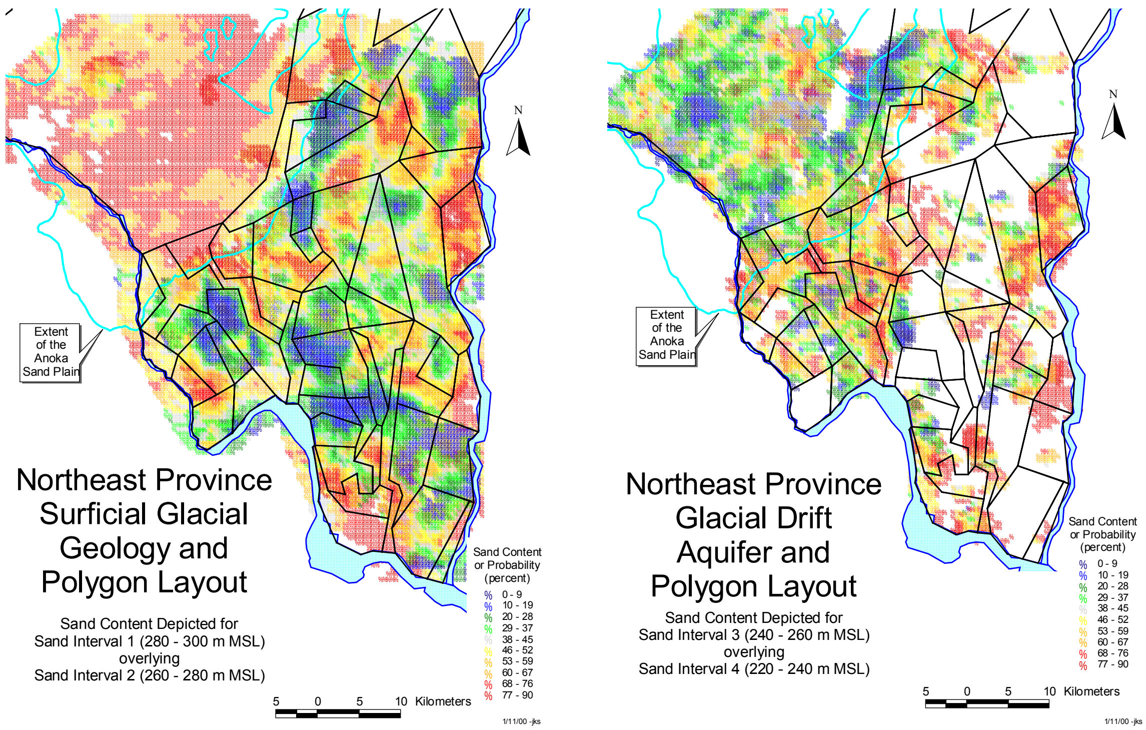


Figure 6. Sand Content Composite Coverages of Surficial Drift Materials and Glacial Drift Aquifer

The polygon mesh overlies the bedrock geology coverage in Figure 7. Note the presence of the Phalen and the Southern Washington County buried bedrock valleys, and the polygons that represent them

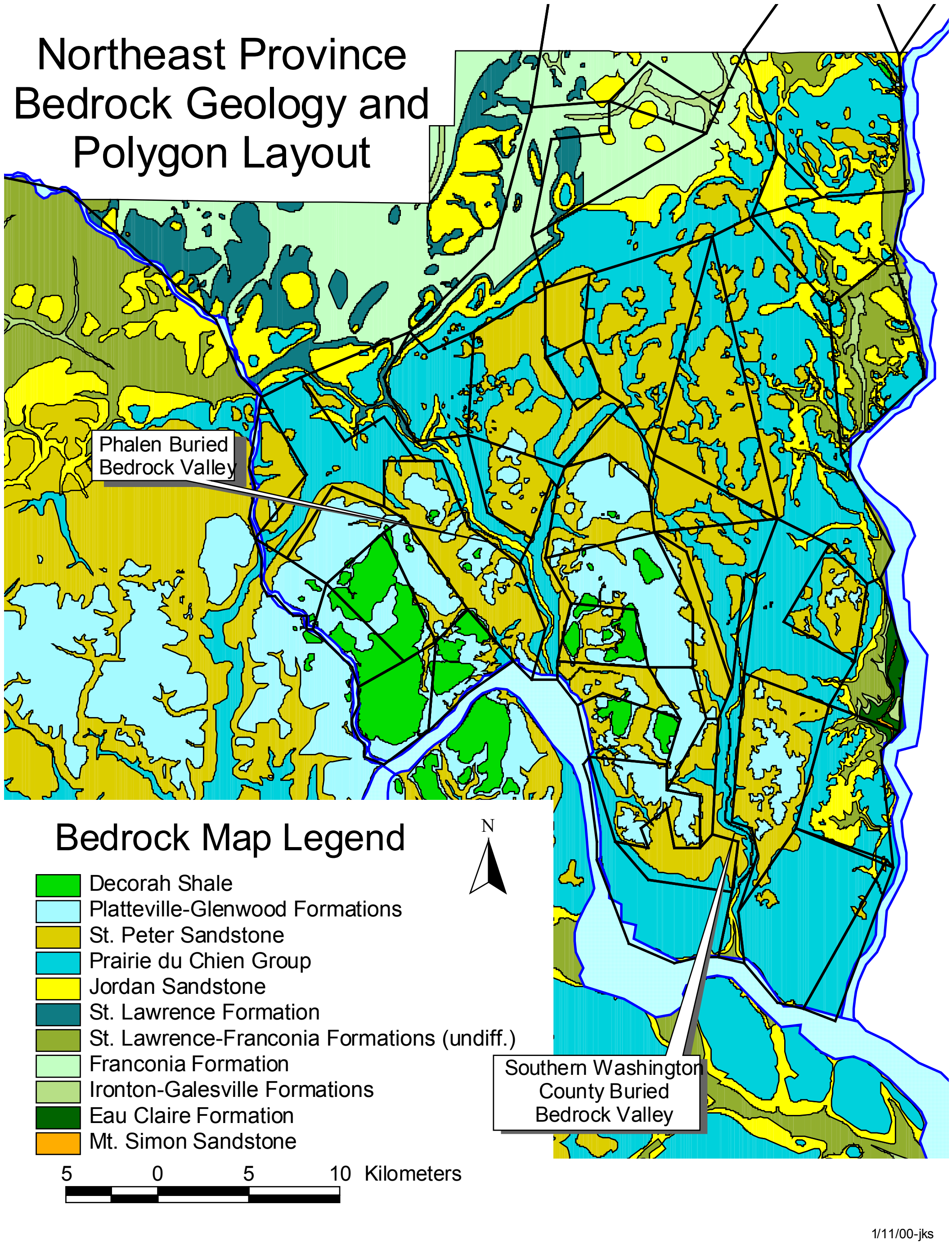


Figure 7. Northeast Province Bedrock Geology and Polygon Layout

In order to distinguish between the polygons that comprise the mesh as presented in the preceding pages, the individual polygons must be given unique designations. Two types of polygon naming conventions were used to name the polygons described, and are discussed in the following paragraphs. The first convention is a general one and covers standard infiltration and leakage polygons. The second naming convention deals with polygons that are defined by large surface water bodies, or that represent far-field conditions.

The general naming convention used for standard infiltration and leakage polygons uses the following format:

[field 1][field 2]-[number]

Where: field 1 — Is a single letter that represents which hydrologic province the model lies in. Because this document is describing a Northeast Province model, the designation used in these files is almost exclusively indicative of the Northeast Province. The letter prefixes are assigned as follows:

E	Northeast Province
S	Southern Province
W	Northwest Province

field 2 — Is generally represented by the first letter of the county name in which the polygon predominantly lies. This convention was used for the primary seven counties in the metropolitan area, and the letter designations are assigned as follows:

A	Anoka County
C	Carver County
D	Dakota County
H	Hennepin County
R	Ramsey County
S	Scott County
W	Washington County

A judgment call was made to assign the letter to polygons that straddle county boundaries.

number — This is the sequential number assigned to the polygons within each county. These numbers are generally assigned by starting in the northernmost part of the county and working southward.

Polygons not falling under the general category include those defined by large surface water bodies and buried bedrock valleys, and those that represent far-field conditions. These are covered in the following paragraphs:

Surface Water Bodies: The first letter prefix designates the hydrologic province where the surface water body is found—in this case that is an "E" for the Northeast Province. The name of the water body is then indicated in the remainder of the polygon name. A list of the polygons defined by and named after surface water bodies in the Northeast Province follows:

E-CHISAGO_L	Chisago chain of lakes
E-FOREST_L	Forest Lake
E-B-MARINE_L	Big Marine Lake
EA-LCHAIN	A chain of lakes in Anoka County (hence the "A" after the "E" prefix), that includes Howard Lake, among others
E-B-EAGLE	Bald Eagle Lake
E-W-BEAR_L	White Bear Lake

Buried Bedrock Valleys: Again, the "E" prefix designates the Northeast Province. The three polygons representing the extent of buried bedrock valleys in the Northeast Province are listed as follows:

E-BVPHAL_N	Northern portion of the Lake Phalen buried bedrock valley
E-BVPHAL_S	Southern portion of the Lake Phalen buried bedrock valley
EW-BV-SOUTH	North-south trending bedrock valley found in southern Washington County (hence the "W" after the "E" prefix)

Far-Field Features: Polygons falling within the Northeast Province hydrologic boundaries follow the general naming convention described for standard infiltration and leakage polygons described above.

[field 1][field 2]-[number]

Where:	field 1	Designates the hydrologic province—"E" is used here for the Northeast Province.
	field 2	Is "FF", indicating "far-field".
	number	Is the sequential number assigned to each of these polygons.

The geometry of these polygons is determined in part by the areal extent of lower hydrostratigraphic units, which will help facilitate linking the upper layers with the lower layers, should the need arise.

One other polygon occurring outside the Northeast Province was used to induce flow toward the major discharge zones, and is illustrated in red in Figure 8. This roughly "J"-shaped polygon includes the western portion of Hennepin County, the northern portion of Dakota County, and the portion of Wisconsin adjoining the St. Croix River Valley.

The polygon mesh with labels is presented in Figures 8 and 9 below. Figure 8 emphasizes the regional layout, and Figure 9 focuses on the metropolitan area.

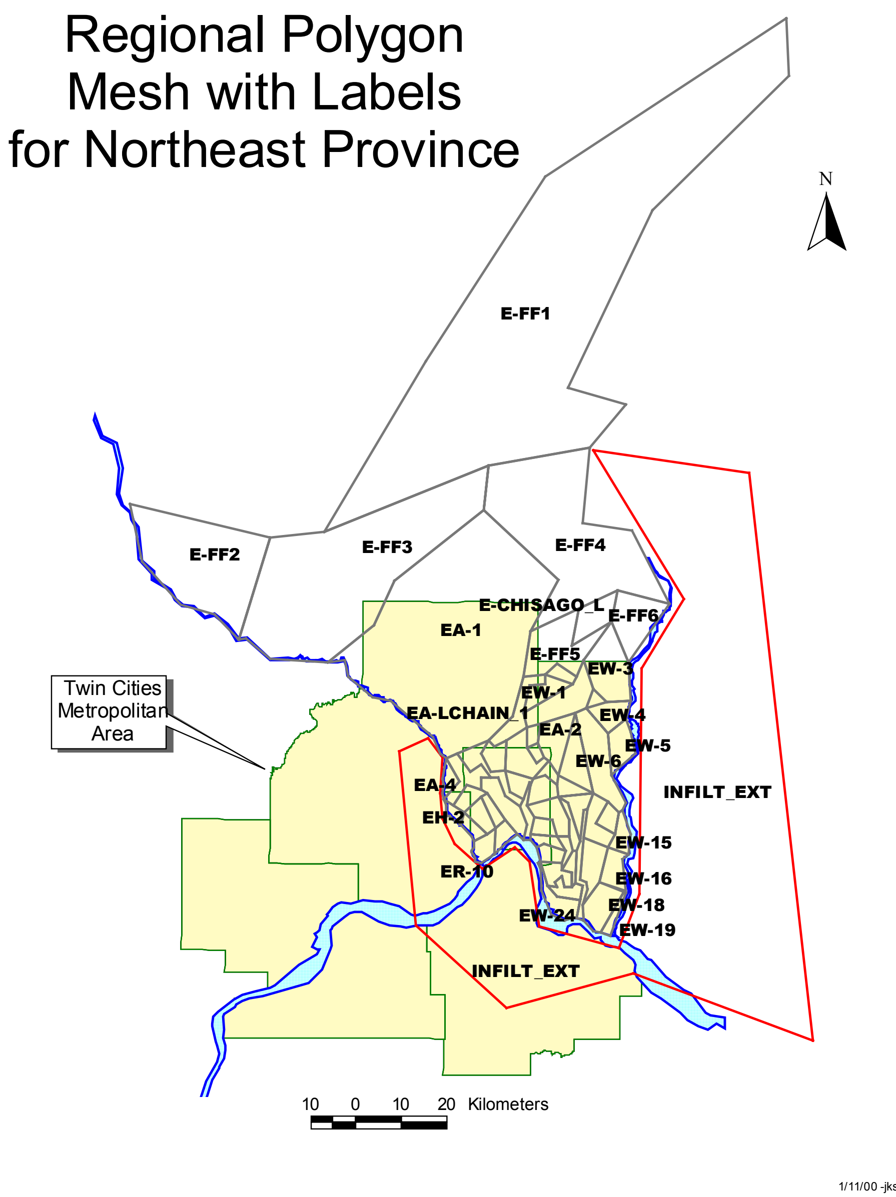


Figure 8. Regional Polygon Mesh with Labels

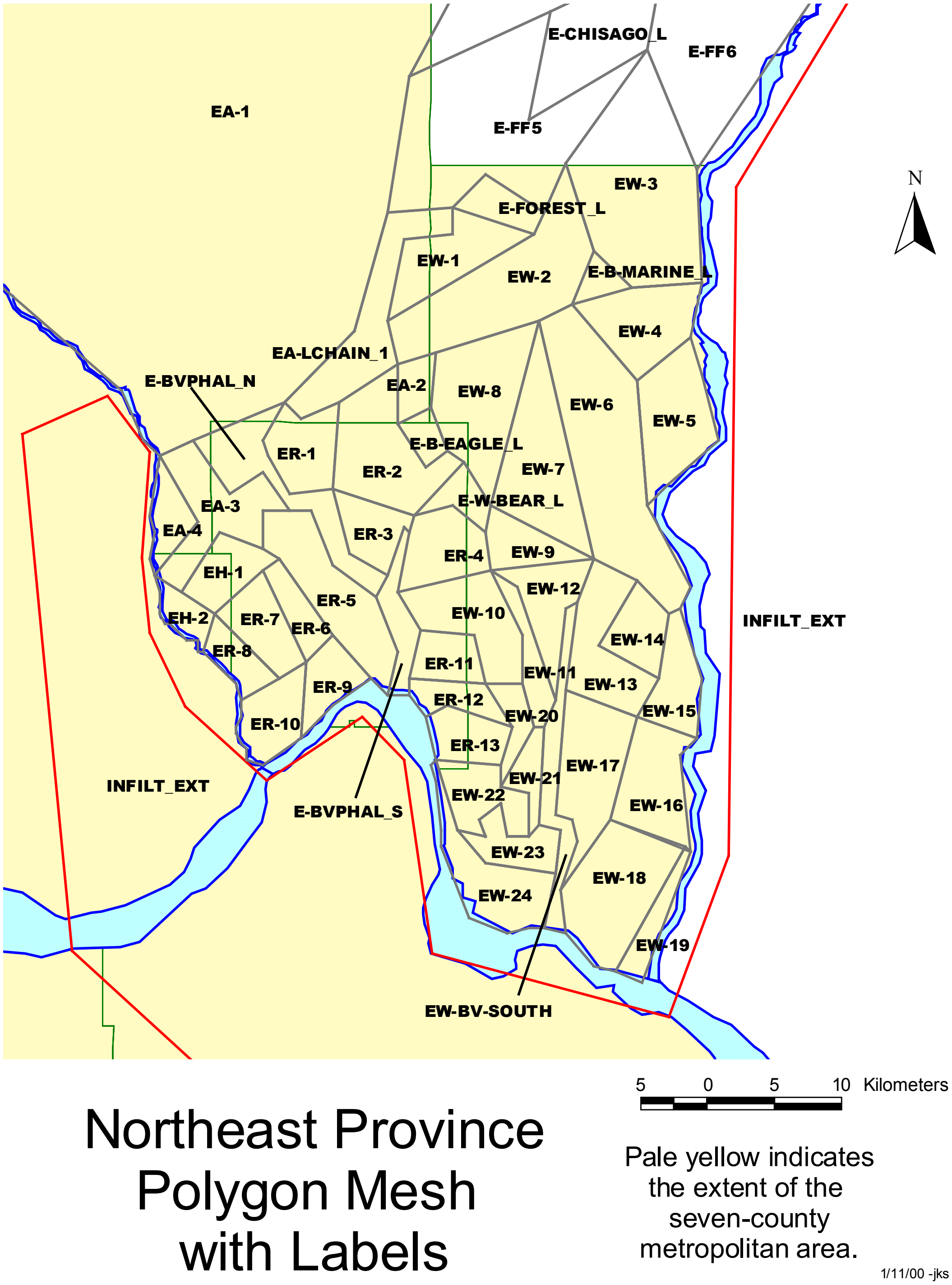


Figure 9. Polygon Mesh with Labels, Metro Area

The polygon mesh provides the framework for modeling the infiltration and leakage values, which are entered as given-strength flux. Assignment of the leakage values to individual polygons for each layer will be discussed below in the subsection labeled **Modeling of Leakage** under **Model Adjustment and Calibration**.

Curvilinear Line-Sink Construction

Head-specified curvilinear line-sinks were used to represent hydrologic boundaries in all three layers. Experimentation was conducted using different types of elements to represent the surface waters: head-specified line-sinks, resistance line-sinks, head- and resistance-specified (resistance) variable strength areal elements (VARELs), and resistance-specified (leaky) VARELs to vertically transmit flow between aquifers to the modeled boundary. We found that the head-specified line-sink was the most computationally efficient and also provided a good approximation of the boundary conditions for the regional models, even if they represented surface water bodies that are not in direct hydraulic communication with the aquifer.

Order and overspecification values for curvilinear line-sinks control model accuracy and optimization of the solution in a least squares sense in the vicinity of the element. In this model, the order of the curvilinear elements generally is set at 4, with an overspecification of 1.5 to 2. These values provide sufficient accuracy for the regional extent of this model. However, higher values were typically used for long curvilinear strings to maintain hydrologic control. Site-specific applications will necessitate increasing order and overspecification values on curvilinear elements in the area of interest—the respective default values of 6 and 4 assigned by MLAEM provide a good starting point for this type of detailed work.

Some of the line-sinks represent surface waters, while others represent seepage faces of the aquifer that may daylight near the stream valley. An example of this would be Layer 1 curvilinear line-sinks that represent discharge to the Mississippi and St. Croix River valleys. Starting at St. Anthony Falls, these curvilinear elements follow the bluff line through downtown St. Paul, and curve up along the St. Croix River valley. The glacial drift, sitting on top of the Platteville and Decorah Formations, is not in direct hydraulic connection with the Mississippi or St. Croix Rivers. Head values assigned to this chain of line-sinks represent a seepage face. The distance between the seepage face and the river may be greater than that represented by the line-sinks, which follow the valley edges. However, we chose to use consistent curvilinear string geometries throughout all three layers to keep the regional simulation as simple as possible. Site-specific applications might require modification of the seepage face geometry to better reflect natural conditions.

Use of curvilinear line-sinks in each aquifer layer are presented and illustrated in the following paragraphs.

Layer 1 Curvilinear Line-Sinks. Figure 10 illustrates the placement of the curvilinear line-sinks in Layer 1 of the Northeast Province as well as the hydrography. The curvilinear line-sinks are used to represent significant regional features, including rivers, as well as chains of lakes. A comparison of the hydrography with the curvilinear line-sinks illustrates that the model is a simplification of reality. Clearly, site-specific modeling will require detailed work to include features representing flow on a local basis.

As previously discussed, curvilinear line-sinks are used to represent the seepage face that follows the bluff line along the Mississippi and St. Croix River valleys. Heads were first assigned to correspond to the topographic elevations of the bluff line. They were then manually adjusted to provide the best fit to head calibration targets.

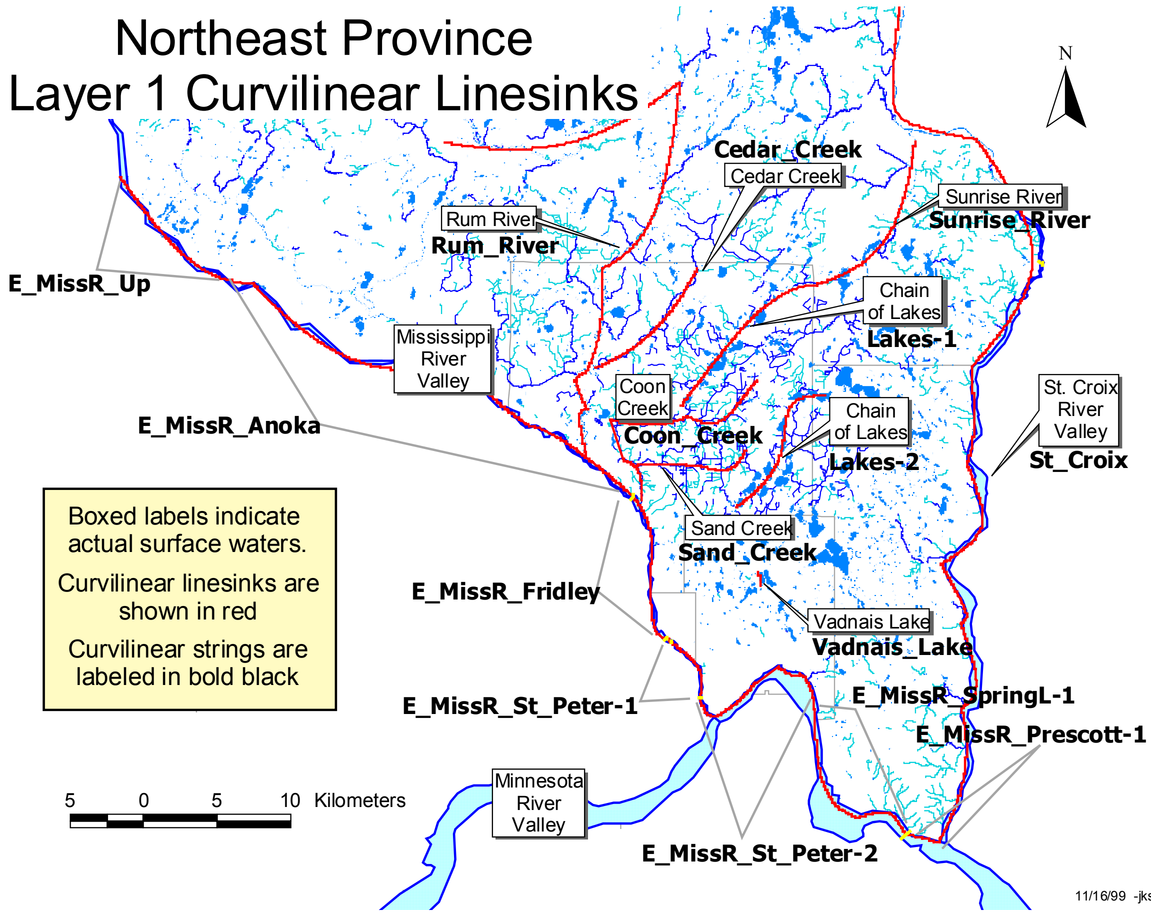


Figure 10. Northeast Province Layer 1 Curvilinear Line-Sinks

The small curvilinear element used to represent Lake Vadnais warrants some explanation. A cluster of high heads in Layer 1 north of downtown St. Paul prompted an evaluation of the potential impact on groundwater induced by water extraction by the St. Paul water utility. Water is conveyed from the Mississippi River via conduits and surface water bodies to Lake Vadnais from which it is taken to the St. Paul water treatment plant. St. Paul water utility personnel stated that the average uptake of water from Lake Vadnais for the treatment plant is 50 million gallons (MG) per day. They also provided specific numbers regarding the total volume of water withdrawn and the contribution from the Vadnais watershed for the years 1996, 1997, and 1998, which are presented in Table 2.

Table 2

Water Useage for St. Paul

Given in Millions of Gallons for Each Year

Year	Mississippi River Withdrawal	Contribution of Vadnais Watershed	Total
1996	14,775	402	15,177
1997	12,599	2,843	15,442
1998	15,666	404	16,070

The contribution from the Lake Vadnais watershed represents a net withdrawal of water that is assumed to come from groundwater. The 1997 value of 2,843 MG may be suspect because it was so high. However, given the low contribution from the Mississippi River, it seems entirely plausible that groundwater comprised a greater compliment of total amount extracted in response to the lower withdrawal from the Mississippi River. Note that the *total* withdrawal rate for that year (15,442 MG) seems quite in line with the other two values (15,177 MG & 16,070 MG).

Because the additional withdrawal is assumed to come from Lake Vadnais, it was represented with a given-strength curvilinear line-sink with a discharge rate based on the Lake Vadnais watershed numbers that were provided. Two values were used to bracket the withdrawal conditions: 1) 403 MG/year (4,180 m^3/day), the mean value for the years 1996 and 1998, and 2) 2,843 MG/year (29,500 m^3/day) from 1997. Both runs yielded noticeable improvements on the calibration near Lake Vadnais. However, the 2,843 MG/year rate created a far-reaching effect that reduced modeled heads too much in the aquifer over a large area. That fact coupled with the data consistency for 1996 and 1998 were used to select the 403 MG/year value as the model extraction rate from Lake Vadnais by the St. Paul water utility.

Layer 2 Curvilinear Line-Sinks. Layer 2 relies on the same string geometries for the curvilinear line-sinks that were used in Layer 1, except that the limited areal extent of the St. Peter Sandstone does not require hydrologic control extending to the northwest quite as far (Figure 11). Therefore, some of the far-field curvilinear line-sinks were not used, and the curvilinear strings labeled Sunrise_River, Sand_Creek, Lakes-1, and Lakes-2 represent the northwest flow boundary. No curvilinear strings are used to represent the Mississippi River to the northwest of curvilinear string E_MissR_Fridley. The Mississippi River is in contact with the St. Peter Sandstone from immediately below St. Anthony Falls dam in Minneapolis, continuing downstream below the Ford dam, all the way to the lower end of Pig's Eye Lake. Elevations specified for the line-sink along this stretch reflect the elevations of the pools between the Ford and Hastings dam (dams illustrated in yellow), and between the St. Anthony Falls and Ford dams. The elevations specified downstream of this area and along the St. Croix River valley represent seepage faces. Because little data was available for determining the elevations, these elevations were assigned using best judgment, and are considered subject to change on the basis of improved data.

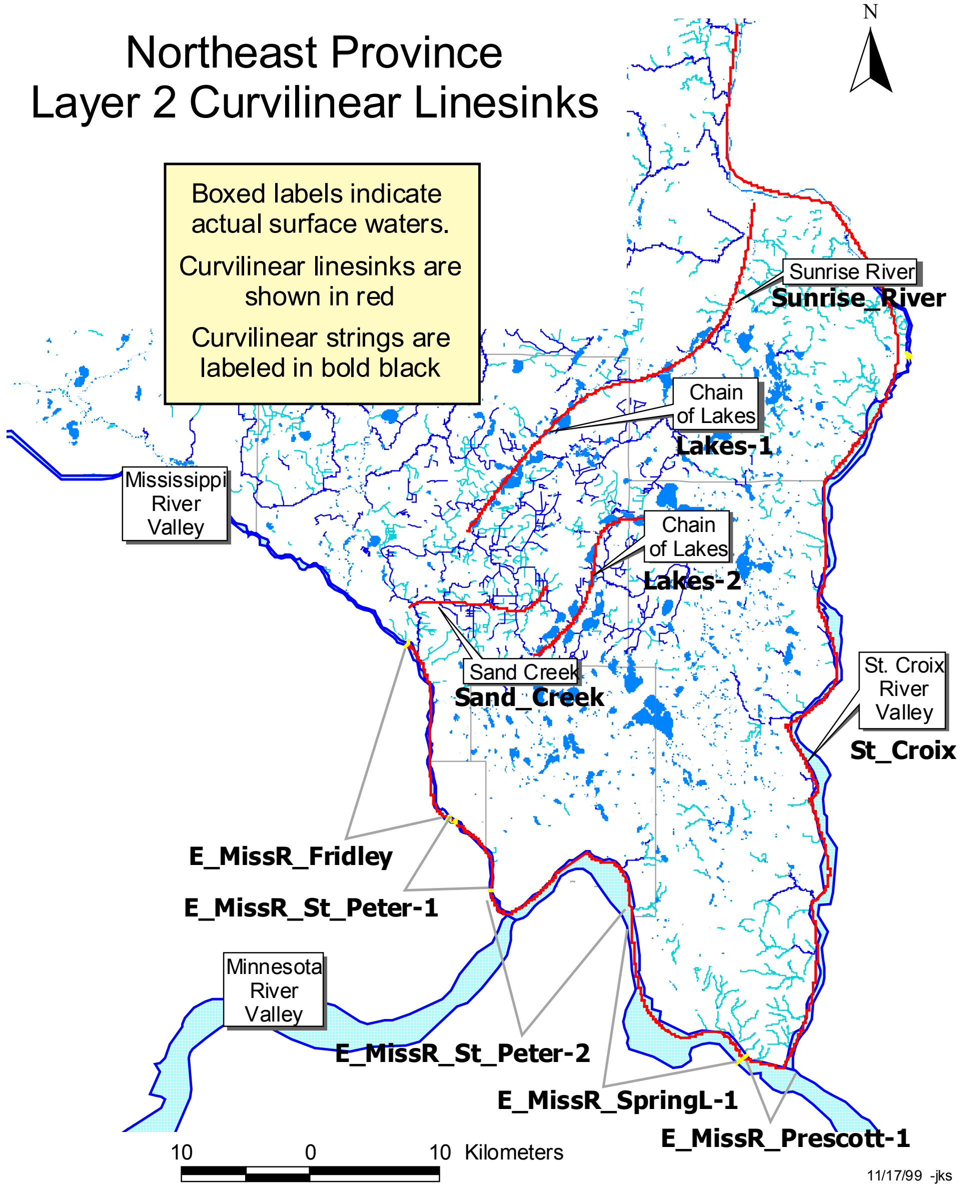


Figure 11. Northeast Province Layer 2 Curvilinear Line-Sinks

Layer 3 Curvilinear Line-Sinks. Hydrologic boundaries for Layer 3 extend farther to the northwest than for those in Layer 2 because the Prairie du Chien-Jordan Aquifer extends farther in that direction than the St. Peter Sandstone, and also has some outliers beyond its contiguous occurrence that contain head calibration points. Hence, Layer 3 uses more curvilinear line-sinks than Layer 2 to define the boundaries in the northwestern portion of the model (Figure 12). In general, head values assigned to the strings represent water levels. The notable exception to this is the St. Croix River string—heads in the southern portion are defined by the river water level. However, moving northward from Afton, Minnesota, a seepage face is represented with head elevations assigned to reflect the base of the Jordan Sandstone. These seepage face head values exceed the river water level elevations, since the base of the Prairie du Chien-Jordan Aquifer climbs above the St. Croix River water level moving northward, as a consequence of the Twin Cities Structural Basin.

Also note the presence of the St_Croix_East curvilinear line-sink. This was placed in Layer 3 to intercept flow from the east that would otherwise contribute to the total discharge to the St. Croix River. Measured stream discharge data that are available represent only the contribution of the Layer 3 aquifer from the Northeast Province. In order to compare those measured values with the modeled discharge, modeled flow from the east must be separated out, which is accomplished by the presence of St_Croix_East.

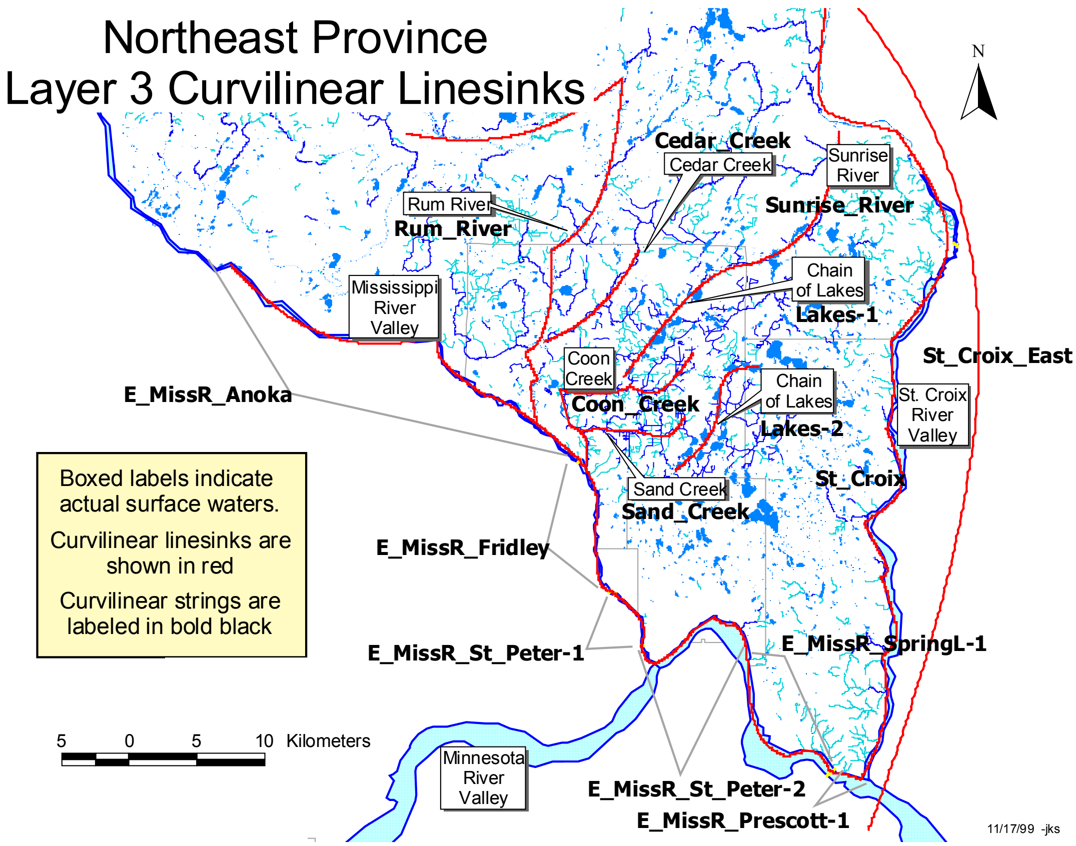


Figure 12. Northeast Province Layer 3 Curvilinear Line-Sinks

Inhomogeneity Placement

Inhomogeneities were used to represent large aquifer zones with hydraulic properties that differ significantly from those assigned globally in all three layers of the Northeast Province model. Each inhomogeneity is defined in the model by a polygon with associated changes in hydraulic properties. In the Northeast Province, these represent the Anoka Sand Plain, and the more highly permeable alluvium in old valleys incised into the bedrock surface. Figure 13 identifies the two main buried bedrock valleys used for creating the inhomogeneities in Layer 1—the Lake Phalen and Stillwater buried bedrock valleys—and presents the geometry used to define them (outlined in bold red). Inhomogeneity polygons for Layers 2 and 3 are subsets of the polygon geometries used in Layer 1, and are described in the appropriate sections below.

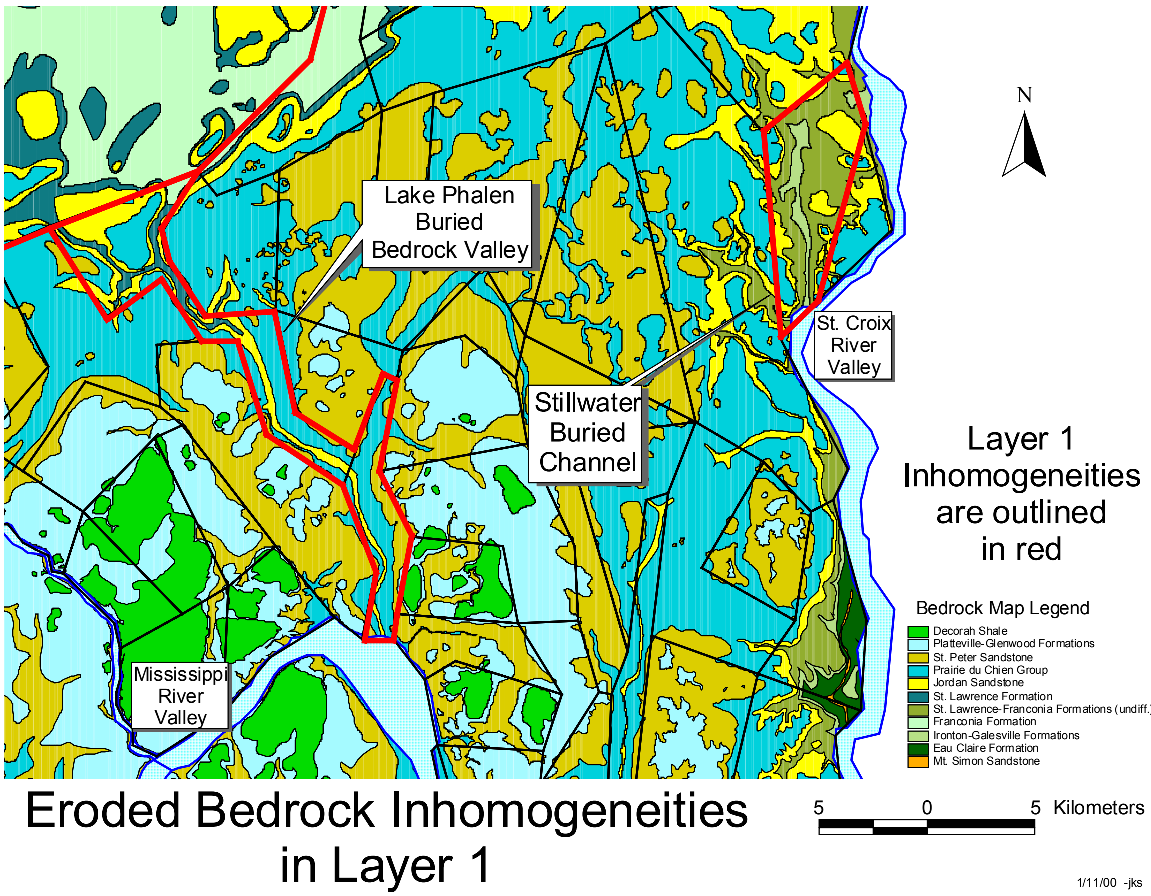


Figure 13. Eroded Bedrock Inhomogeneities in Layer 1

Analytic elements called "doublets", defined by line segments, coincide with the inhomogeneity polygon sides, and are used to mathematically impose a continuous head across the inhomogeneity boundary. Order and overspecification values for doublets control model accuracy and optimization of head values in a least squares sense on either side of the doublet. In this model, the order is generally specified as 3, with an overspecification of 1.5 to 2. These values provide sufficient accuracy for the regional extent of this model. However, higher values were typically used for long doublet segments to maintain hydrologic control. Site-specific applications will necessitate increasing order and overspecification values on the doublets in the area of interest—the respective default values of 6 and 4 assigned by MLAEM provide a good starting point for this type of detailed work.

The inhomogeneities used in each layer for the Northeast Province are described in the following paragraphs.

Layer 1 Inhomogeneities. Three inhomogeneities of high hydraulic conductivity were constructed in Layer 1, which has a global hydraulic conductivity of 21 m/day. These are illustrated in Figure 14 along with the sand content map of the surficial glacial drift materials. The most prominent of the inhomogeneities, the Anoka Sand Plain (polygon Anoka_SP), was included simplistically as an inhomogeneity, with a hydraulic conductivity of 50 m/day, extending well beyond the metropolitan area. Constructing the inhomogeneity in this manner was easy to do, but application of the model in this region will likely require the insertion of additional hydraulic boundaries, and other detail. The Phalen and Stillwater buried bedrock valleys constitute the remaining two inhomogeneities (polygons BV_Phalen and Stillwater_Inhomogeneity) with a hydraulic conductivity value of 200 m/day assigned to each. These are also illustrated in Figure 15, which shows the sand content of the glacial drift at depth. Overall, the figures indicate that these zones contain a high percentage of sand. Ultimately, their inclusion and final geometry were shaped largely by calibration procedures.

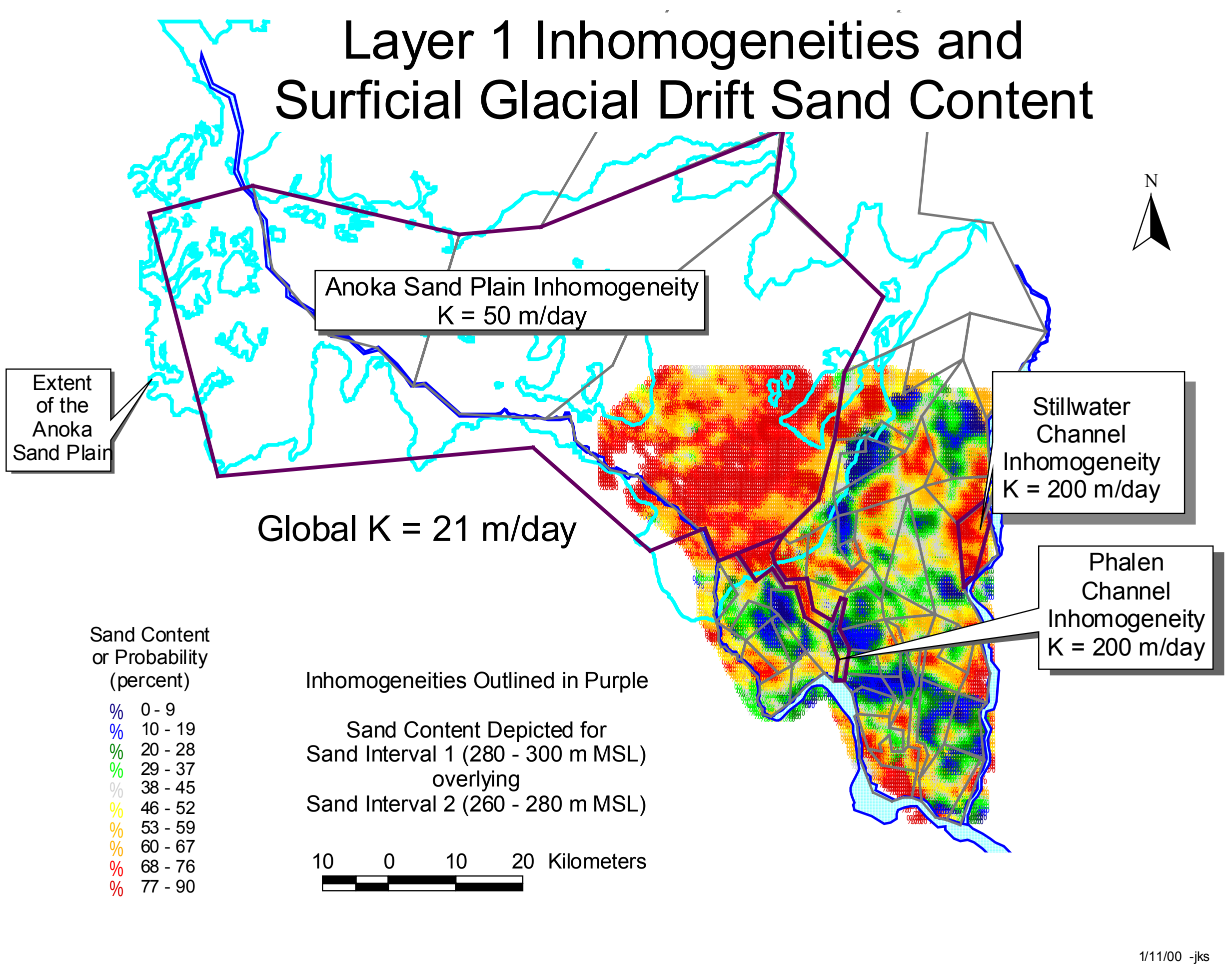


Figure 14. Layer 1 Inhomogeneities and Surficial Glacial Drift Sand Content

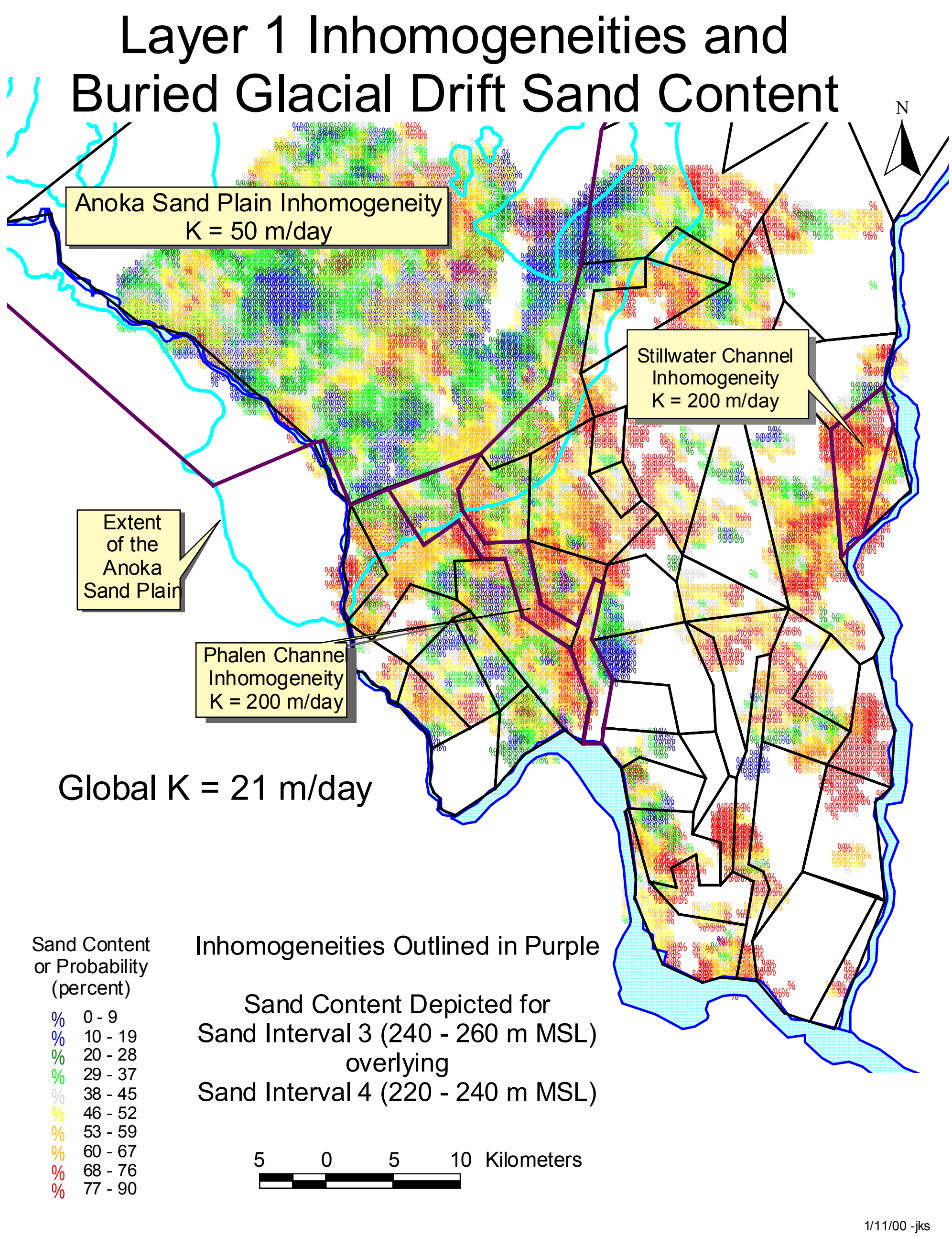


Figure 15. Layer 1 Inhomogeneities and Buried Glacial Drift Sand Content

Layer 2 Inhomogeneities. The only inhomogeneity found in Layer 2 is the Phalen buried bedrock valley, as shown on Figures 14 and 15 for Layer 1. Its shape and hydraulic conductivity are identical to that used in Layer 1, providing a sharper contrast to the Layer 2 global hydraulic conductivity of 3.3 m/day. Figures 16 and 17 illustrate the location of this inhomogeneity with the composite sand content maps of the surficial glacial drift material on the left, and the buried drift aquifer on the right. As with Layer 1, the inclusion and assignment of hydraulic conductivity values was done in conjunction with calibration procedures.

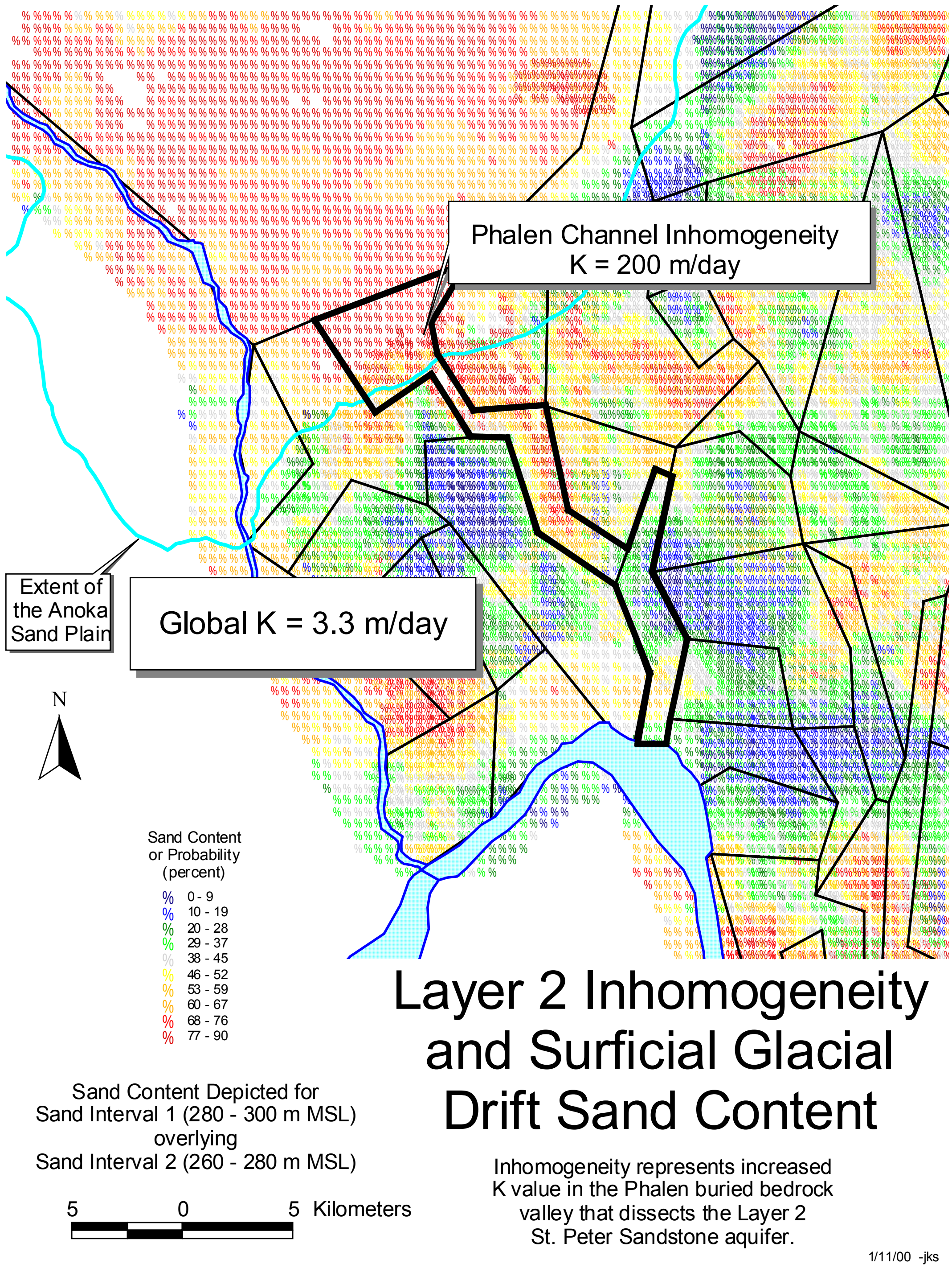


Figure 16. Layer 2 Inhomogeneity with Surficial Glacial Drift Sand Content

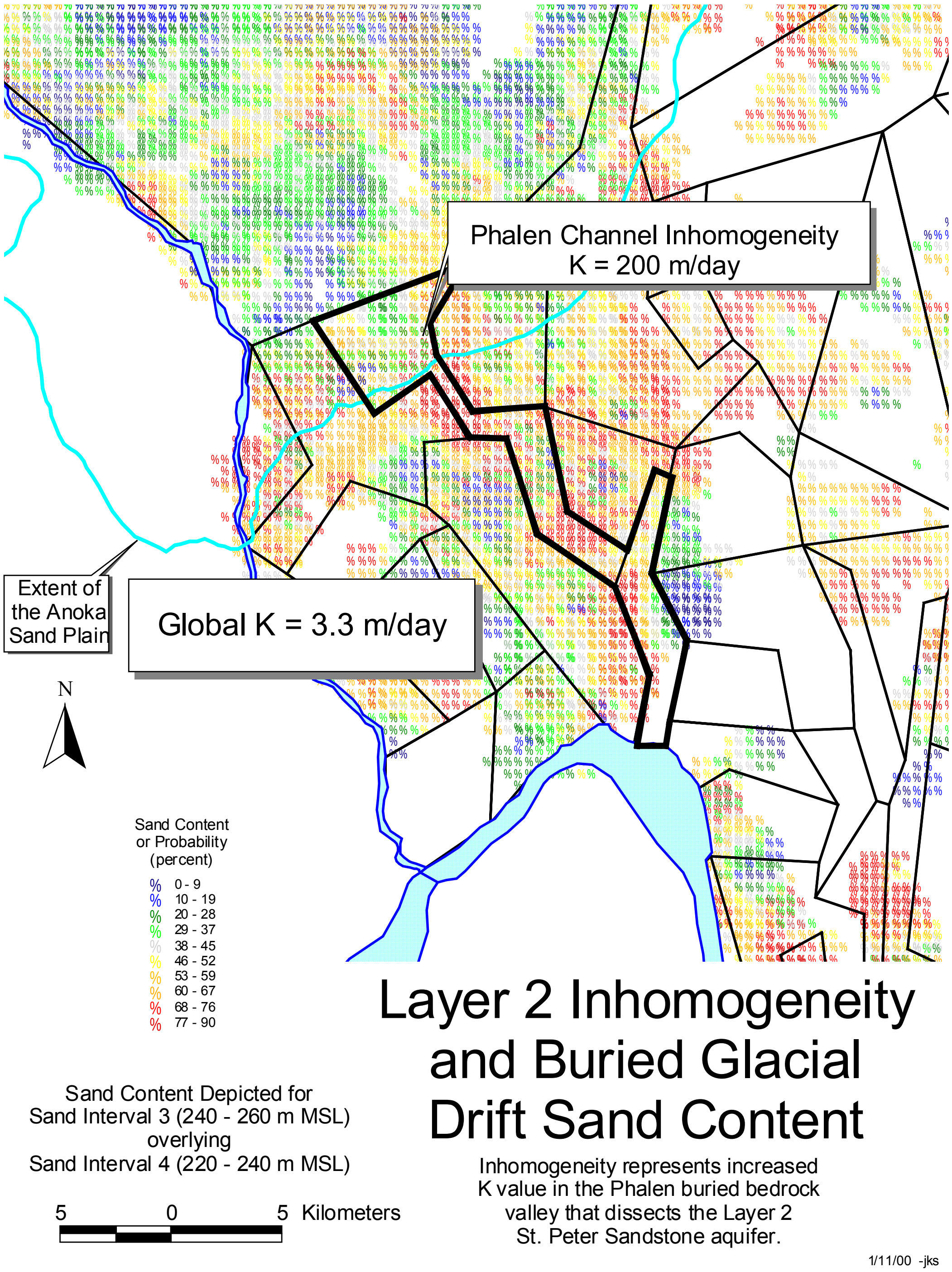


Figure 17. Layer 2 Inhomogeneity with Buried Glacial Drift Sand Content

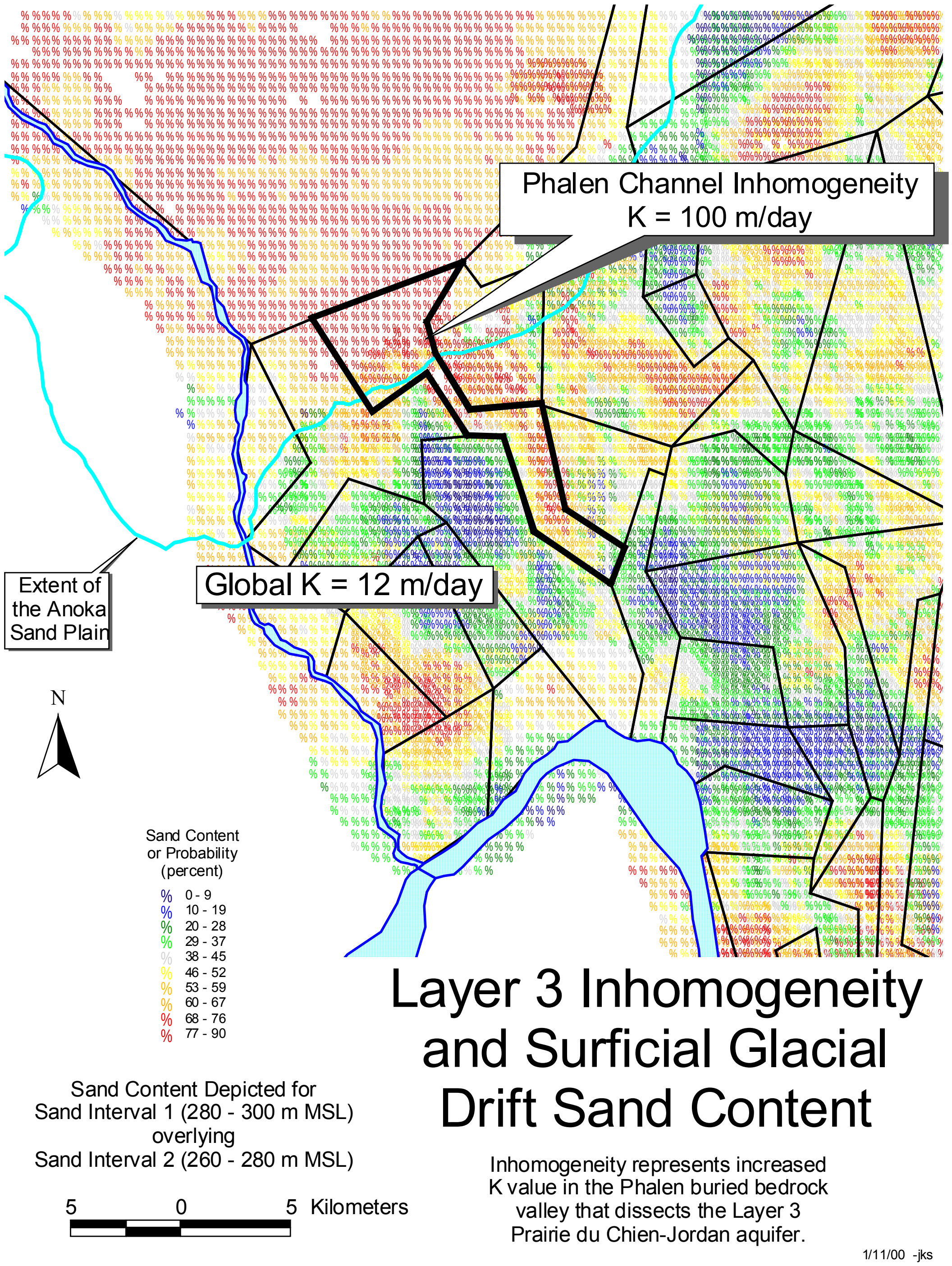


Figure 18. Layer 3 Inhomogeneity with Surficial Glacial Drift Sand Content

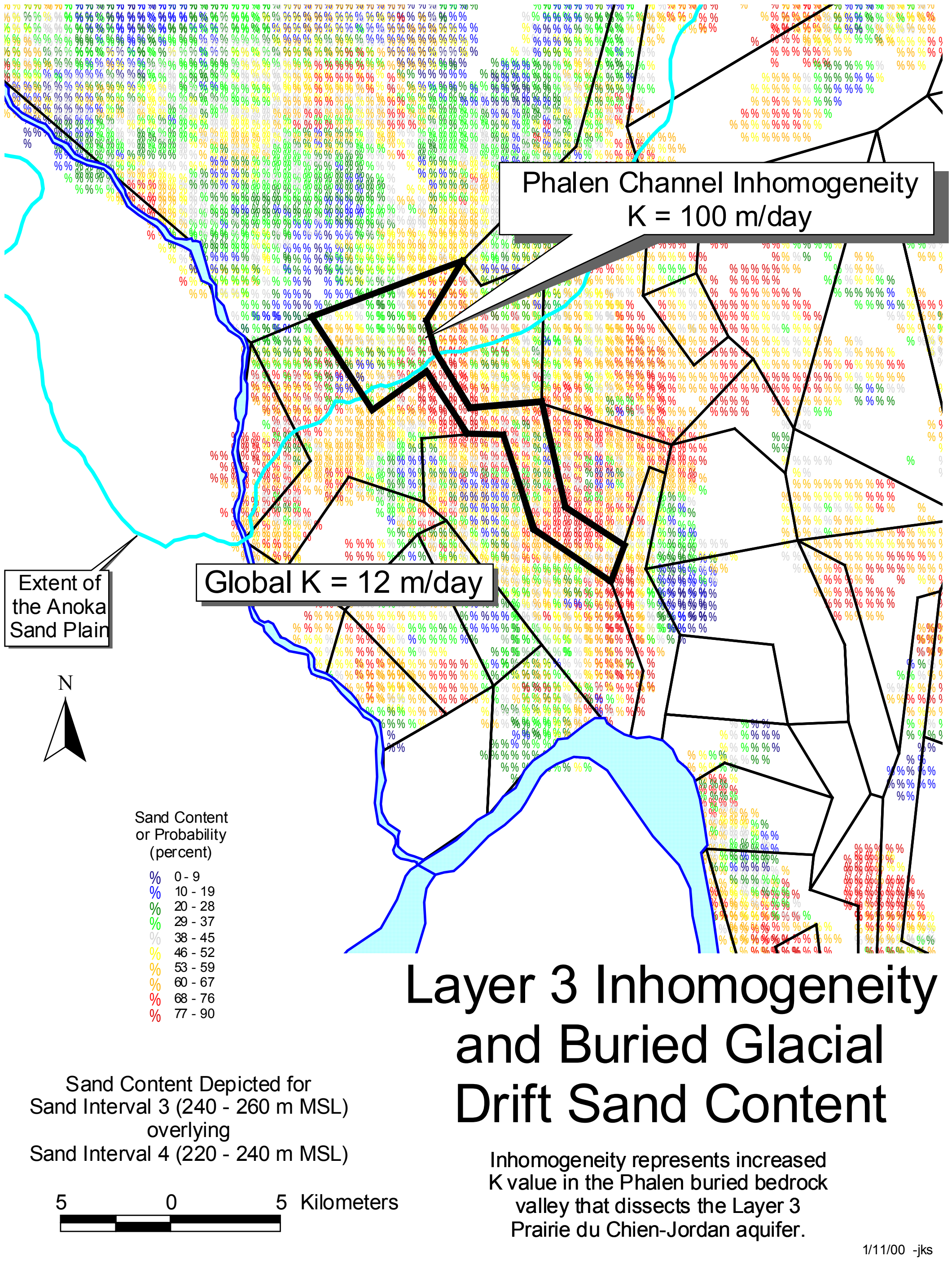


Figure 19. Layer 3 Inhomogeneity with Buried Glacial Drift Sand Content

Layer 3 Inhomogeneities. Layer 3 only includes the upper portion of the Phalen buried bedrock valley as an inhomogeneity, as can be seen in Figures 18 and 19. Figure 18 illustrates this inhomogeneity with the sand content maps of the surficial glacial drift material, and Figure 19 illustrates it with the buried drift aquifer. The global value for hydraulic conductivity in Layer 3 is 12 m/day. The hydraulic conductivity within the inhomogeneity is 100 m/day, half the value assigned to the overlying layers. In addition to model calibration, this idea may receive support from the sand content maps in Figures 18 and 19, which indicate an overall decrease in sand content in the glacial drift aquifer (at depth) compared to the surficial glacial drift. As with Layers 1 and 2, the geometry and assignment of hydraulic parameters to the Layer 3 inhomogeneity resulted in large part from manual calibration procedures to measured water levels.

Impermeable Walls

Difficulties in calibrating Layer 3 in the southern portion of Washington County prompted an evaluation of the structure of the bedrock geology in that area. Inspection of the Bedrock Map of the Seven-County Twin Cities Metropolitan Area (Minnesota Geological Survey Map M-55, Plate 1, 1986) shows the Hudson-Afton Anticline just to the south of Stillwater, Minnesota, trending south-southwest in the Prairie du Chien Group, which occurs as the first bedrock unit. Two faults, the Cottage Grove Fault and the Hastings Fault, flank this feature parallel to its axis. Little is directly known about how these faults might impact groundwater flow through the Prairie du Chien-Jordan aquifer. However, during the development and calibration of the model, a cluster of low modeled heads in this area led to speculation that vertical off-set from the fault might effect blockage of flow in the Prairie du Chien-Jordan aquifer. Two curvilinear impermeable walls were placed in the model, representing the Cottage Grove and Hastings Faults (Figure 20), based on the assumption that the vertical displacement of these faults causes a "damming" effect on groundwater flow within the aquifer. The placement of these features within Layer 3 of the model resulted in modest improvement to the modeled heads in the vicinity. However, the flow regime for the aquifer in this area is not well understood, and further investigation is needed to better characterize the impacts of the geologic structure in this area, including the extent and degree to which each fault might obstruct groundwater flow within the Prairie du Chien-Jordan aquifer.

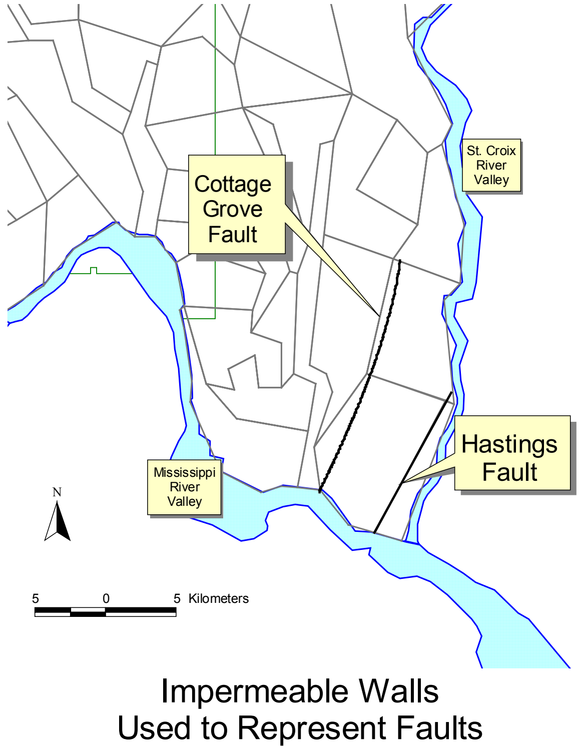


Figure 20. Impermeable Walls Used to Represent Faults in Layer 3

Pumping—Domestic Wells

Groundwater discharge from domestic wells over large regions is difficult to quantify. Domestic wells were generally not included within the regional Metro Model, except where they offer a plausible means to improve model calibration. Typically, domestic withdrawals are intrinsic to the infiltration rates that are determined through calibration procedures. However, generally low net infiltration rates, coupled with high modeled heads in the Northeast Province Layer 2 model required a mechanism for reducing the heads. Two clusters of high modeled heads were seen in the calibration plots, as shown in Figure 21, both in areas of high well density and relatively low recharge rates. The cluster to the northwest is in the North Oaks area, largely centered around Pleasant Lake. The other area is to the east and south of White Bear Lake, in an area near the chain of lakes that includes Long Lake and Lakes Jane, Olson, and Demontreville. All wells in the County Well Index (CWI) database screened in the St. Peter Sandstone that fall within the two areas of concern (outlined in Figure 22), were designated as pumping wells. The CWI use code for these wells, which include the wells used in the head calibration dataset, indicate that 599 out of a total of 604 wells were designated as individual domestic wells. The modeled water levels in the wells within these two areas are typically in the order of 10 m too high. These anomalies may reflect hydrogeologic variations not currently understood or captured in the model. However, given the spatial density of these wells, it is possible that generally lower measured heads represent the cumulative pumping from individual households in the areas.

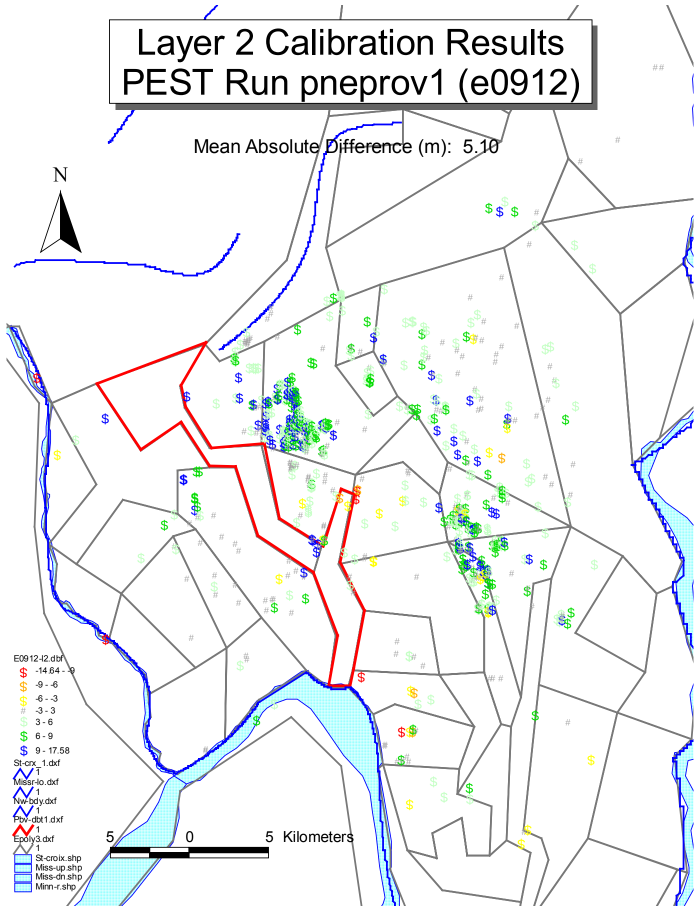
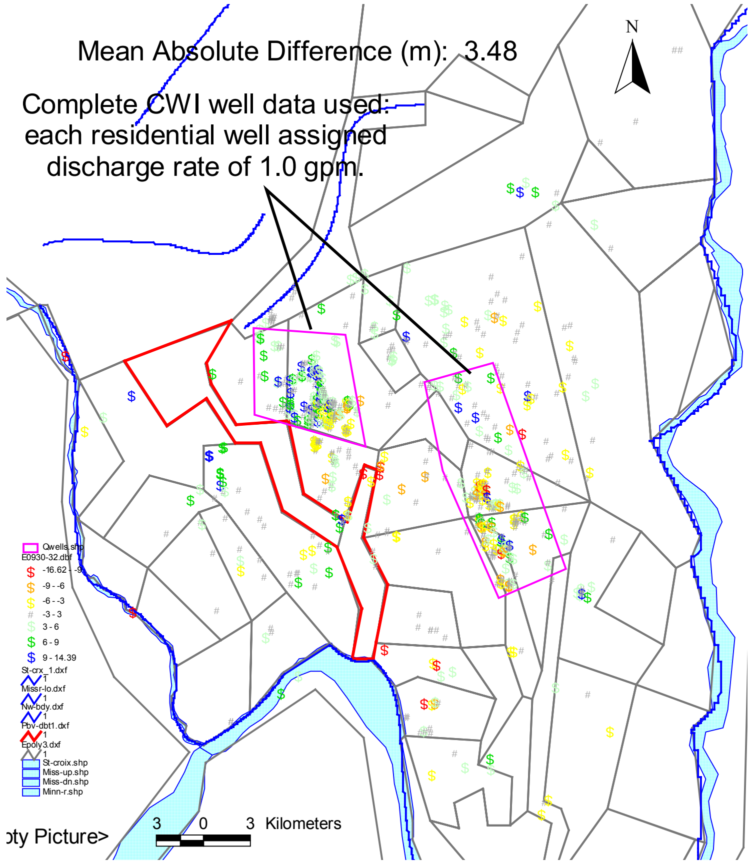


Figure 21. Clusters of High Modeled Heads in Layer 2

A potential problem in assigning typical discharge rates to these wells is that they may not necessarily account for the entire withdrawal for domestic consumption, given that CWI may not include all domestic wells that have been installed in the area. Anecdotal evidence in other areas of the Northeast Province indicates that CWI does not account for a large percentage of the total domestic wells. Additionally, the assignment of discharge rates that remove water from the system is based on the assumption that the households are sewered and remove the water from the system, rather than return water to the aquifer system via septic systems. Limited resources do not currently permit the investigation and resolution of these issues. But with no other mechanism currently identified to reduce the head in these areas, domestic pumping is used as the current working hypothesis in the conceptual model to reduce the heads.

Several approaches taken to assign discharge rates to the wells in the two areas of concern were either not effective in reducing the heads or resulted in discharge rates that were too high to be justified. Finally, it was decided that, to assign discharge rates to the wells, it was necessary to know the populations of the area in question.



Layer 2 e0930-3 Calibration Results

Figure 22. Calibration Results for Layer 2 with Domestic Pumping in Two Zones

Using the Minnesota State Planning agency web page (http://www.mnplan.state.mn.us/) the population of North Oaks was determined to be 3,844 as of April 1, 1998. Determining the populations of the other areas without distinct municipal boundaries was more difficult and could not be conducted with current resources. Personnel with the Minnesota Department of Natural Resources (DNR) stated that a study conducted by DNR determined that the mean total residential water use in the period from 1993 to 1994 was 95 gallons per capita per day (gcd). This value coincides very well with a value determined by Met Council in 1993 of 93 gcd. Rounding these values off to 100 gcd value, the total domestic discharge for North Oaks was estimated to be 384,400 gallons/day, or 266 gpm. The North Oaks municipal boundary was found to contain 267 of the wells from the pumping well dataset. Distributing the estimated discharge among these North Oaks wells produced an average of 1.00 gpm for each. The total number of wells in the North Oaks area, including those that are outside the strict municipal boundary is 300, half of the total number of pumping wells. For lack of better information at present, this discharge rate is assumed to reflect total use of the pumping wells in the White Bear Lake area as well. Figure 22 illustrates the improvement in the calibration plot for these two areas (compare with Figure 21). The mean value of 1.00

gpm for each well represents pumping not only from the wells in the dataset, but from other wells not accounted for in CWI. The overall distribution of the wells in the dataset would tend to spread the effects of the pumping over the areas to decrease the head. However, data that better define all domestic well locations and their pumping rates would be required to do site-specific modeling of Layer 2 in these areas.

Model Adjustment and Calibration

The upper three aquifer layers of the Northeast Province model were calibrated primarily by adjusting the input elevations of curvilinear line-sinks, placement of hydraulic conductivity inhomogeneities, and the infiltration rates of the polygons. This portion of the model presents special challenges that arise from the influence of the structural geology of the bedrock units. The base elevations of these units, as well as the overlying glacial drift aquifer, occur above the water level of the adjoining major discharge zones in some areas. Curvilinear line-sinks are used to represent seepage faces in these zones. However, in the absence of a distinct physical manifestation of discharge from each layer, elevations that are representative of the seepage face can be difficult to determine. Changes to the input elevations will likely occur as better information is collected, prompting further changes to leakage rates. Additionally, local-scale modeling may require changes to the geometry of the curvilinear line-sinks to better represent site-specific conditions.

After input heads were assigned to the curvilinear line-sinks and inhomogeneities were inserted, the infiltration rates to the polygon elements were adjusted to achieve a best fit to the measured head points. This was an iterative procedure that involved adjustments to the input heads throughout the process. Leakage rates were adjusted using both manual calibration procedures and PEST, an automated model calibration program. The most recent round of calibration was conducted using manual procedures.

Modeling of Leakage

The final infiltration rates used in the model are presented Table 3 below (Northeast Province Leakage Inputs, Version 1.00). Note that the negative values refer to downward leakage, and that a negative net value indicates a gain of water to the aquifer from that polygon, following MLAEM's convention of data input. This is seen both in Table 3 and in the figures that plot the net leakage rates for each polygon. However, this convention is dropped in the discussions of infiltration and leakage presented here, so that leakage and infiltration rates will not be referred to as negative. These values were determined through manual adjustment and calibration procedures, in conjunction with manually adjusting the input heads on the curvilinear line-sinks. PEST could be used to attempt to improve the fit to measured heads by adjusting the leakage values. However, the current leakage rates should suffice until more detailed modeling is conducted for the Northeast Province. Such modeling could entail changes to hydraulic properties and boundary heads. Further adjustments to leakage would be most beneficial after the other parameters have been better defined.

Table 3

Northeast Province Leakage Inputs

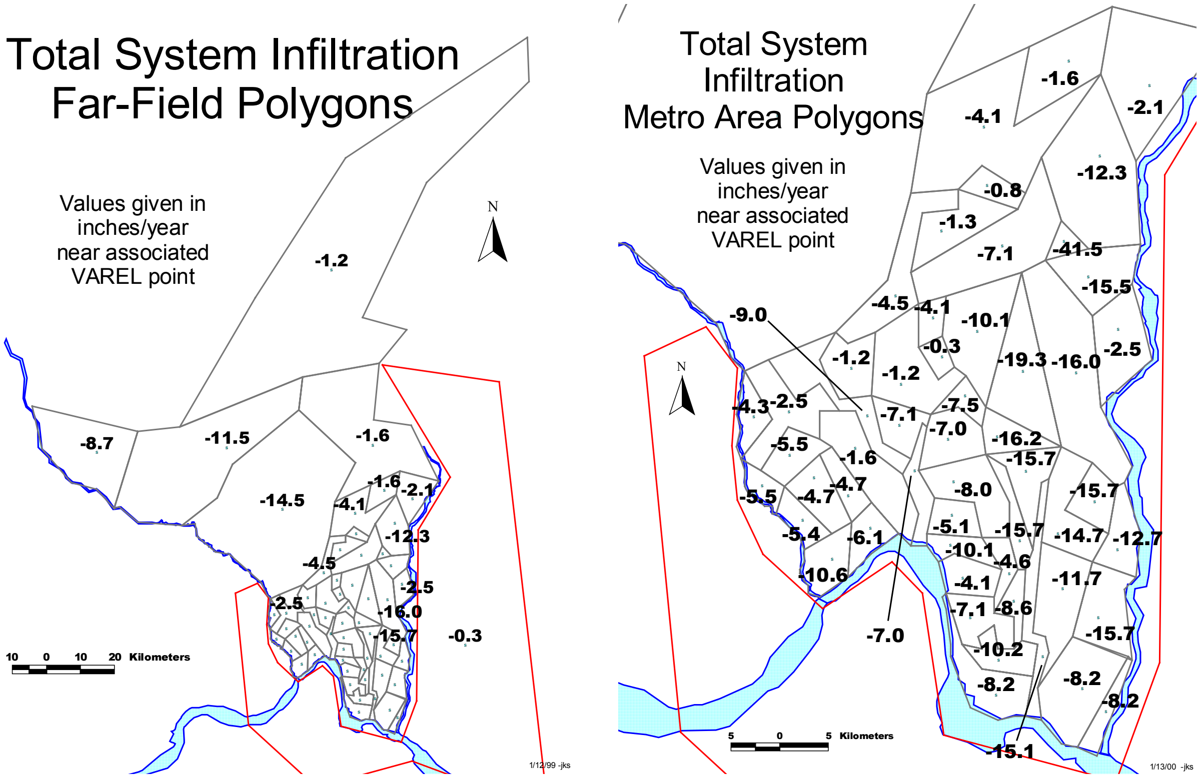
Version 1.00

POLYGON	Layer 1					Layer 2				Layer 3	
	Top (Total Infiltration)		Bottom	Net (Top - Bottom)		Top	Bottom	Net (Top -Bottom)		Top (same as net)	
	(m/day)	(in/year)	(m/day)	(m/day)	(in/year)	(m/day)	(m/day)	(m/day)	(in/year)	(m/day)	(in/year)
EA-1	-1.01E-03	-14.5	-4.18E-04	-5.92E-04	-8.5	-4.18E-04	-2.78E-04	-1.40E-04	-2.0	-2.78E-04	-4.0
EA-2	-2.85E-04	-4.1	-2.78E-04	-7.00E-06	-0.1	-2.78E-04	-2.71E-04	-7.00E-06	-0.1	-2.71E-04	-3.9
EA-3	-1.74E-04	-2.5	-1.04E-04	-7.00E-05	-1.0	-1.04E-04	-9.74E-05	-6.60E-06	-0.1	-9.74E-05	-1.4
EA-4	-2.99E-04	-4.3	-2.30E-04	-6.90E-05	-1.0	-2.30E-04	-8.35E-05	-1.47E-04	-2.1	-8.35E-05	-1.2
EA-LCHAIN_1	-3.13E-04	-4.5	-4.18E-05	-2.71E-04	-3.9	-4.18E-05	-6.96E-06	-3.48E-05	-0.5	-6.96E-06	-0.1
EH-1	-3.83E-04	-5.5	-3.13E-04	-7.00E-05	-1.0	-3.13E-04	-2.78E-04	-3.50E-05	-0.5	-2.78E-04	-4.0
EH-2	-3.83E-04	-5.5	-3.13E-04	-7.00E-05	-1.0	-3.13E-04	-2.78E-04	-3.50E-05	-0.5	-2.78E-04	-4.0
ER-1	-8.35E-05	-1.2	-1.39E-05	-6.96E-05	-1.0	-1.39E-05	-6.96E-06	-6.94E-06	-0.1	-6.96E-06	-0.1
ER-2	-8.35E-05	-1.2	-1.39E-05	-6.96E-05	-1.0	-1.39E-05	-6.96E-06	-6.94E-06	-0.1	-6.96E-06	-0.1
ER-3	-4.94E-04	-7.1	-3.55E-04	-1.39E-04	-2.0	-3.55E-04	-6.96E-06	-3.48E-04	-5.0	-6.96E-06	-0.1
ER-4	-4.87E-04	-7.0	-2.78E-04	-2.09E-04	-3.0	-2.78E-04	-1.39E-04	-1.39E-04	-2.0	-1.39E-04	-2.0
ER-5	-1.11E-04	-1.6	-7.65E-05	-3.45E-05	-0.5	-7.65E-05	-4.18E-05	-3.47E-05	-0.5	-4.18E-05	-0.6
ER-6	-3.27E-04	-4.7	-3.13E-04	-1.40E-05	-0.2	-3.13E-04	-2.78E-04	-3.50E-05	-0.5	-2.78E-04	-4.0
ER-7	-3.27E-04	-4.7	-3.13E-04	-1.40E-05	-0.2	-3.13E-04	-2.78E-04	-3.50E-05	-0.5	-2.78E-04	-4.0
ER-8	-3.76E-04	-5.4	-3.62E-04	-1.40E-05	-0.2	-3.62E-04	-2.78E-04	-8.40E-05	-1.2	-2.78E-04	-4.0
ER-9	-4.24E-04	-6.1	-4.11E-04	-1.30E-05	-0.2	-4.11E-04	-2.78E-04	-1.33E-04	-1.9	-2.78E-04	-4.0
ER-10	-7.38E-04	-10.6	-7.24E-04	-1.40E-05	-0.2	-7.24E-04	-5.85E-04	-1.39E-04	-2.0	-5.85E-04	-8.4
ER-11	-3.55E-04	-5.1	-3.48E-04	-7.00E-06	-0.1	-3.48E-04	-2.09E-04	-1.39E-04	-2.0	-2.09E-04	-3.0
ER-12	-7.03E-04	-10.1	-6.96E-04	-7.00E-06	-0.1	-6.96E-04	-4.87E-04	-2.09E-04	-3.0	-4.87E-04	-7.0
ER-13	-2.85E-04	-4.1	-2.78E-04	-7.00E-06	-0.1	-2.78E-04	-2.09E-04	-6.90E-05	-1.0	-2.09E-04	-3.0
EW-1	-9.05E-05	-1.3	-5.57E-05	-3.48E-05	-0.5	-5.57E-05	-3.48E-05	-2.09E-05	-0.3	-3.48E-05	-0.5
EW-2	-4.94E-04	-7.1	-2.23E-04	-2.71E-04	-3.9	-2.23E-04	-2.09E-04	-1.40E-05	-0.2	-2.09E-04	-3.0
EW-3	-8.56E-04	-12.3	-5.08E-04	-3.48E-04	-5.0	-5.08E-04	-4.87E-04	-2.10E-05	-0.3	-4.87E-04	-7.0
EW-4	-1.08E-03	-15.5	-6.61E-04	-4.19E-04	-6.0	-6.61E-04	-5.92E-04	-6.90E-05	-1.0	-5.92E-04	-8.5
EW-5	-1.74E-04	-2.5	-1.04E-04	-7.00E-05	-1.0	-1.04E-04	-6.96E-05	-3.44E-05	-0.5	-6.96E-05	-1.0
EW-6	-1.11E-03	-16.0	-6.26E-04	-4.84E-04	-7.0	-6.26E-04	-5.57E-04	-6.90E-05	-1.0	-5.57E-04	-8.0
EW-7	-1.34E-03	-19.3	-7.10E-04	-6.30E-04	-9.1	-7.10E-04	-6.26E-04	-8.40E-05	-1.2	-6.26E-04	-9.0
EW-8	-7.03E-04	-10.1	-2.16E-04	-4.87E-04	-7.0	-2.16E-04	-2.09E-04	-7.00E-06	-0.1	-2.09E-04	-3.0
EW-9	-1.13E-03	-16.2	-6.40E-04	-4.90E-04	-7.0	-6.40E-04	-5.57E-04	-8.30E-05	-1.2	-5.57E-04	-8.0
EW-10	-5.57E-04	-8.0	-3.48E-04	-2.09E-04	-3.0	-3.48E-04	-2.78E-04	-7.00E-05	-1.0	-2.78E-04	-4.0
EW-11	-1.09E-03	-15.7	-6.05E-04	-4.85E-04	-7.0	-6.05E-04	-5.57E-04	-4.80E-05	-0.7	-5.57E-04	-8.0
EW-12	-1.09E-03	-15.7	-6.05E-04	-4.85E-04	-7.0	-6.05E-04	-5.57E-04	-4.80E-05	-0.7	-5.57E-04	-8.0
EW-13	-1.02E-03	-14.7	-6.05E-04	-4.15E-04	-6.0	-6.05E-04	-5.57E-04	-4.80E-05	-0.7	-5.57E-04	-8.0
EW-14	-1.09E-03	-15.7	-6.05E-04	-4.85E-04	-7.0	-6.05E-04	-5.57E-04	-4.80E-05	-0.7	-5.57E-04	-8.0
EW-15	-8.84E-04	-12.7	-3.97E-04	-4.87E-04	-7.0	-3.97E-04	-3.48E-04	-4.90E-05	-0.7	-3.48E-04	-5.0
EW-16	-1.09E-03	-15.7	-6.05E-04	-4.85E-04	-7.0	-6.05E-04	-5.57E-04	-4.80E-05	-0.7	-5.57E-04	-8.0
EW-17	-8.14E-04	-11.7	-3.27E-04	-4.87E-04	-7.0	-3.27E-04	-2.78E-04	-4.90E-05	-0.7	-2.78E-04	-4.0
EW-18	-5.71E-04	-8.2	-5.64E-04	-7.00E-06	-0.1	-5.64E-04	-5.57E-04	-7.00E-06	-0.1	-5.57E-04	-8.0
EW-19	-5.71E-04	-8.2	-5.64E-04	-7.00E-06	-0.1	-5.64E-04	-5.57E-04	-7.00E-06	-0.1	-5.57E-04	-8.0
EW-20	-3.20E-04	-4.6	-3.13E-04	-7.00E-06	-0.1	-3.13E-04	-2.78E-04	-3.50E-05	-0.5	-2.78E-04	-4.0
EW-21	-5.98E-04	-8.6	-5.92E-04	-6.00E-06	-0.1	-5.92E-04	-5.57E-04	-3.50E-05	-0.5	-5.57E-04	-8.0
EW-22	-4.94E-04	-7.1	-4.87E-04	-7.00E-06	-0.1	-4.87E-04	-3.48E-04	-1.39E-04	-2.0	-3.48E-04	-5.0
EW-23	-7.10E-04	-10.2	-7.03E-04	-7.00E-06	-0.1	-7.03E-04	-6.96E-04	-7.00E-06	-0.1	-6.96E-04	-10.0
EW-24	-5.71E-04	-8.2	-5.64E-04	-7.00E-06	-0.1	-5.64E-04	-5.57E-04	-7.00E-06	-0.1	-5.57E-04	-8.0
E-W-BEAR_L	-5.22E-04	-7.5	-3.83E-04	-1.39E-04	-2.0	-3.83E-04	-3.48E-04	-3.50E-05	-0.5	-3.48E-04	-5.0
EW-BV-SOUTH	-1.05E-03	-15.1	-1.04E-03	-1.00E-05	-0.1	-1.04E-03	-6.96E-04	-3.44E-04	-4.9	-6.96E-04	-10.0
E-BVPHAL_N	-6.26E-04	-9.0	-4.18E-04	-2.08E-04	-3.0	-4.18E-04	-1.39E-04	-2.79E-04	-4.0	-1.39E-04	-2.0
E-BVPHAL_S	-4.87E-04	-7.0	-4.18E-04	-6.90E-05	-1.0	-4.18E-04	-1.39E-04	-2.79E-04	-4.0	-1.39E-04	-2.0
E-B-EAGLE_L	-2.09E-05	-0.3	-1.39E-05	-7.00E-06	-0.1	-1.39E-05	-6.96E-06	-6.94E-06	-0.1	-6.96E-06	-0.1
E-B-MARINE_L	-2.89E-03	-41.5	-1.50E-03	-1.39E-03	-20.0	-1.50E-03	-1.39E-03	-1.10E-04	-1.6	-1.39E-03	-20.0
E-CHISAGO_L	-1.11E-04	-1.6	-4.18E-05	-6.92E-05	-1.0	-4.18E-05	-6.96E-06	-3.48E-05	-0.5	-6.96E-06	-0.1
E-FOREST_L	-5.57E-05	-0.8	-4.87E-05	-7.00E-06	-0.1	-4.87E-05	-6.96E-06	-4.17E-05	-0.6	-6.96E-06	-0.1
E-FF1	-8.35E-05	-1.2	-1.39E-05	-6.96E-05	-1.0	-1.39E-05	-6.96E-06	-6.94E-06	-0.1	-6.96E-06	-0.1
E-FF2	-6.05E-04	-8.7	-1.39E-05	-5.91E-04	-8.5	-1.39E-05	-6.96E-06	-6.94E-06	-0.1	-6.96E-06	-0.1
E-FF3	-8.00E-04	-11.5	-2.44E-04	-5.56E-04	-8.0	-2.44E-04	-2.09E-04	-3.50E-05	-0.5	-2.09E-04	-3.0
E-FF4	-1.11E-04	-1.6	-4.18E-05	-6.92E-05	-1.0	-4.18E-05	-6.96E-06	-3.48E-05	-0.5	-6.96E-06	-0.1
E-FF5	-2.85E-04	-4.1	-1.46E-04	-1.39E-04	-2.0	-1.46E-04	-6.96E-06	-1.39E-04	-2.0	-6.96E-06	-0.1
E-FF6	-1.46E-04	-2.1	-7.65E-05	-6.95E-05	-1.0	-7.65E-05	-6.96E-06	-6.95E-05	-1.0	-6.96E-06	-0.1
INFILT_EXT	-2.09E-05	-0.3	-1.39E-05	-7.00E-06	-0.1	-1.39E-05	-6.96E-06	-6.94E-06	-0.1	-6.96E-06	-0.1

Note in Table 3 that the model inputs in units of m/day are provided along with total infiltration and net rates for each layer in units of inches/year, to allow for more ready comparison with the rates given in literature. As currently set up, the total system infiltration enters the model through the top of Layer 1. The given-strength leakage leakage approach is based on the assumption that the water leaving the bottom of one aquifer is identical to the water entering the top of the underlying aquifer, with no loss of water via the separating layer. Hence, the leakage rates for water leaving the bottom of Layer 1 are identical to the rates entering the top of Layer 2, just as the rates for the bottom of Layer 2 are identical to those for the top of Layer 3. Although net leakage rates are not specified in this model, they are listed to provide a sense of the water throughput for each layer. Refer the Overview of the Twin Cities Metropolitan Groundwater Model for more detailed description on application of the given-strength leakage approach.

Total system infiltration rates are plotted (inches/year) for each polygon on Figure 23 at both regional and metropolitan area scales. Net leakage rates for each aquifer layer will be presented in a similar fashion later as part of this discussion. The most notable value perhaps is that for Big Marine Lake, which is 41.5 inches/year. As seen in the Table 3 and figures below, 20 inches/year of leakage is distributed to both Layers 1 and 3. Infiltration rates this high could only be justified if the lake is located in a closed watershed with no surface water outlet or one that is very limited. Indeed Big Marine Lake is situated in a closed basin that lacked a surface water control outlet until 1984, when one was installed due to the rising water levels in the lake. Since its installation, the water level in Big Marine Lake has remained relatively constant. However, even at the engineered maximum crest level of 940.6 feet MSL, the lake could still serve as an area of focused recharge to the aquifers below. Hence, the 41.5 inches/year infiltration rate used for Big Marine Lake is plausible, and currently offered as the technical approach to calibrate to heads in the glacial drift aquifer in the area. Inspection of the calibration plots indicates that both Layers 1 and 3 could perhaps benefit by increasing the net infiltration rates for Big Marine Lake even more. Further analysis of the water budget of the lake will help resolve whether or not the lake contributes such a high rate of recharge to the groundwater system, or perhaps even greater.

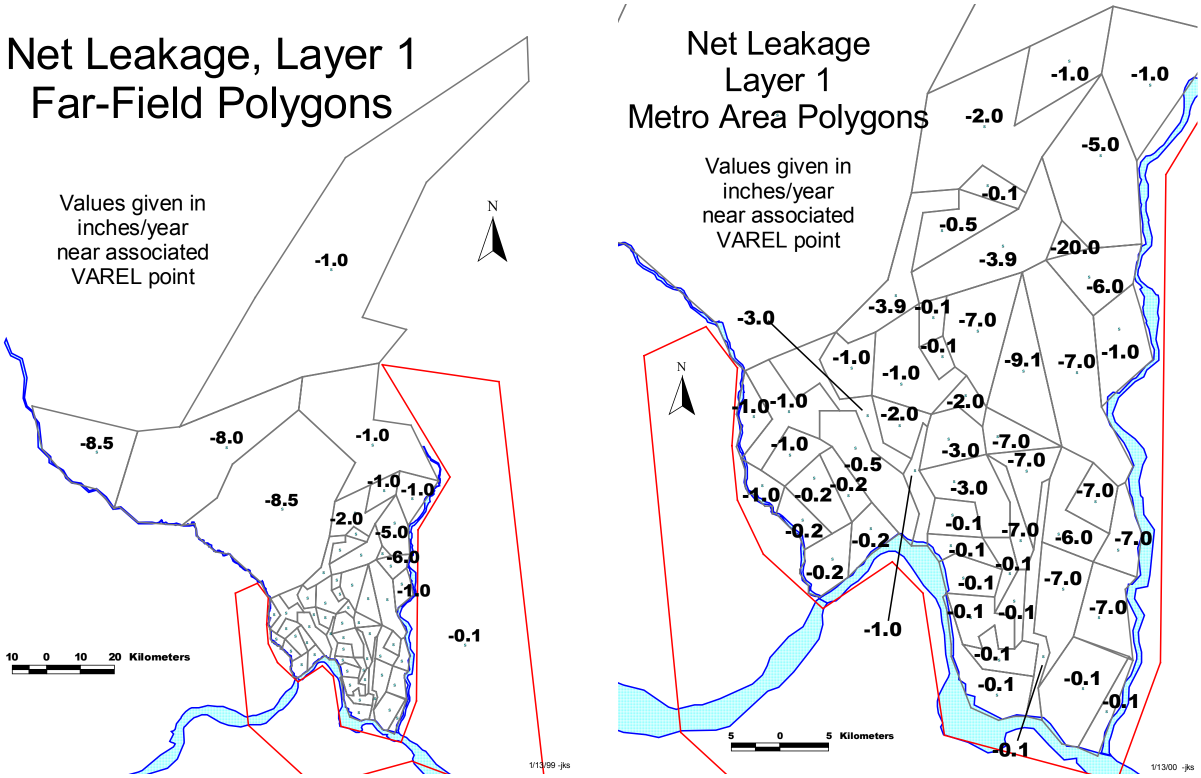
Polygons encompassing the Anoka Sandplain region, E-FF2, E-EE3, and EA-1 (see Figure 8), had total system infiltration rates of 8.7, 11.5, and 14.5 inches/year, respectively, a reasonable range for this sandy glacial outwash terrane. Excluding Big Marine Lake, the total system infiltration rates for polygons within the metropolitan area range from less than 1 inch/year to 19.3 inches/year. Values for polygons in the western half of the province fall roughly within the 2 to 7 inches/year range, significantly lower than the values in the eastern half in general. These values typically fall between 7 to 19.3 inches/year. Much of the area encompassed by these polygons can be characterized as a glaciated landscape of interrupted drainage, leaving very few surface water drainage features on glacial terrane that is dominated largely by high sand contents. These conditions are conducive to greater infiltration rates. Nine of the polygons have total infiltration rates that exceed 14 inches/year. Values falling near the upper end of the range will need to be re-evaluated as further work is conducted in the area to better understand the water throughput of the system.



Regional View **Metropolitan Area**

Figure 23. Total System Infiltration Rates—Regional and Metro Scales

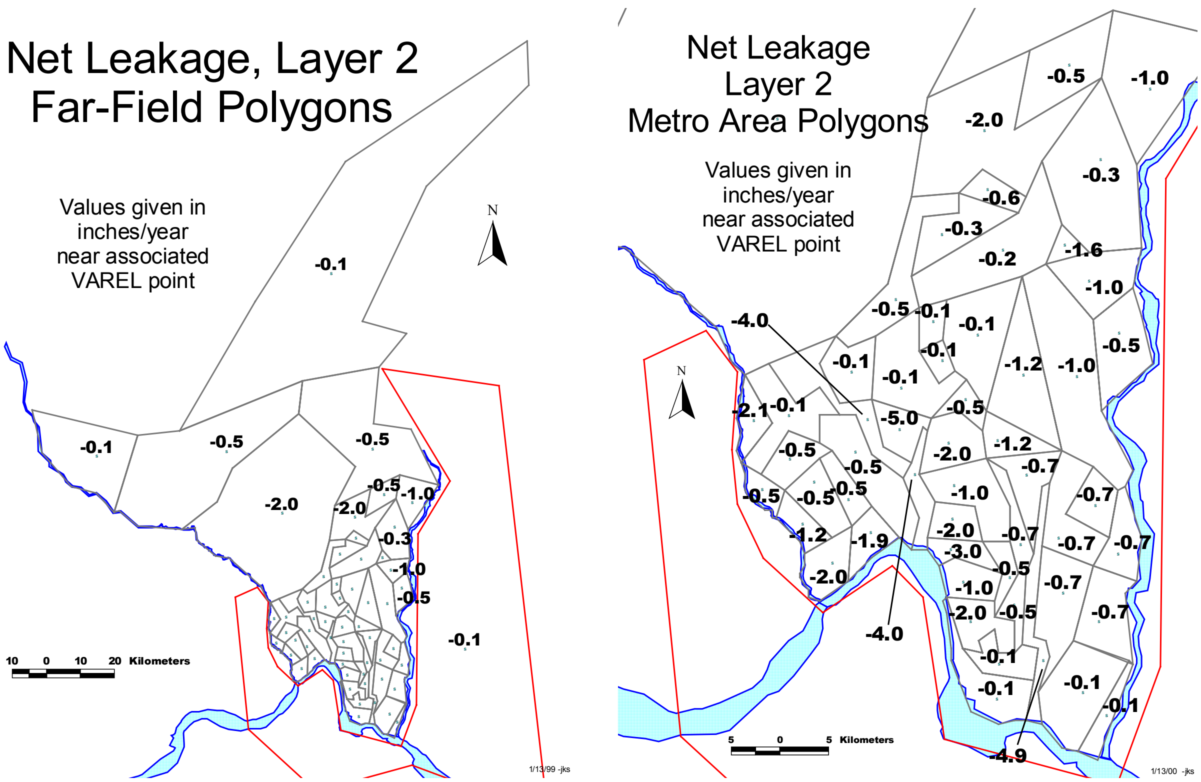
The distribution of net leakage to Layer 1 on a polygon-by-polygon basis is presented in Figure 24 at both regional and metro scales. Minimal influxes of water are typical to the polygons that flank the Mississippi River. The overall absence of calibration points in these net leakage zones in the eastern half suggests that the water table may not even be present within the glacial materials. Additional investigation is required to determine whether this is the case. The low net leakage zone in southern Ramsey County, is the area that is not likely to be in direct hydraulic communication with the rest of the contiguous aquifer as previously discussed. The heads, likely perched, are at a much higher level than can be readily simulated by the model, resulting in low net recharge rates to minimize the modeled head in this area. The other noteworthy aspect is the high net infiltration rate (20 inches) at Big Marine Lake, as previously discussed.



Regional View **Metropolitan Area**

Figure 24. Net Leakage to Layer 1—Regional and Metro Scales

Figure 25 illustrates the net infiltration rates for Layer 2 at both regional and metro scales. In general the net rates for Layer 2 are substantially lower (many values less than 1 inch/year) than those for Layers 1 and 3. This is consistent with the theory that distribution of infiltration to a multi-layered system will occur in proportion to the transmissivity of each layer. The transmissivity value of the St. Peter Sandstone is much lower than the values for the glacial drift and Prairie du Chien-Jordan Aquifers, so it would be expected to generally have lower net infiltration rates. Net infiltration rates of approximately 4 to 5 inches/year are seen in the buried bedrock valley areas, where the St. Peter Sandstone is not even present, and sandy lithologies tend to predominate. The rate for polygon ER-3 (see Figure 9), located between the buried Phalen channel and its main branch, is 5.0 inches/year, especially high in comparison to the net rates for other polygons. This particular area reacts sensitively to a range of inputs, and more information is required to better simulate groundwater flow. Changes to the model in this area are expected as better information and data become available.

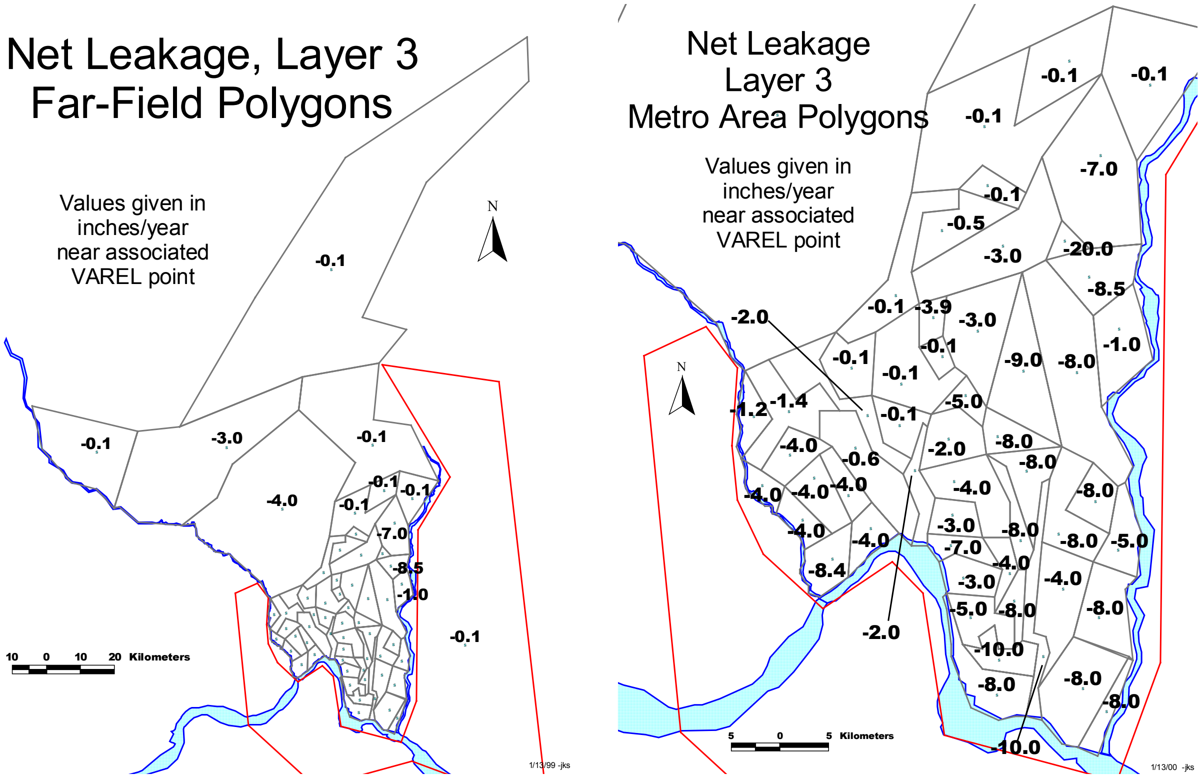


Regional View **Metropolitan Area**

Figure 25. Net Leakage to Layer 2—Regional and Metro Scales

Net infiltration rates to Layer 3, the Prairie du Chien-Jordan aquifer, are presented in Figure 26. Except for Big Marine Lake with a value of 20 inches/year as previously discussed, the maximum value is 10 inches/year, which occurs in two polygons. As with Layer 1, the higher infiltration rates tend to be found in the eastern portion of the Washington County, with values around 8 inches/year predominating. The other striking trend is that the rates tend to be very low in the northern portion of the Metro Area, ranging from 0.1 to 0.5 inches/year in the zone encompassing the outer extent of the Prairie du Chien-Jordan aquifer.

As additional work is conducted on the model and as new information and data are gathered, these infiltration rates will be re-evaluated to determine how well they represent natural conditions. Changes to the conceptual model and to the infiltration values will undoubtedly change as more information becomes available.



Regional View **Metropolitan Area**

Figure 26. Net Leakage to Layer 3—Regional and Metro Scales

Model Results

Comparison to Measured Heads

This section presents the most current calibration results of the Northeast Province model of Layers 1, 2, and 3. The descriptive statistics of the mean absolute difference (of computed minus measured heads) are presented in the Table 4. The calibration plots and modeled piezometric surfaces for Layers 1, 2 and 3 are presented on the pages following the statistics of mean absolute differences. The modeled head contours are presented in feet MSL to allow ready comparison with previously published data and results that have been produced in units of feet. Plots in metric units can be readily produced on request.

The Layer 1 calibration plot and modeled head contour map are shown in Figures 27 and 28, respectively. Inspection of the calibration plot reveals two areas in particular that are not well represented by the computed heads of the model. One area is the cluster of wells within the St. Croix River floodplain near Stillwater. Because discharge out of the aquifer likely occurs under seepage face conditions at an elevation above that of the St. Croix River, it is not appropriate to calibrate the model to those wells. The other area includes a portion of Minneapolis and St. Paul adjoining the eastern side of the Mississippi River, in an area encompassed by polygons ER-7 and ER-8 (see Figure 9). These eight wells appear to represent perched conditions in the glacial drift aquifer that are not in direct hydraulic communication with the remainder of the drift aquifer. Eliminating the calibration points from these two clusters in Layer 1 in areas that are not representative of the contiguous drift aquifer resulted in a reduction of the mean absolute difference from 3.67 m to 2.54 m. Although these calibration points may not be representative of the head in the contiguous drift aquifer, they are still shown on the Layer 1 calibration plot below. Note that the Layer 1 model in the vicinity of polygons ER-7 and ER-8 is not considered representative—additional work will be required to develop a local-scale model of this area.

The inclusion of the high hydraulic conductivity (200 m/day) inhomogeneity in the buried bedrock channel north of Stillwater (inhomogeneity polygon Stillwater_Inhomogeneity within polygon EW-5), did not reduce the head enough to achieve a good fit to measured heads. Further work will be required to provide a better model fit in this area. Possibilities include increasing the inhomogeneity hydraulic conductivity if evidence indicates that even higher values are possible, and examining the contribution of water attributable to leakage polygons outside polygon EW-5.

The Layer 1 model appears to be somewhat dry in a zone near the intersection of polygons E_BVPhal_S, E_BVPhal_N, and ER-5 (refer to Figure 9). Again the cause of this cluster is not known and further investigation is required to resolve this issue, particularly if local-scale modeling is to be conducted in that vicinity.

As previously discussed, special problems in calibration were posed in the area around Big Marine Lake (polygon E-B-Marine_L) despite the fact that it is contributing 20 inches/year of recharge to Layer 1.

Table 4
Descriptive Statistics for Mean Absolute Difference Values

	Layer 1	**Layer 1** without St. Croix R. & Odec anomalies	**Layer 2**	**Layer 3**
Mean	3.67	2.54	3.55	3.90
Standard Error	0.20	0.07	0.10	0.10
Median	2.27	2.16	2.90	3.22
Mode	2.69	2.69	0.52	4.92
Standard Deviation	6.05	1.98	2.79	3.14
Sample Variance	36.65	3.93	7.76	9.84
Kurtosis	19.81	3.56	1.59	2.57
Skewness	4.37	1.45	1.11	1.37
Range	40.07	15.01	19.52	20.76
Minimum	0.00	0.00	0.00	0.00
Maximum	40.07	15.01	19.52	20.77
Sum	3307.14	2192.92	2764.68	3511.32
Count	900	862	779	900

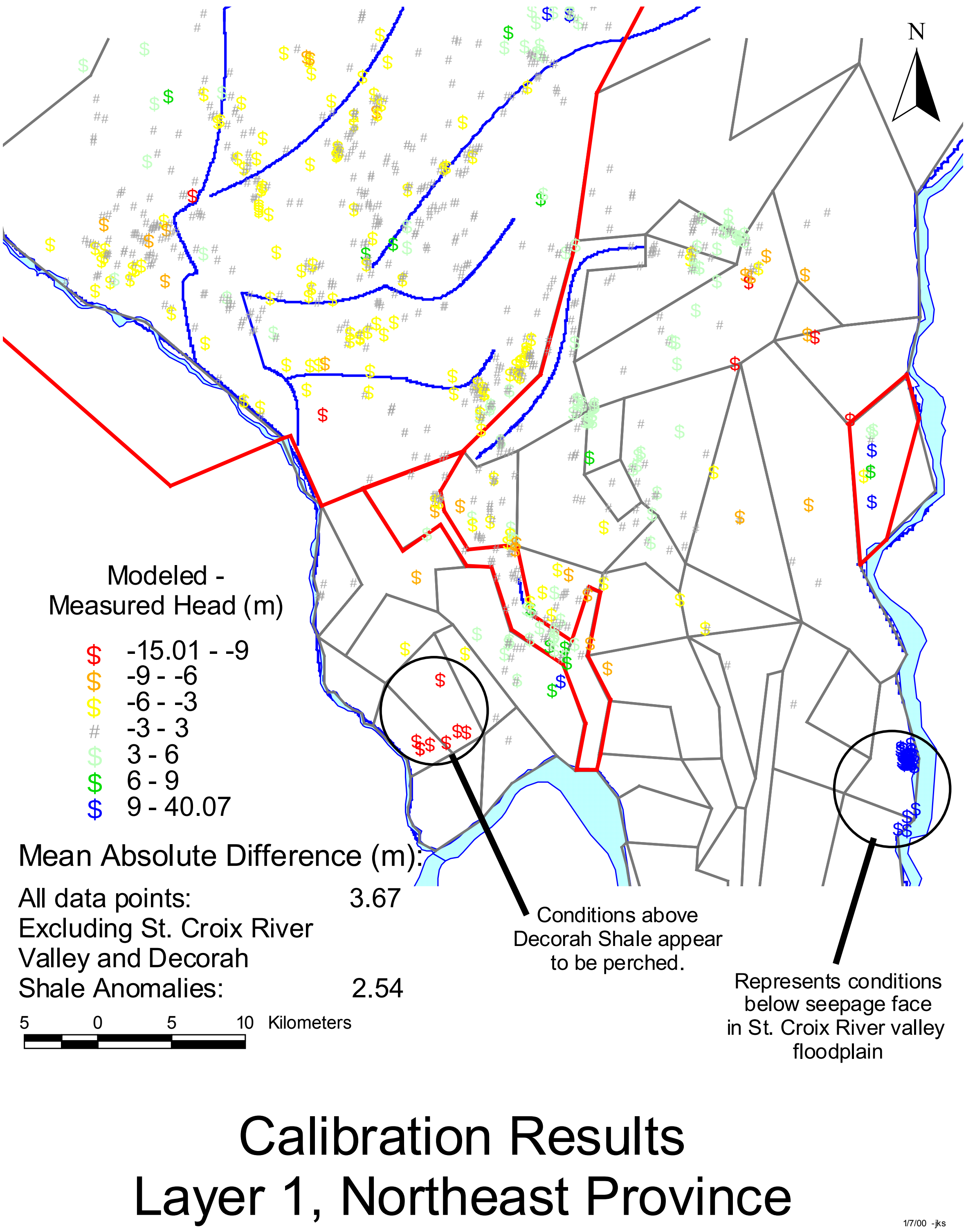


Figure 27. Layer 1 Calibration Plot

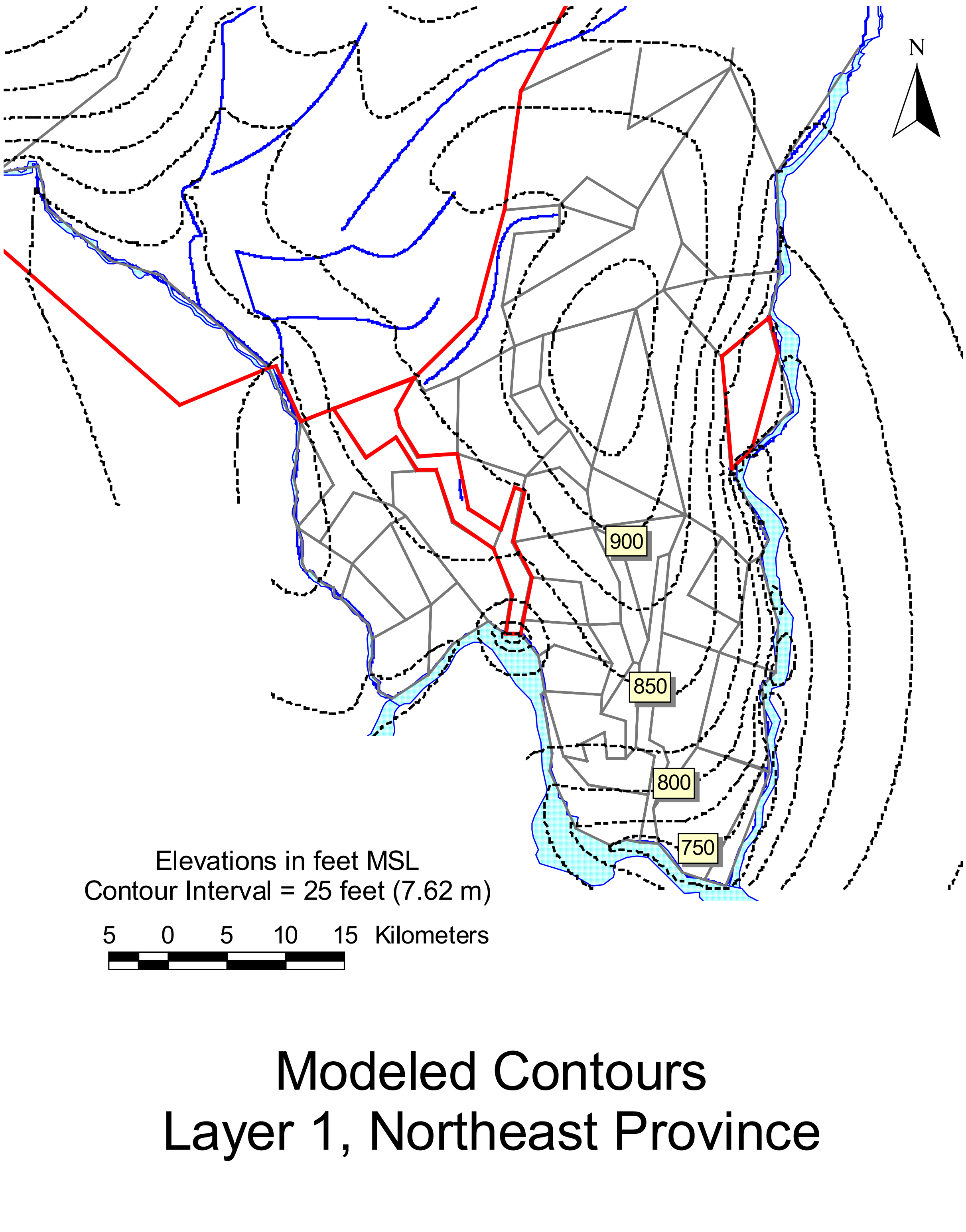


Figure 28. Layer 1 Piezometric Contours

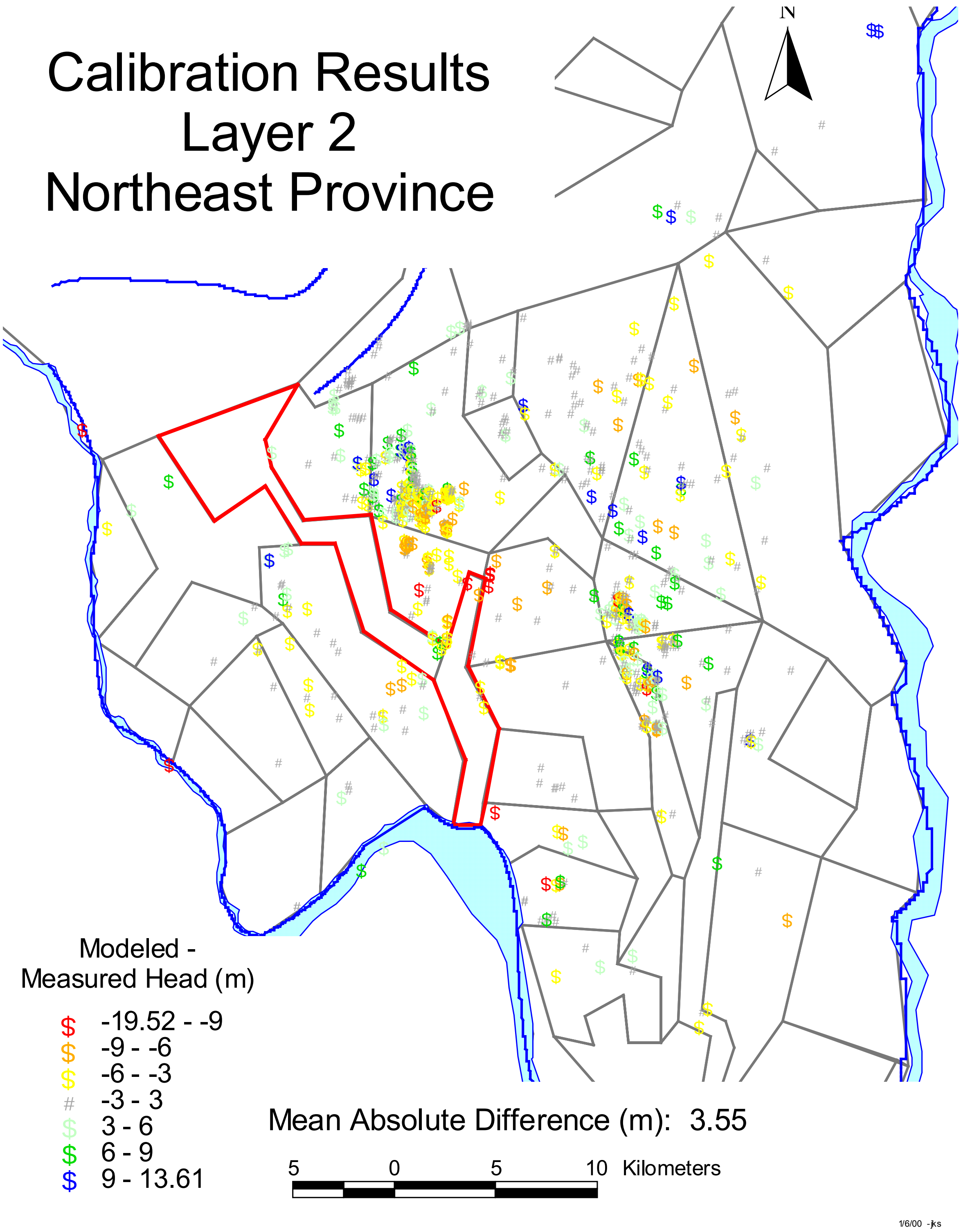


Figure 29. Layer 2 Calibration Plot

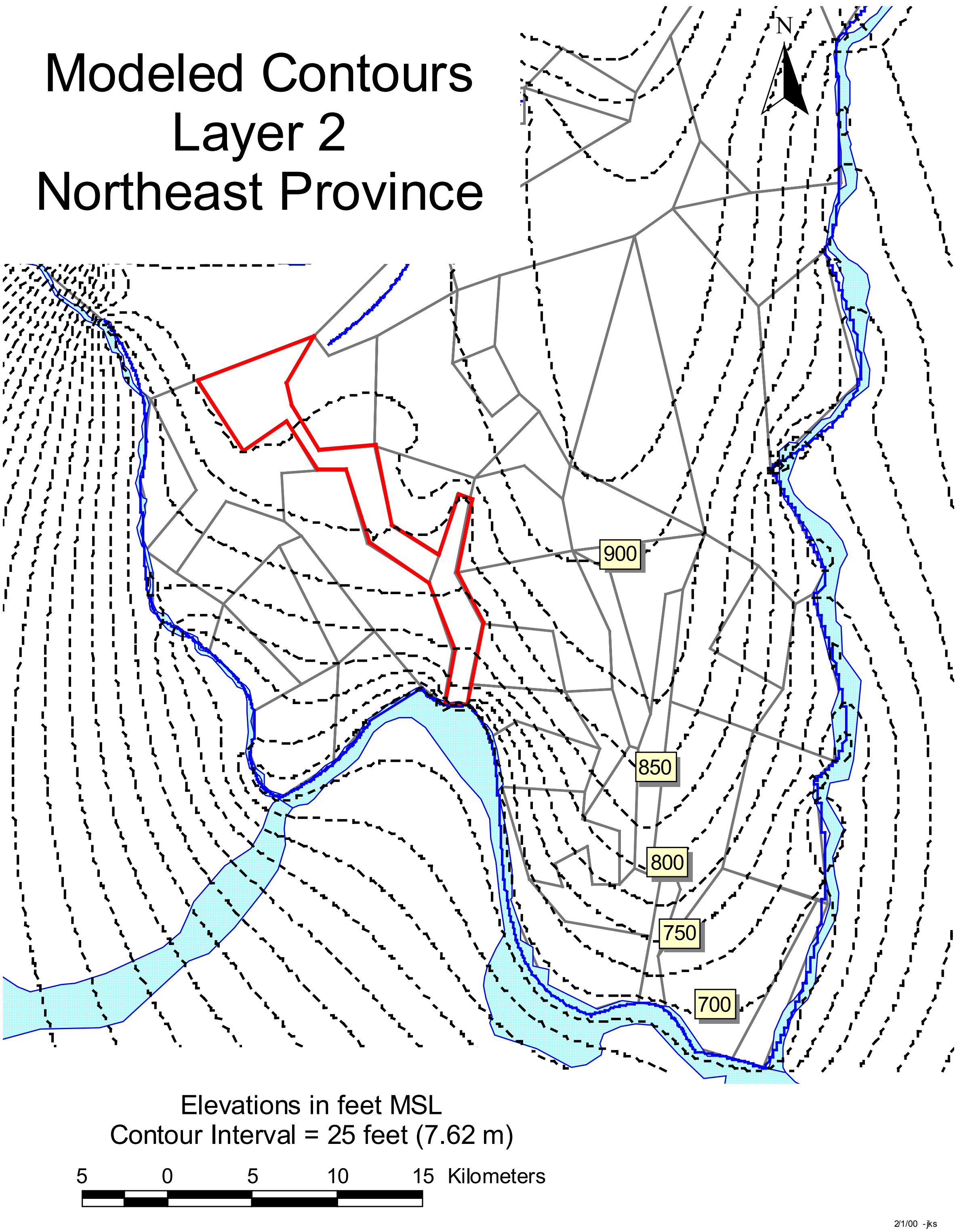


Figure 30. Layer 2 Piezometric Contours

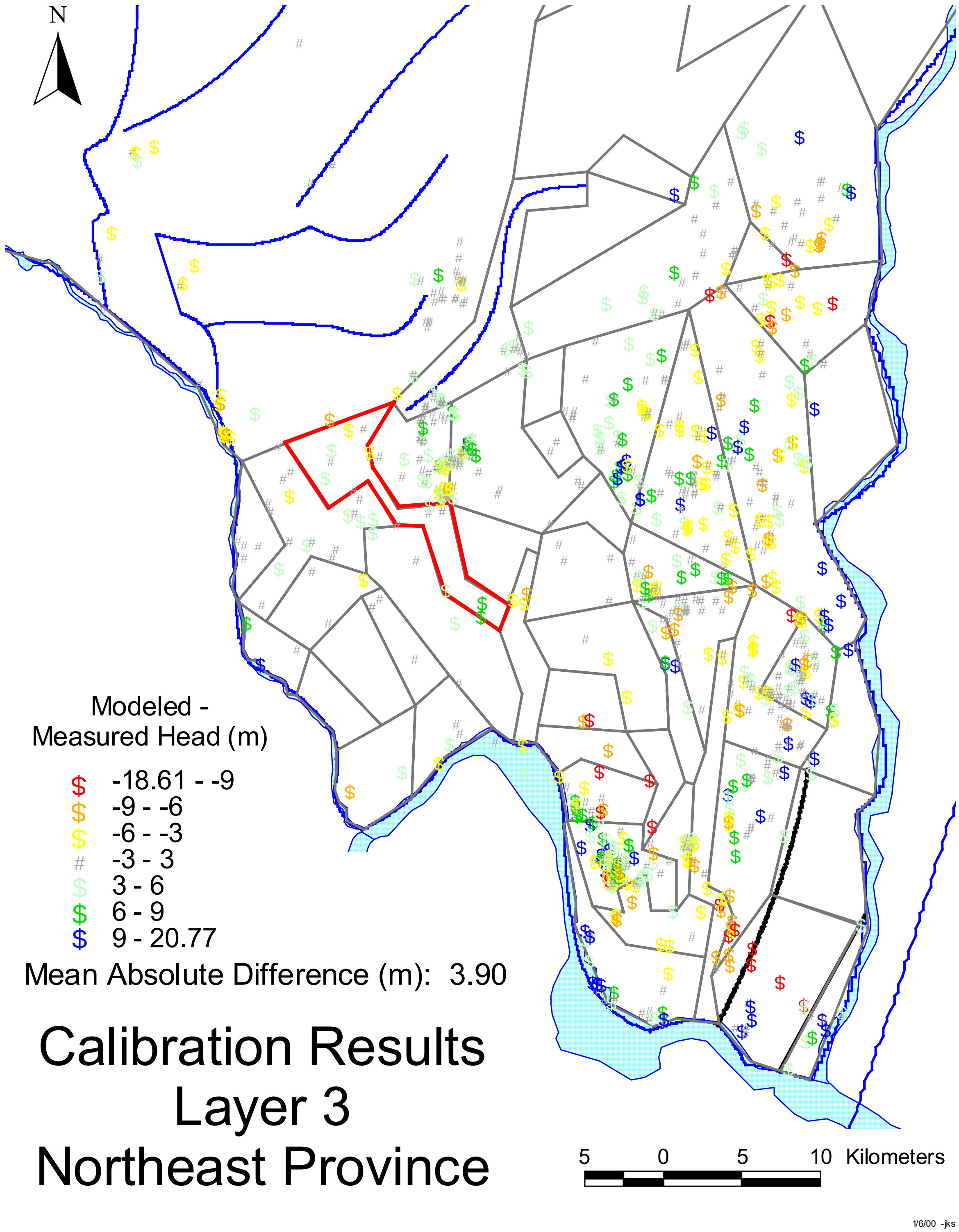


Figure 31. Layer 3 Calibration Plot

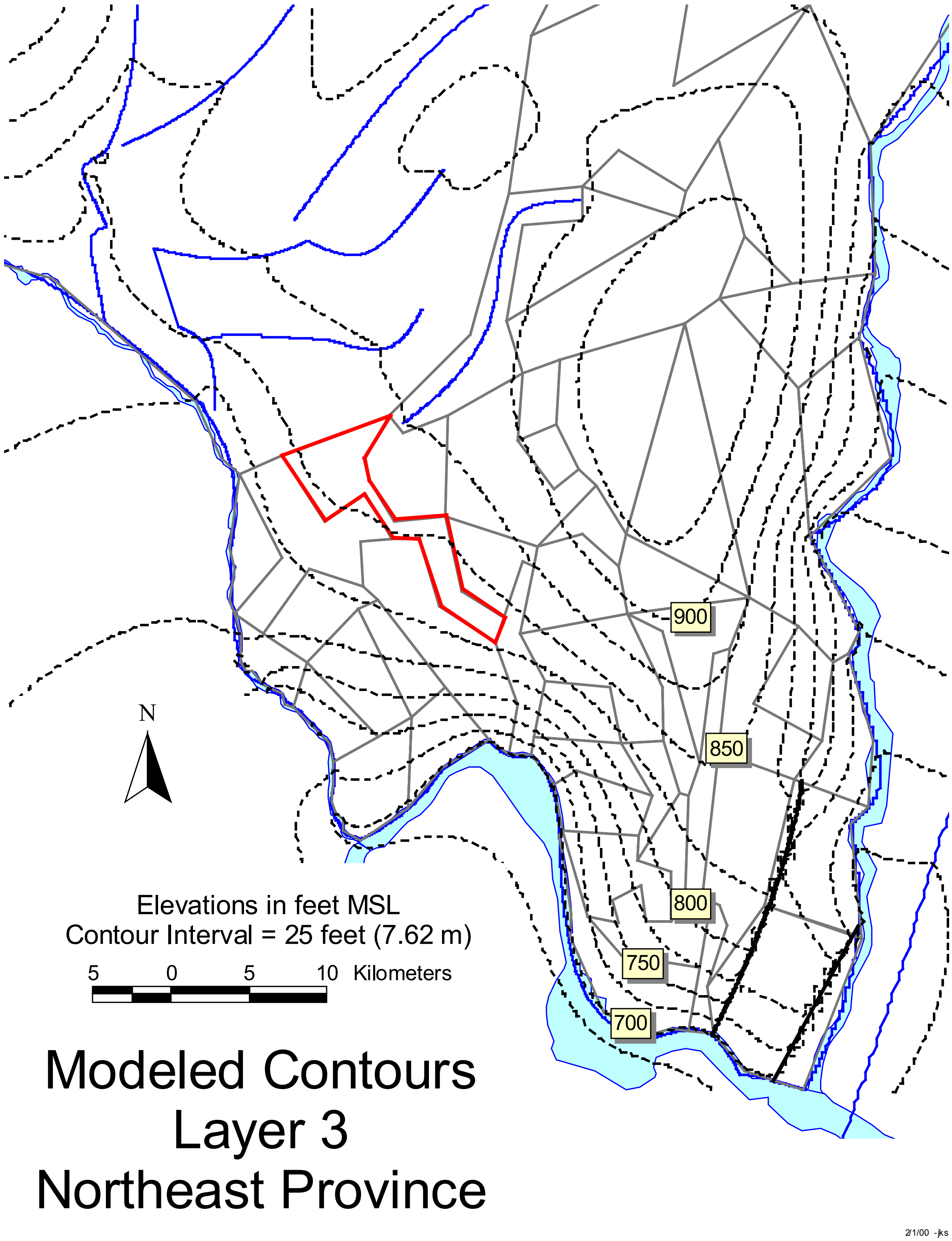


Figure 32. Layer 3 Piezometric Contours

Figures 29 and 30 illustrates the calibration plot and modeled piezometric surface, respectively, for Layer 2. The mean absolute difference of modeled minus measured heads for Layer 2 was 3.55 m (Table 4), indicating a poorer fit to measured heads than for Layer 1 (exclusive of the two anomalous clusters discussed). It is believed that the greater difference is due to local-scale influences that are not captured in the regional model. These effects could include limited extent of the aquifer, inhomogeneities, and pumping not currently represented in the model.

The Layer 3 model had a value for the absolute mean difference between modeled and measured heads of 3.90 m. The calibration plot and modeled piezometric surface for Layer 3 are presented in Figures 31 and 32, respectively. Inspection of the calibration plot shows that a wide range of variability exists, and that no significant trends and clusters are readily discernible. One possible exception to this is the presence of a zone of "dry" calibration points, which, on the basis of a few points, gives the appearance of running transverse to the Cottage Grove Fault. Currently, no potential cause of this phenomenon is known. However, recent variogram analysis conducted by Metro Model personnel reveals large differences in the variograms and maximum correlation lengths between wells screened only in the Prairie du Chien Group and wells screened only in the Jordan Sandstone in the northeast province. This suggests that these units are not universally hydraulically connected, and that significant differences in head distributions might exist between the two. Some of the difficulties in achieving a better calibration might be attributable to variations in the head distribution of the two aquifers, which are represented by one dataset that includes heads for wells screened in either or both aquifers. Other possibilities that could result is such wide variability of calibration head differences include system heterogeneity, poorly defined boundary conditions, and local pumping effects.

Comparison to Measured Discharges

Efforts to fit the model to measured heads are a necessary part of the calibration process, but it does not however, ensure the water balance is correct. In addition to calibration to head values, it is important that the water throughput in the model compares favorably with that of the actual system, where measured. Presently, we do not have much data on aquifer discharge rates to surface water bodies. Further complicating this issue in the Northeast Province is the structural geology constraints on the system, that render simple flat-lying layer-cake stratigraphy models of the aquifer system to be of little use. The geometry of the seepage faces that serve as discharge zones is likely quite complicated, and does not lend itself well to measuring the actual discharge of groundwater. Although more stream discharge data are becoming available, the only information we had to work with at the time of this analysis were discharge data for tributary streams to the St. Croix River. After analyzing the data, the focus was placed on the lower reaches of the streams near the St. Croix River. A review of the geology indicated that discharge to the lower reaches of these streams was most representative of water discharging from the Prairie du Chien-Jordan aquifer. When the streams were individually placed in the model, the modeled discharges did not consistently compare favorably to the measured results. This is because the streams are very localized features that were placed in a regional model—without refining the local hydrogeologic conditions in the vicinity of the streams, the model cannot be expected to produce representative discharges. However, because the values from the lower portions of the stream represent discharge from the Prairie du Chien-Jordan aquifer, these discharge values can be used to compare to Layer 3 discharges to the St. Croix River.

Table 5 presents a summary of the analysis of the discharge data for the lower portions of Trout Brook, and Silver, Browns, and Valley Branch Creeks provided by personnel from the St. Croix Watershed Research Station. The range of discharge rates ranges from 1.0 m^3/day-m to 3.9 m^3/day-m, with a mean of approximately 2.3 m^3/day-m. These values will be compared against the discharge computed for the western side of the St. Croix River.

Table 5
Measured Discharge to Lower Reaches of St. Croix River Tributaries

Representing Discharge from the Prairie du Chien-Jordan Aquifer

Stream Name	Curvi String Name	Total Discharge (m^3/sec)	Total Discharge (m^3/day)	Length of Stream Curvi (Arcview) (m)	Discharge per meter Stream Length (m^3/(sec*m))	Discharge per meter Stream Length (m^3/(day*m))
Silver Creek	Silver_Creek	0.024	2074	580	4.14E-05	3.6
Browns Creek	Browns_Creek_1	0.076	6566	1700	4.47E-05	3.9
Valley Branch Creek	Valley_Branch_Main			2640		
	& Valley_Branch_N1	0.060	5184	790	1.75E-05	1.5
	Valley_Branch_S1	0.040	3456	3310	1.21E-05	1.0
Trout Brook	Trout_Brook	0.059	5098	3180	1.86E-05	1.6

The computed discharges from the Northeast Province model are presented in Table 6 for each individual line-sink in each of the three aquifer layers. The computed discharge values for each string are presented in the first three columns. String lengths, estimated using Arcview, are in the next column. The next three columns provide the discharge per unit length for each string, and the sum total discharge from all three layers is presented in the far-right column. As additional data become available, comparisons to the modeled results will be made, and the model will be adjusted accordingly. As shown in the table, the overall mean discharge rate to the western shore of the St. Croix River (curvilinear string ST_CROIX) is 2.62 m^3/day-m, which compares very well to the measured values presented above, which range from 1.0 m^3/day-m to 3.9 m^3/day-m and have a mean of 2.3 m^3/day-m. This agreement indicates that the modeled water throughput in the Prairie du Chien-Jordan aquifer falls well within the range of actual conditions.

Although discharges from Layers 1 and 2 have not yet been directly measured or determined, the favorable comparison of the Layer 3 St. Croix River discharge placed in context of the entire upper three-layer groundwater system, bolsters confidence that the water balance in Layers 1 and 2 is generally representative of actual conditions. This confidence arises from the constraint loosely imposed by the apportionment of recharge to aquifer layers on the basis of relative transmissivity values. If Layer 3 indicates good agreement to water throughput, and the total infiltration is proportionally distributed to the three layers roughly as a function of relative transmissivity values, then we can conclude that the water balance in the upper two layers is also reasonably representative of actual conditions.

Table 6
Modeled Discharge to Curvilinear Linesinks
Northeast Province

Curvilinear String	Modeled Discharge to String (m^3/day)			Approx. String Length (m)	Discharge per unit length (m^3/day-m) for individual aquifer layers			Total Discharge per Length (m^3/day-m)
	Layer 1	Layer 2	Layer 3		Layer 1	Layer 2	Layer 3	
RUM_RIVER	7.22E+05		2.33E+05	84800	8.51	0.00	2.75	11.26
SUNRISE_RIVER	7.95E+04	4.15E+04	3.67E+04	24000	3.31	1.73	1.53	6.57
LAKES-1	1.23E+05	9.97E+04	4.96E+04	23800	5.18	4.19	2.09	11.46
LAKES-2	6.18E+04	1.84E+04	3.01E+04	20190	3.06	0.91	1.49	5.46
CEDAR_CREEK	1.25E+05		5.52E+04	18720	6.66	0.00	2.95	9.61
COON_CREEK	8.66E+04		3.75E+04	32920	2.63	0.00	1.14	3.77
SAND_CREEK	4.13E+04	3.77E+04	1.90E+04	15400	2.68	2.45	1.24	6.36
E_MISSR_UP	1.41E+05			22620	6.23	0.00	0.00	6.23
E_MISSR_ANOKA	4.70E+05		1.01E+05	59420	7.90	0.00	1.70	9.61
E_MISSR_FRIDLEY	9.62E+04	2.86E+04	9.26E+03	19000	5.06	1.51	0.49	7.05
E_MISSR_ST_PETER-1	1.97E+03	1.06E+04	4.61E+04	9800	0.20	1.08	4.70	5.98
E_MISSR_ST_PETER-2	3.51E+04	5.64E+04	1.46E+05	23700	1.48	2.38	6.16	10.03
E_MISSR_SPRINGL-1	3.27E+04	1.65E+04	9.86E+04	21400	1.53	0.77	4.61	6.91
E_MISSR_PRESCOTT-1	9.46E+03	3.08E+03	8.78E+03	4300	2.20	0.72	2.04	4.96
ST_CROIX	4.95E+05	1.27E+05	3.31E+05	126600	3.91	1.00	2.62	7.53
ST_CROIX_EAST			4.82E+04	121000	0.00	0.00	0.40	0.40
VADNAIS_LAKE	4.18E+03			1710	2.44	0.00	0.00	2.44

High Capacity Well Discharge

Following the calibration procedures in which leakage rates were adjusted to fit the model to calibration targets of measured heads and discharge measurements, pumping discharge rates of high capacity wells were entered in the model for the 1995 pumping season. These discharge rates were taken from the Minnesota DNR's groundwater appropriations database, known as the State Water Use Data System (SWUDS). These well extraction rates were included to evaluate their effect on the flow systems and to determine how best to include them in applications of the model.

The addition of the pumping wells to the model affected each layer differently. The mean absolute difference values between modeled and measured heads are given in Table 7 for both the pumped and unpumped conditions. Because the model was already calibrated by adjusting leakage rates before the addition of the high-capacity pumping wells, the mean absolute difference would be expected to increase since the extraction of water from these wells was already intrinsically accounted for in the leakage rates that were used. The more significant the extraction rate is for a layer, the greater the mean absolute difference will be for pumped conditions.

Table 7 indicates a marginal increase in the mean absolute difference in both Layers 1 and 2 with the addition of the pumping wells—only 2 cm for each. Calibration plots for Layers 1, 2, and 3 with the SWUDS wells discharge are presented in Figures 33, 34, and 35, respectively. A comparison of the calibration plots for Layer 1 and 2 to the non-pumped conditions (Figures 27 and 29, respectively) shows little noticeable difference in the calibration plots, consistent with the small difference in mean absolute values. The pumping wells within Layer 1 are distributed over a larger area than for the other layers because many of the wells lie within the Anoka Sand Plain area. Spreading the withdrawals over a larger area will diminish the drawdown effects to the aquifer. Little change was seen in the head distribution of Layer 2 from the addition of the high capacity pumping wells, since only three pumping wells were entered.

Table 7

Mean Absolute Difference Values

	Layer 1	**Layer 1** without St. Croix R. & Odec anomalies	**Layer 2**	**Layer 3**
Without High Capacity Pumping	3.67	2.54	3.55	3.90
With High-Capacity Pumping	3.69	2.56	3.58	5.49

The greatest response to the addition of the high-capacity production wells occurred in Layer 3, evidenced by the increase in the mean absolute difference of greater than 1.5 m, and inspection of the calibration plots with (Figure 35) and without (Figure 31) pumping. The addition of the pumping wells significantly dries the aquifer out. This indicates that the pumping effects of the high-capacity wells in the Prairie du Chien-Jordan aquifer, while very significant, are already reflected in the leakage rates of Northeast Province prior to their inclusion in the model.

In general, pumping extraction is already reflected in the leakage rates that were determined before adding in the high capacity pumping wells. Regional flow and leakage conditions can be better simulated by using these leakage values without explicitly adding the pumped wells. However, the pumping wells will need to be explicitly entered for site-specific models in the area of interest to reflect local flow conditions. Ideally, the model would be calibrated again with the inclusion of the high capacity pumping wells by adjusting the leakage rates. The pumping wells could be placed around the areas of interest along with leaky and/or resistance elements that would replace the given strength elements that are found between aquifer layers. Current resources do not yet permit an additional round of calibration with the inclusion of the pumping wells. Therefore, local modeling should be conducted by 1) including the high capacity pumping wells in the area of interest, 2) adjusting the leakage values locally to recalibrate the model, 3) replacing these given-strength leakage values between aquifers with leaky elements, and 4) proceeding with the local model development.

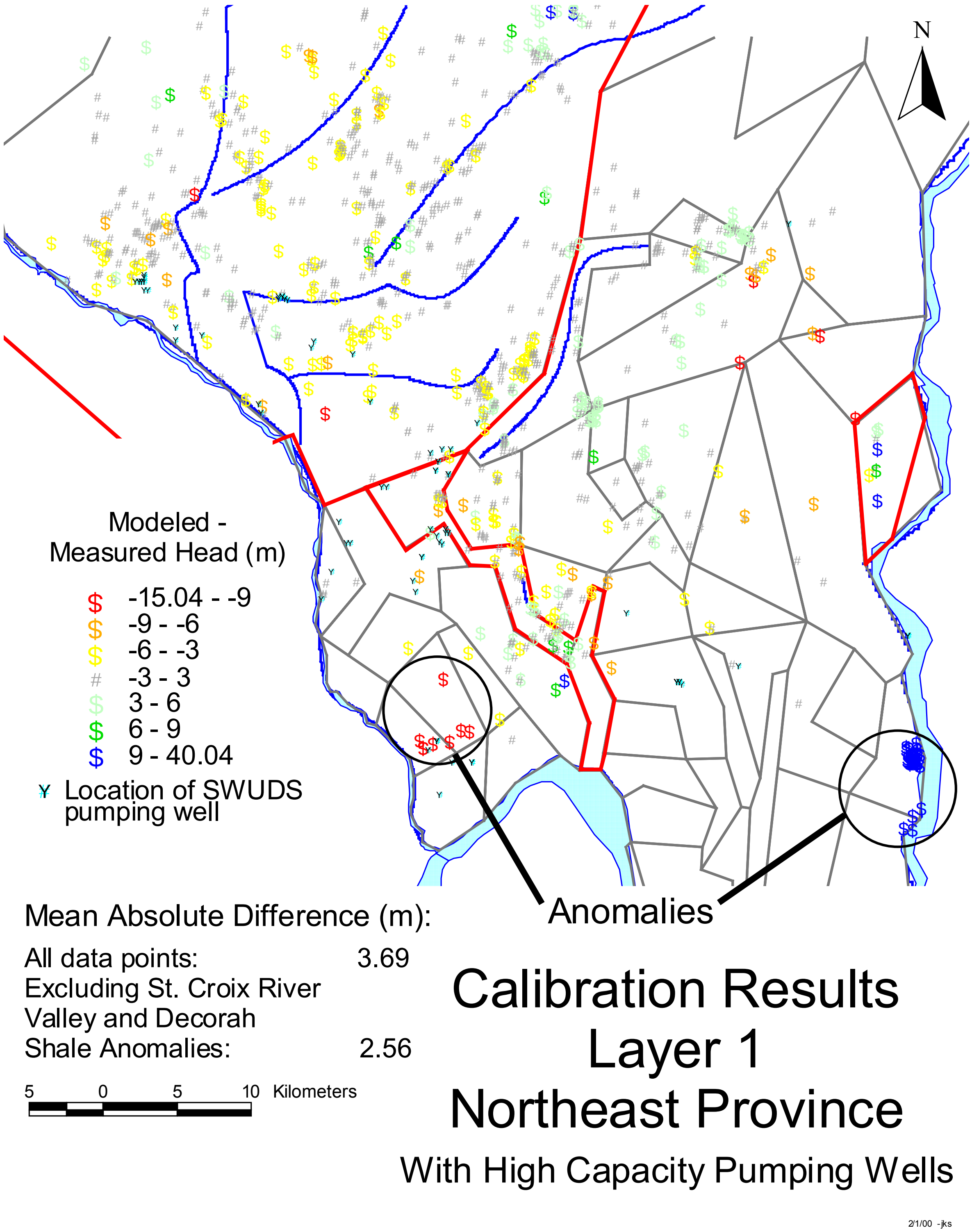


Figure 33. Calibration Plot for Layer 1with SWUDS Wells

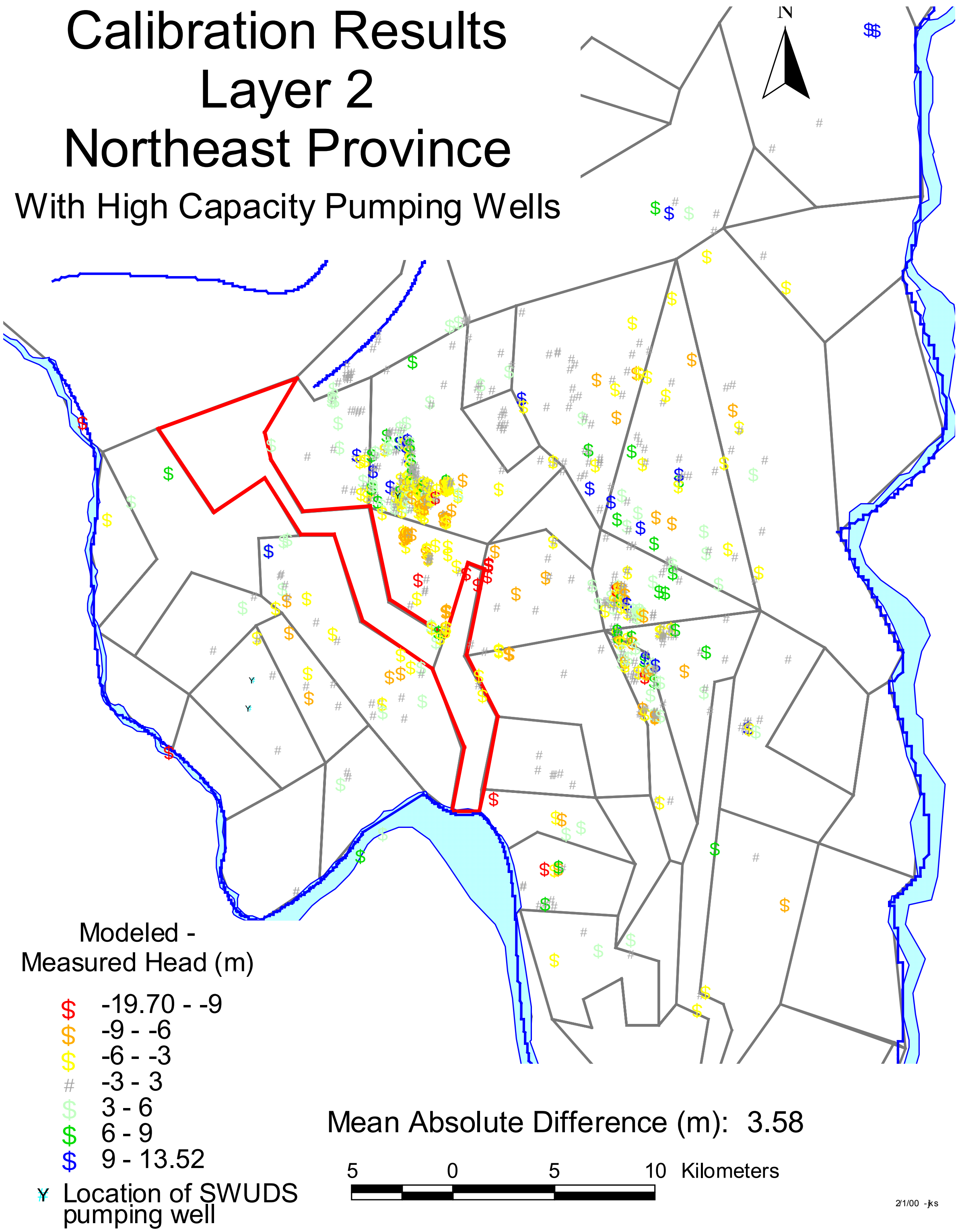


Figure 34. Calibration Plot for Layer 2 with SWUDS Wells

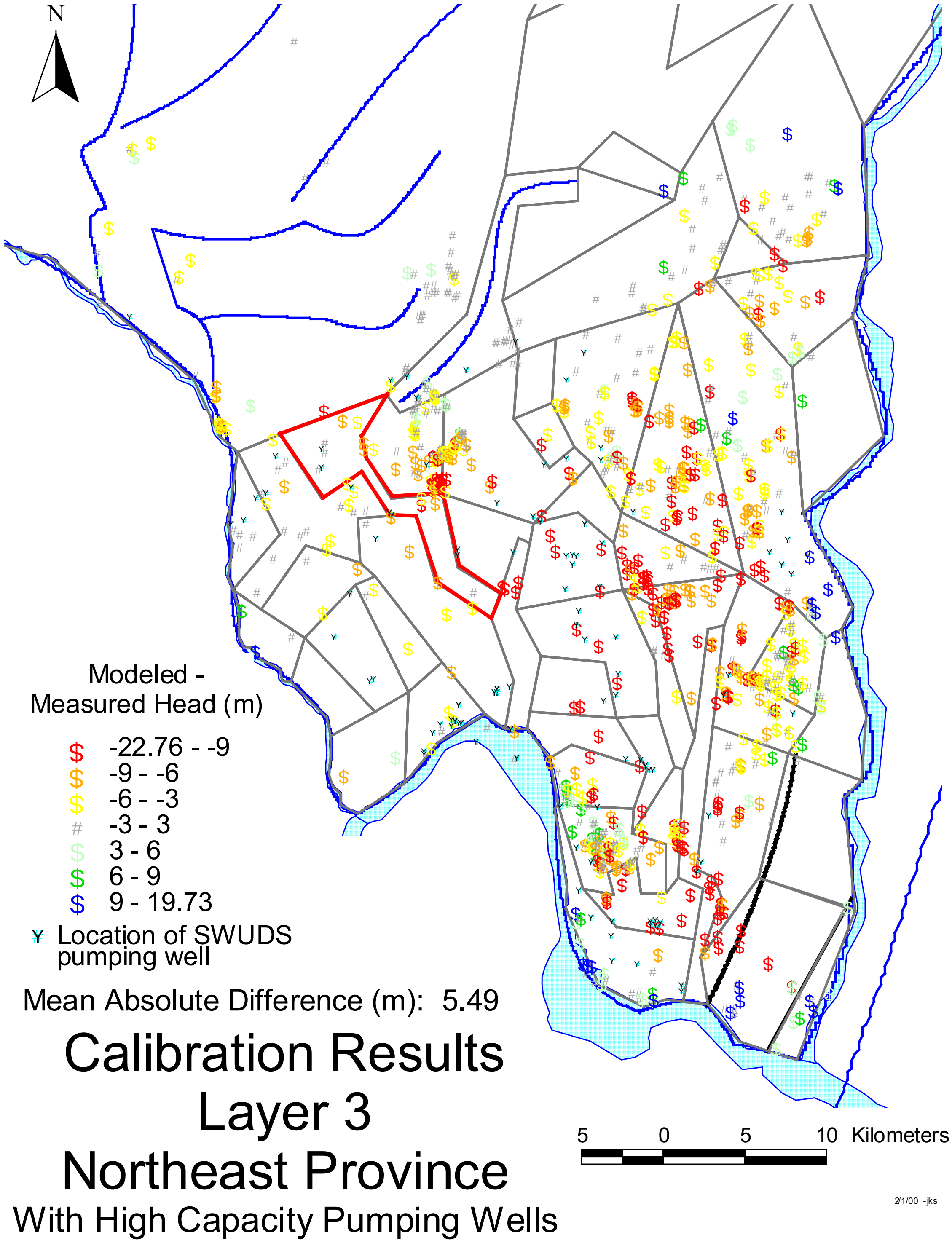


Figure 35. Calibration Plot for Layer 3 with SWUDS Wells

Head Differences—an Internal Consistency Check

Although the current given-strength approach to modeling leakage on a regional basis allows for water to move vertically through the aquifer system, it does not permit simulation of the interactions that occur between aquifers. For example, the effects of pumping in one aquifer will not induce greater leakage from another aquifer using the model with the given-strength approach to leakage. This type of simulation can be achieved by replacing given-strength VARELs with leaky VARELs. In a real aquifer system, flow between aquifers is driven by the head difference between them. However, the given-strength approach does not constrain the model in such a way that groundwater necessarily flows from higher head to lower head between aquifers. Leakage in the Northeast Province has been prescribed as downward in all the polygons. This implies, in a natural system, that heads decrease moving downward through the aquifer system. Zones within the model that have a vertical upward gradient are not congruent with the direction of groundwater flow. Identification of these zones can serve as an indicator of problem areas within the model. Evaluation of the head differences provides a good internal consistency check for the model.

Modeled head values for each aquifer were gridded at a density that readily allows graphical depiction of the head differences between aquifers, which are plotted in the following two figures using a color scheme that was chosen to indicate positive (downward) differences in head between aquifer layers (greater than 3 m), and negative (upward) differences in head (less than -3 m). Head differences implying downward leakage are represented by the pale green to dark blue color scheme, and head differences that would imply upward leakage are represented by the yellow to red color scheme. Increasing color intensity indicates increasing magnitude of the head differences. The gray color-coding represents zones of relatively small head differences (+/- 3 m). Zones represented by gray are not considered to be problematic, even if upward leakage is implied because the model does not generally represent an accuracy level much better than +/- 3 m on a regional scale. Additionally, modifications made to the model for site-specific applications can be used to better match field conditions than is possible on a regional basis.

Figure 36 illustrates gridded differences in head between Layers 1 and 2 in the metropolitan area and implies that leakage driven by head differences would be either downward or neutral except for two areas. This is reasonably consistent with the specified flow directions. The gray area in the central portion of the province indicates that the head difference is less than 3 m, representing relatively neutral conditions. However, moving towards the Mississippi and St. Croix Rivers in the south the head differences are indicative of conditions representing downward flow, with the intensity increasing towards the river. This is attributable to the difference in boundary condition elevations for the two aquifers at the rivers—Layer 1 represents seepage face conditions along the bluffline, and Layer 2 represents the surface water level. Two main areas have head differences that would suggest upward leakage—one at the northwest end of the Phalen bedrock channel, and the other in the north and northeastern portions of the model. However, the Layer 2 St. Peter Sandstone aquifer is essentially absent in these areas, so the data do not really indicate a head difference between the glacial drift aquifer and the St. Peter Sandstone aquifer. Unless Layer 2 in these areas is to be used as a subdivision of the glacial drift aquifer for site-specific modeling, it is hard to attach meaning to the head differences where the Layer 2 aquifer is absent.

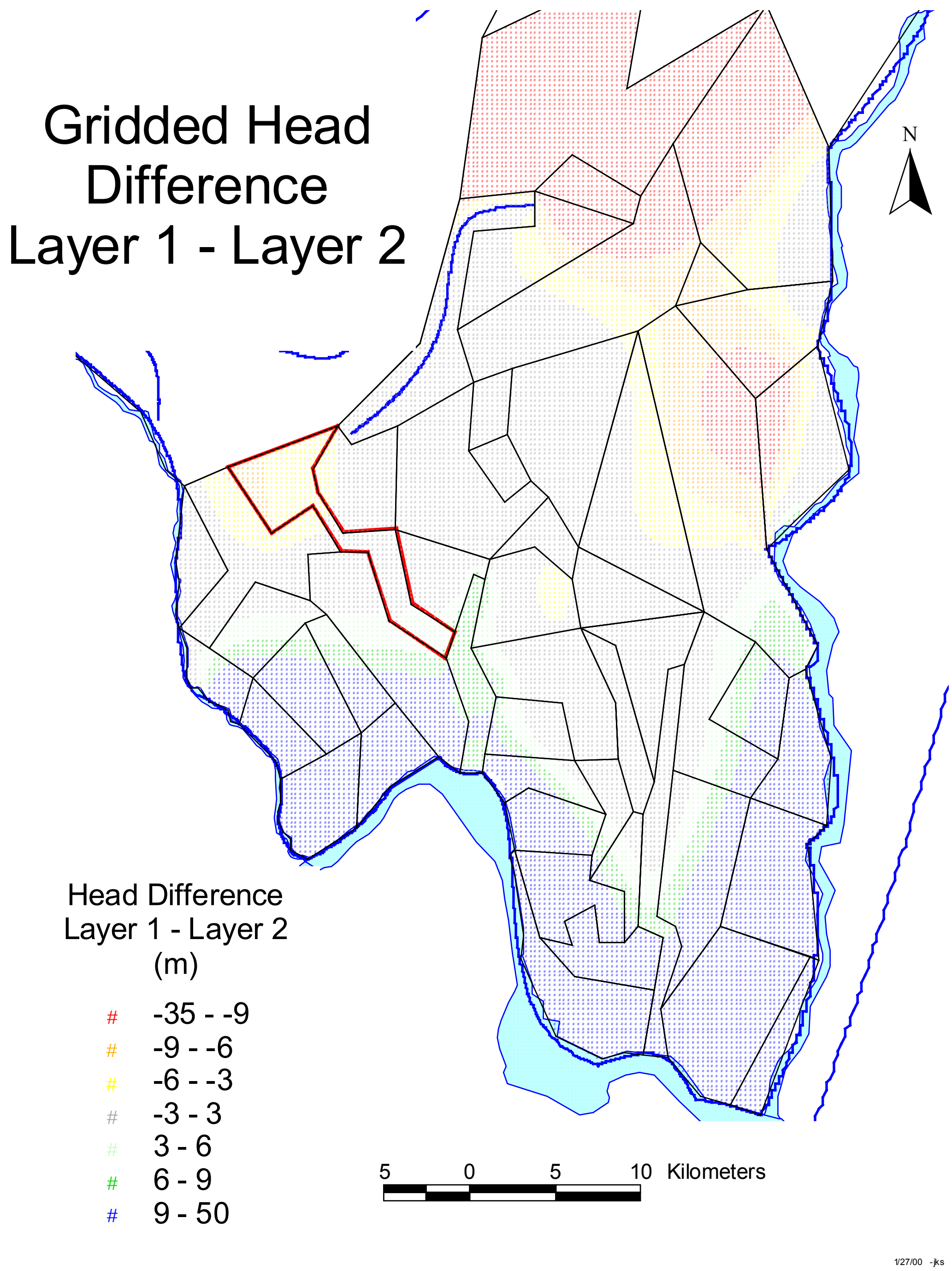


Figure 36. Gridded Modeled Head Difference
Layer 1 – Layer 2

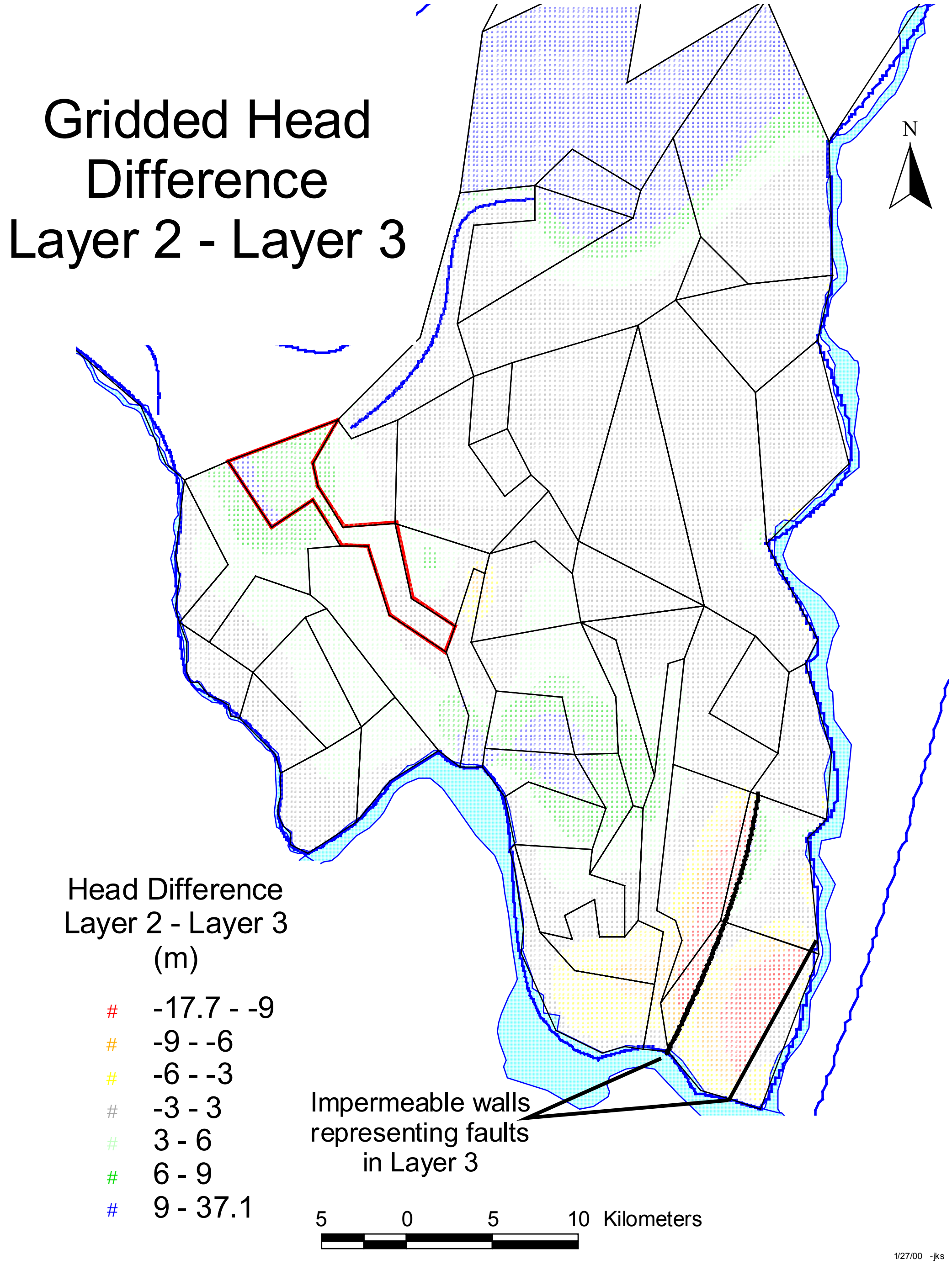


Figure 37. Gridded Modeled Head Difference
Layer 2 – Layer 3

The gridded head difference between Layers 2 and 3 is illustrated in Figure 37, and indicates fairly neutral differences (+/- 3 m) throughout much of the Northeast province. Head differences indicating vertical downward leakage between the two layers is indicated for the western and south-central portions of the Northeastern Province. Again this compares favorably with the leakage directions specified in the model. The presence of the two impermeable walls representing the Hastings and Cottage Grove faults in Layer 3 shows a significant response in the head difference plots. The impermeable walls essentially “dam” up water in the Layer 3 aquifer, causing higher heads on the upgradient side of the wall. The illustration of gridded head difference indicates that the head is high enough that the vertical flow direction would actually be reversed so that water would flow from Layer 3 to Layer 2 in these areas, based on the model. The impermeable walls were included as part of the effort to provide a better calibration to head values. Further investigation is necessary to better characterize the nature of groundwater flow in the area, including interactions between aquifers.

The plots of gridded head differences were constructed as an internal check on the consistency of the Northeast Province model of Layers 1, 2, and 3, and to indicate potential problem areas. Future work should include investigations that will help confirm or refute the findings from the analysis of modeled head differences and help to resolve internal inconsistencies. Site-specific modeling efforts should be conducted in the context of this analysis so that leakage and modeled head differences are consistent with each other.

Data Files, Version 1.00

A brief description of the data files that comprise the Northeast Province model (Version 1.00, January 2000) for Layers 1, 2, and 3 is presented below. A list of other relevant supporting files such as high capacity pumping wells and regional head calibration datasets is found after the model datasets. All of these files can be downloaded from the Metro Model web page.

General Model Datasets:

e_setup.dat	Commands to MLAEM software, and specification of graphical window.
e_aq.dat	Global aquifer parameters for Layers 1, 2, and 3.
polyriv.dat	Polygons defining the Mississippi, Minnesota, and St. Croix River valleys.
e_poly.dat	Polygon mesh for Northeast Province, including both infiltration and inhomogeneity polygons.
e_msr_cu.dat	Curvilinear strings for Mississippi River and associated seepage faces.
e_scr_cu.dat	Curvilinear strings for St. Croix River and associated seepage faces.
e_msc_cu.dat	Curvilinear strings for Rum and Sunrise Rivers; Cedar, Coon, and Sand Creeks; and coarse representations of two lake chains and Lake Vadnais.

Quaternary Aquifer—Layer 1 Datasets

e1_ntop.dat	Infiltration rates for polygons on top of Layer 1; can be considered the total infiltration for the entire three-layer aquifer system.
e1_msr.dat	Boundary conditions (elevation heads) for relevant portions of the Mississippi River and associated seepage faces.
e1_scr.dat	Boundary conditions (elevation heads) for St. Croix River and associated seepage faces.
e1_msc.dat	Boundary conditions (elevation heads) for Rum and Sunrise Rivers; Cedar, Coon, and Sand Creeks, and two lake chains; additionally, given-strength specified for coarse representation of Lake Vadnais.
e1_inh.dat	Hydraulic parameters and doublets for the Anoka Sand Plain, Buried Phalen Channel, and Buried Stillwater Channel Inhomogeneities.
e1_nbot.dat	Leakage out of bottom of Layer 1 specified for each polygon—same as leakage into the top of Layer 2.

St. Peter Sandstone Aquifer—Layer 2 Datasets

e2_ntop.dat	Leakage into top of Layer 2 specified for each polygon—same as leakage out of the bottom of Layer 1.
e2_msr.dat	Boundary conditions (elevation heads) for relevant portions of Mississippi River.
e2_scr.dat	Boundary conditions (elevation heads) for St. Croix River and associated seepage faces.
e2_msc.dat	Boundary conditions (elevation heads) for Sunrise River, Sand Creek, and two lake chains.
e2_inh.dat	Hydraulic parameters and doublets for the Buried Phalen Channel Inhomogeneity.
e2_Q-dom.dat	Estimated discharge rates distributed over a network of domestic wells near North Oaks and south of White Bear Lake.
e2_nbot.dat	Leakage out of bottom of Layer 2 specified for each polygon—same as leakage into the top of Layer 3.

Prairie du Chien-Jordan Aquifer—Layer 3 Datasets

e3_ntop.dat	Leakage into top of Layer 3 specified for each polygon—same as leakage out of the bottom of Layer 2.
e3_msr.dat	Boundary conditions (elevation heads) for relevant portions of the Mississippi River and associated seepage faces.
e3_scr.dat	Boundary conditions (elevation heads) for St. Croix River and associated seepage faces.
e3_msc.dat	Boundary conditions (elevation heads) for Rum and Sunrise Rivers; Cedar, Coon, and Sand Creeks, and two lake chains.

e3_inh.dat	Hydraulic parameters and doublets for the northern portion of the Buried Phalen Channel Inhomogeneity.
e3_wall.dat	Impermeable walls representing offset from the Hastings and Cottage Grove Faults.

Call File for Northeast Province Layers 1, 2, and 3 Model

callne.dat	Version 1.00 call file dataset for the Northeast Province Layers 1, 2, and 3; calls the model datasets described above.

The files described above are all that are needed to run the Northeast Province model of Layers 1, 2, and 3. However, some additional files presented below may be of use to the modeler. High capacity well discharge data and head calibration datasets are discussed separately below.

High Capacity Well Discharge

Datasets with high-capacity discharge data were constructed from the DNR's groundwater appropriations database known as the State Water Use Data System (SWUDS) for the 1995 pumping year. Datasets for other years can be constructed on request. These datasets are to be entered separately. As previously mentioned, Version 1.00 of the model already includes these discharges intrinsically in the infiltration rates on a regional basis. The files are split up according to model layer:

e1_qswud.dat	High capacity pumping well discharge in the Glacial Drift Aquifer taken from the 1995 SWUDS database; for use in Layer 1.
e2_qswud.dat	High capacity pumping well discharge in the St. Peter Sandstone Aquifer taken from the 1995 SWUDS database; for use in Layer 2.
e3_qswud.dat	High capacity pumping well discharge in the Prairie du Chien-Jordan Aquifer taken from the 1995 SWUDS database; for use in Layer 3.

Regional Calibration Datasets

Calibration datasets that were constructed to calibrate the model on a regional basis are included below. As described in the Overview of the Twin Cities Metropolitan Groundwater Model, these data were geostatistically winnowed from CWI database to provide head calibration targets over a very large area. As such, these data can only be appropriately applied to regional model development and calibration. Site-specific data are necessary for calibrating the locally refined model. The datasets are split up according to model layer:

e1_cal.dat	Head calibration dataset for Layer 1, developed from measured static water levels in the Glacial Drift Aquifer.
e2_cal.dat	Head calibration dataset for Layer 2, developed from measured static water levels in the St. Peter Sandstone Aquifer.
e3_cal.dat	Head calibration dataset for Layer 3, developed from measured static water levels in the Prairie du Chien-Jordan Aquifer.

Application and Use of the Metro Model

The Northeast Province portion of the Metro Model for Layers 1, 2, and 3 has been presented as a starting point for constructing models on a more local scale. A regional system has been developed that will require modification to local scale models for two reasons. First, on a regional basis, the model will not provide a correct coarse representation of the flow system in all areas. Use of all available data on a more local basis will help lead to a better representation. Second, local detail will need to be incorporated to properly simulate local groundwater flow conditions.

Model elements themselves will require modification and/or replacement for more site-specific modeling. For example, order and overspecification values will likely need to be increased on both curvilinear elements and doublets in the area of interest to provide sufficient control to model the groundwater system. Also, multi-aquifer systems will require replacement of given-strength areal elements with leaky elements, which can actually propagate hydraulic interactions between aquifers. Additionally, control point placement is critical to properly simulate leakage effects between aquifers. Metro Model staff can provide guidance for applications of the model.

Changes and improvements are expected to the model. They will be periodically posted on this web site. To ensure that you are using the latest version of the Metro Model, be sure to frequently check it. The version currently posted is 1.00. The version number for future releases will be incrementally increased and will readily allow users to determine if they are using the most current version available.