Environmental Analysis of Well Water in Mecosta County: A Comprehensive and Integrated Approach (Year 2)

A Final Report Submitted To:

The Fremont Area Community Foundation

Submitted by the Annis Water Resources Institute
Grand Valley State University

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Narrative

1. Describe the project or program and location in which grant funds were used including dates of service, population and number served, activities completed, supplies/equipment purchased, staff involved, and any other concrete data regarding the grant:

This project consisted of three main goals: 1) creating a GIS (Geographic Information System) database of groundwater information in Mecosta County; 2) sampling a statistically-determined subset of wells for water quality and coliform bacteria; and 3) developing a conceptual groundwater model for the region.

Our work plan consisted of six tasks. This project was conceived and developed as a two-year commitment, as we first needed to collect information in Year 1 to complete the remaining tasks in Year 2. The Year 1 report was submitted in March, 2004. The current Year 2 report provides a brief overview of the tasks completed during Year 1, but focuses primarily on the tasks accomplished from April 2004 through March 2005 (but note that the final workshop will take place in May, 2005). Below we list each task and provide the relevant information requested:

Task 1: Host kick-off meeting(s) in Mecosta County (Year 1)

This task was completed with the project partners identified in our proposal on April 8th, 2003 at Ferris State University's Community Building in Big Rapids. More detail is provided in the Year 1 report. A second public meeting was held on June 24, 2003 also at Ferris State University's Community Building. Kurt Thompson from AWRI gave the presentation.

In addition, AWRI staff have presented the scope and findings of the Ice Mountain project on several occasions, adding value to the original project. These presentations include Science Scholarship Day and GIS Day at Grand Valley State University, classes relating GIS to Public Administration, Geography and Natural Resource Management at Grand Valley State University, and to MDEQ's Groundwater Advisory Council.

Task 2: Create a GIS data base

At the start of the groundwater project, AWRI staff collected all the digital well information for Mecosta County that was available from the Michigan Department of Environmental Quality (MDEQ). The data were downloaded from the Michigan Geographic Data Library at the Center for Geographic Information (www.michigan.gov\cgi). This initial dataset held 1753 well locations with information regarding well depth and static water level, but did not catalog the actual water source (aquifer) or the individual sub-surface formation descriptions, thicknesses, or depths for each well. This stratigraphic information detailing the "geology" of each water well was a critical component to the construction of the conceptual model for the sub-surface water resources of the project area (Task 4).

Approximately 1200 of the 1753 well points were matched to their unique drilling record using the MDEQ's scanned water well records, but the remaining records could not be found. Initially, staff considered searching the District #10 Health Department files to potentially recover these missing records but after a discussion with the project's health department contact, it was decided that the time involved in completing such a search, coupled with the unknown quality of these water records, would result in a non-productive use of project resources. Instead, in the interest of both time and efficiency, staff chose to concentrate their labors on searching for additional well records from an existing and accessible data source: www.deq.state.mi.us/well-logs. This MDEQ-hosted Internet site contains the scanned drilling records of over 1 million water wells, archived by county, and separated by the U.S. Public Land System of tier, range, and section numbers. Staff first created a map characterizing the spatial distribution of the 1200 matched well records in Mecosta County. This map was used both to illustrate the distribution of wells in the project area where groundwater data were available, and to highlight areas where data were lacking. Using the map as a guide, staff completed a focused and systematic search through thousands of well records in Mecosta County and downloaded all the available records for these areas. Altogether, a total of 1469 well records were retrieved, given point locations, and entered into the groundwater database.

To prepare the groundwater data for Task 4, the digital database was separated by each well's aquifer source. Groundwater wells were split into those that were constructed in the "free" or unconfined water table and those that were completed in an aquifer that was confined by geologic layer(s) of a relatively low permeability. The vast majority of the 1469 wells entered into the digital groundwater data were wells finished in the confined glacial drift aquifer. The unconfined glacial drift aquifer wells (470 total) were split out of the groundwater database and placed into classes based upon the year the well was constructed. These subsets of digital unconfined water wells were given to Dr. Michael Chu and used in conjunction with other GIS data to produce the conceptual groundwater model. The unconfined groundwater level contours generated as part of the modeling process were converted into a GIS data layer to provide groundwater flow direction within the project area. This data layer will be included with all the other final GIS datasets for distribution to project partners.

Task 3: Sampling Wells, Sample Analyses, Data Processing, Results and Discussion

The objective of this task was to identify a subset of "approved" well taps with the District #10 Health Department that would provide a reasonable geographical representation of Mecosta County within the Muskegon River Watershed, perform groundwater sampling and analysis from those taps, examine and interpret the data, and search for patterns in their distribution and any correlations to land use.

Selection of Wells and Sample Collection in the Field

During the spring of 2003, sample locations for all existing digital public water supplies were mapped using ArcView GIS software to assist in identifying wells for sampling. AWRI personnel met with the District #10 Health Department to select suitable field locations based on geographic location and previous water quality and bacteriological data from archived well records. As a result, 70 Type II Non-community well supplies were identified for collection of samples. (A noncommunity water supply, otherwise known as a type II water supply, serves any nonresidential facility that provides water for drinking or domestic purposes to 25 or more persons at least 60 days of the year or has 15 or more service connections. Examples include motels, factories, schools, restaurants, campgrounds, churches, and businesses that have their own water supply and serve 25 or more people per day). The name and location of each sample point is presented in Figure 1 (well location map) and Table 1. As directed by District #10, owners of well taps were not given notice prior to groundwater sampling.

During the summer of 2003 and 2004, AWRI personnel collected samples from 49 wells in 2003 and 21 wells in 2004, for a total of 70 samples. Sampling was conducted only from the approved taps, and not from hoses. As specified by District #10 Health Department procedures, water was allowed to run at full flow for 5-10 minutes to flush stagnant water before collecting the samples. After flushing, a sample was collected for immediate direct measurements of pH, specific conductance, oxidation-reduction potential (ORP), turbidity, temperature, dissolved oxygen, and total dissolved solids (TDS) using a Hydrolab DataSonde 4a in the field. At the same time, samples for subsequent laboratory analyses were collected in 3 separate containers: two 18 oz. sterile Nasco Whirl-Pak™ bags for microbiological and dissolved organic carbon (DOC) analyses, and one pre-cleaned 500 ml plastic bottle for all other analytical parameters. All samples were kept on ice in coolers and hand delivered to AWRI laboratories within 4 hours of collection.

Table 1. Type II Non-community wells sampled for groundwater and their 1998 Land Use Classification.

Sample #	Sample Location Name	Address	1998 Land Use	AWRI No.	Sampling Date
1	Roben Hood Airport	21325 18 Mile Rd	Transportation	10562	7/21/03
2	Roben Hood Airport	21326 18 Mile Rd	Transportation	10563	7/22/03
3	Roben Hood Airport	21327 18 Mile Rd	Transportation	10564	7/23/03
4	Roben Hood Airport	21328 18 Mile Rd	Transportation	10565	7/24/03
5	Hanson Amoco	19585 30th Ave	not available	10680	7/29/03
6	Haymarsh Lakes	Dam Access Rd	Broadleaf Forest	10681	7/29/03
7	Borland BP	4847 Northland Dr	Shrub Rangeland	10708	7/31/03
8	Wheatland Township Park	405 Sheridan	not available	10709	7/31/03
9	Mecosta Township Hall	19729 11 Mile Rd	Residential	10776	8/5/03
10	Stanwood Buffalo Park	Stanwood Dr	Open & Other	10777	8/5/03
11	Northland United Meth. Church	6842 Northland Dr	Comm., Svcs, Instit.	10778	8/5/03
12	Kinney Park	White Pine Trail	Comm., Svcs, Instit.	10779	8/5/03
13	Mecosta Pines Campground	550 Talcott	Coniferous Forest	10780	8/5/03
14	Country Daycare	9052 11Mile Rd	Comm., Svcs, Instit.	10811	8/6/03
15	Mayfair Clubhouse	Mayfair	Open & Other	10812	8/6/03
16	MDOT-Big Rapids	Southbound US-131	Transportation	12666	6/15/04
17	Brockway Wesleyan Church	10951 3 Mile Rd	Comm., Svcs, Instit.	10814	8/6/03
18	Hearts of the Lake Plaza	10981 90th Ave	Coniferous Forest	10815	8/6/03
19	St. Michaels Cath. Church	5045 9 Mile Rd	Comm., Svcs, Instit.	10825	8/7/03
20	Antlers Lakeside Restaurant	10107 Buchanan	Herbaceous Rangeland	10826	8/7/03
21	Wheatland Church of Christ	3025 11 Mile Rd	Comm., Svcs, Instit.	10827	8/7/03
22	School Section Lake Park	9003 90th Ave	Residential	10828	8/7/03
23	New Hope United Meth. Church	7296 9 Mile Rd	Comm., Svcs, Instit.	10829	8/7/03
24	Sarns Resort Well 2	4398 Newcosta Rd	Broadleaf Forest	10830	8/11/03
25	Parkers Landing	22265 8 Mile Rd	Herbaceous Rangeland	10831	8/11/03
26	Luther Bible School	1018 230th Ave	Herbaceous Rangeland	10832	8/11/03
27	Grange General Store	20751 8 Mile Rd	Comm., Svcs, Instit.	10833	8/11/03
28	Ruddy Dux	20055 8 Mile Rd	Comm., Svcs, Instit.	10834	8/11/03
29	Seasons Country Inn	10431 Northland Dr	Comm., Svcs, Instit.	10835	8/11/03
30	Northland Riverside Park	4th Street	Shrub Rangeland	10864	8/12/03
31	Trailside BP	525 3rd Street	Comm., Svcs, Instit.	10865	8/12/03
32	PT Plus	15200 220th Ave	Comm., Svcs, Instit.	10866	8/12/03
33	Dagget-Gilbert Funeral Hm	13985 Northland Dr	Comm., Svcs, Instit.	10867	8/12/03
34	FSU Katke Golf Course	1003 Perry Street	Open & Other	10868	8/12/03
35	Meceola Country Club	14777 150th Ave	Open & Other	10902	8/13/03

Table 1 cont'd. Type II Non-community wells sampled for groundwater and their 1998 Land Use Classification.

Sample #	Sample Location Name	Address	1998 Land Use	AWRI No.	Sampling Date
36	Wheatland Township Library	207 Michigan Ave	Residential	10903	8/13/03
37	Camp Brethern Heights	9478 Brethern Hgts	Residential	10904	8/13/03
38	Mecosta County Senior Center	12594 80th Ave	Comm., Svcs, Instit.	10905	8/13/03
39	Chippewa Hills Bus Garage	2950 Arthur Rd	Cropland	10906	8/13/03
40	First Baptist Church	248 Cass Street	Residential	10949	8/19/03
41	Stanwood Free Methodist Ch.	7456 Stanwood Dr	Comm., Svcs, Instit.	10950	8/19/03
42	Morton Township Library	110 James Street	Comm., Svcs, Instit.	10951	8/19/03
43	Rogers Heights Christian Church	19938 Park Rd	Residential	10952	8/19/03
44	Chapel of the Lakes Luth. Ch.	9407 90th Ave	Residential	10953	8/19/03
45	Currie's Amoco	620 Maple	Comm., Svcs, Instit.	10975	8/21/03
46	Perry Street Mobil Mart	21380 Perry Street	Comm., Svcs, Instit.	10976	8/21/03
47	Riverside Camp	14161 Millpond Rd	Residential	10977	8/21/03
48	Bare Furniture	20979 19 Mile Rd	Residential	10978	8/21/03
49	Pappy's	12085 McKinley	Comm., Svcs, Instit.	10979	8/21/03
50	Speedway	19246 Northland Dr	Herbaceous Rangeland	10980	8/21/03
51	American Legion 554		Herbaceous Rangeland	12706	6/16/04
52	Thermo Gas Company	10029 30th Ave	Comm., Svcs, Instit.	12813	6/24/04
53	Wheatland Music Organization		Cropland	12707	6/16/04
54	Stone Hill Vet Clinic	15906 165th Ave	Comm., Svcs, Instit.	12665	6/15/04
55	Reith-Riley Construction		Herbaceous Rangeland	12724	6/17/04
56	St. Anne Church	23770 2 Mile Rd	Broadleaf Forest	12668	6/15/04
57	Crittenden-Hansen Funeral Hm	469 Wheatland	Residential	12705	6/16/04
58	Northern Shores	9965 11 Mile Rd	Residential	12815	6/24/04
59	MOARC Workshop	21685 Northland	Comm., Svcs, Instit.	12725	6/17/04
60	Buck's Camping	21965 8 Mile Rd	Residential	12703	6/16/04
61	Pizza in Paris	21970 Northland	Comm., Svcs, Instit.	12667	6/15/04
62	Corner Café	6 Front St.	Comm., Svcs, Instit.	12722	6/17/04
63	New Directions	21485 15 Mile Rd	Herbaceous Rangeland	12723	6/17/04
64	Austin Township Hall		Broadleaf Forest	12814	6/24/04
65	Green Township Hall		Residential	12816	6/24/04
66	Morton Township Hall		Comm., Svcs, Instit.	12812	6/24/04
67	Big Rapids Assembly of God	14200 Northland	Comm., Svcs, Instit.	12669	6/15/04
68	Adventure Island	9747 90th Ave	Recreational, open use	12704	6/16/04
69	University Chevrolet	14061 Northland	Comm., Svcs, Instit.	12817	6/24/04
70	Moe-Z-Inn	249 Cass	Comm., Svcs, Instit.	12721	6/17/04

Sample Analyses at AWRI Laboratories

Groundwater samples collected from the Mecosta County wells were analyzed for relevant chemical and microbiological parameters using standard protocols (APHA 1992) and modified methods (see below). The aquatic microbial ecology lab at AWRI led by Dr. Bopi Biddanda completed the analyses of all groundwater samples for bacteria and carbon content, with assistance from laboratory technician, Scott Kendall. In particular, we standardized the method for visualization of low abundances of groundwater bacteria by epifluorescence microscopy, and developed the method for analysis of low concentrations of DOC in groundwater by high temperature catalytic oxidation. The Environmental Chemistry lab at AWRI led by Dr. Rick Rediske completed the analyses of parallel well water samples for a suite of inorganic nutrient species (Cl, SO_4, NO_3-N, NH_3-N, TKN-N, SRP-P, TP-P) as well as *E. coli*. The list of analytical parameters and methods is presented in Table 2.

Table 2. Analytical parameters and methods of groundwater analyses.

Parameter	Method
Chloride (Cl)	Standard Method 4110C
Sulfate (SO_4)	Standard Method 4110C
Nitrate-Nitrogen (NO_3-N)	Standard Method 4110C
Ammonia-Nitrogen (NH_4-N)	Standard Method 4500-NH_3 H.
Total Kjeldahl Nitrogen (TKN-N)	Standard Method 4500-Norg B.
Soluble Reactive Phosphorus (SRP-P)	Standard Method 4500-P F.
Total Phosphorus (TP-P)	Standard Method 4500-P F.
E. coli	EPA Method 1103.1 (mTEC Agar)
Total Bacteria	Microscopic Count of AO-stained cells (modified)
Dissolved Organic Carbon (DOC)	High Temperature Catalytic Oxidation (modified)

For the determination of total bacteria, a 5-ml aliquot of each water sample was preserved with 2% final concentration of 0.2 µm-filtered formaldehyde. A 1-3 ml aliquot was stained with acridine orange, filtered onto 0.2 µm black Millipore polycarbonate filters, mounted on slides, and frozen (-80 ^oC) until observation by epifluorescence microscopy (Hobbie et al 1977). A range of 20-40 fields of view was examined for every sample.

Samples for DOC analysis were filtered through pre-combusted (4 h at 450 ^oC) Whatman GF/F glass fiber filters directly into pre-combusted glass vials (4 h at 550 ^oC), sealed with Teflon-lined caps, and stored frozen until analysis. DOC concentrations were determined by high temperature (680 ^oC) oxidation with a Shimadzu TOC 5000 carbon analyzer (Benner and Strom 1993).

Principal components analysis (PCA) was used to search for gradients in water quality data (cf. Tables 3 and 4) that could be attributed to the 1998 land use for each respective well. PCA is a multivariate data-reduction technique that combines many parameters into single principal component scores. These scores are then plotted in one, two or three dimensions to graphically represent the data. This analysis also plots the variables in the same space so that associations can be drawn between sites and specific parameters. A plot of principal component scores can then be color-coded by factors of interest (i.e. land use and cover, lithology, ecoregion, biotic attributes, etc.). If patterns emerge based on the factor being evaluated, an association between that factor and the variables contributing strongly to the direction of the gradient can be hypothesized.

Results and Discussion

The physical, chemical, and microbiological data from the groundwater samples collected from selected Mecosta County wells are presented in Tables 3 and 4. These data include the abundance of heterotrophic bacteria (i.e., total bacteria) in the ground water and the concentrations of DOC, various nitrogen and phosphorus components, and *E. coli*. All observed values for these parameters are quite low (compared to surface waters), typical of undisturbed groundwater (Chapelle 1993), and showed little if any correlation between the biota (heterotrophic bacteria), dissolved nutrients, and land use. Of the parameters measured, MDEQ regulates nitrates and *E. coli* for safe drinking water (Michigan's Safe Drinking Water Act, 1978*)*. Comparing the data to maximum contaminant levels (MCL) set by MDEQ, all samples were below MCLs for *E. coli* (<1 positive sample) and, in 69 of the 70 wells sampled, for nitrates (<10 mg/L).

One well, located at Thermo Gas Co. (AWRI sample point no. 52)**,** exceeded the MCL for nitrates. In this sample, nitrate (as nitrogen) was detected at 14.2 mg/L compared to the MCL of 10 mg/L (Table 4). Also of note was that groundwater from this well had a pH of 5.0, the lowest pH of all the wells, suggesting that the aquifer is mostly sand and lacks the buffering capacity associated with glacial till. High nitrogen content of groundwater can result from various human activities such as: leaching from landfills, agriculture, accidental chemical spills, mining, leakage of septic tanks, highway de-icing, and others (Canter and Knox 1986). Additional information related to well depth, distance from potential sources (agriculture and septic systems), and aquifer materials would be required to determine the cause of the elevated nitrate levels. However, at the time of this report, the water supply from this well cannot be properly evaluated on the basis of one laboratory sample alone. For example, it is not known whether the sample was collected following an appreciable rain event, which temporarily could flush higher nitrate levels into the groundwater. Furthermore, it could be a natural consequence of dissolution of high nitrate-containing sediments in this particular site.

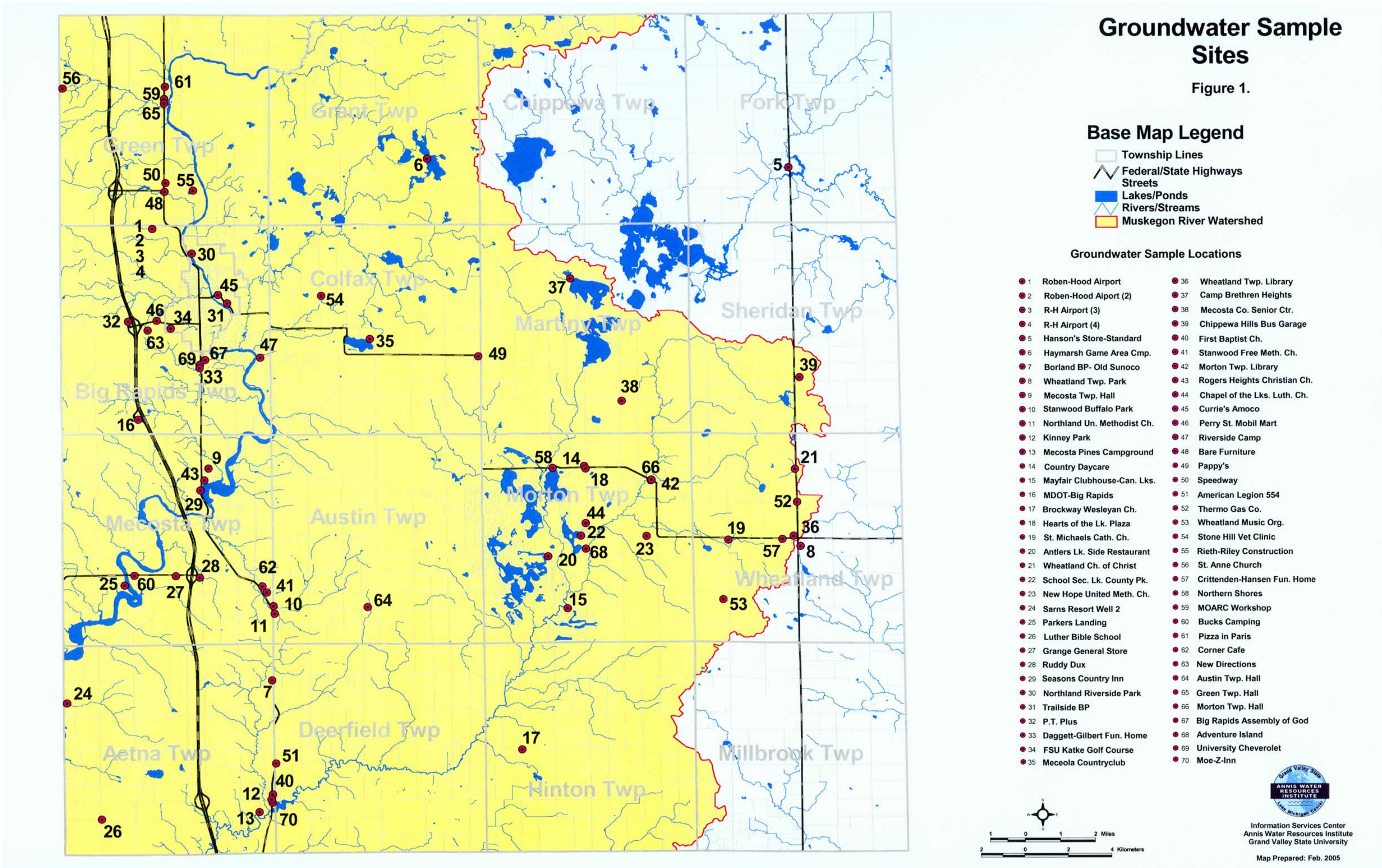
In all, a total of 5 wells had nitrates exceeding 5 mg/L. In addition to Thermo Gas Co., other wells included Northern Shores (9.1 mg/L; Sample #58), Green Township Hall (8.4 mg/L; Sample #65), Meceola Country Club (8.3 mg/L; Sample #35), and Pappy's (6.2 mg/L; Sample #49) (Table 4). Non-community public water supplies are required by law to sample at least once every year for nitrates, but if results exceed 5 mg/L for nitrate, quarterly sampling is required. However, for the same reasons explained above, the water supply from these wells cannot be properly evaluated on the basis of one laboratory sample. It would be useful to locate any existing historic data for these 5 wells to see if this is a one-time occurrence, or if there is a trend of high nitrate content in these wells. At present, we could observe no correlation between the locations of these 5 wells, nitrate levels, and the 1998 land use classification (Figs. 2 and 3).

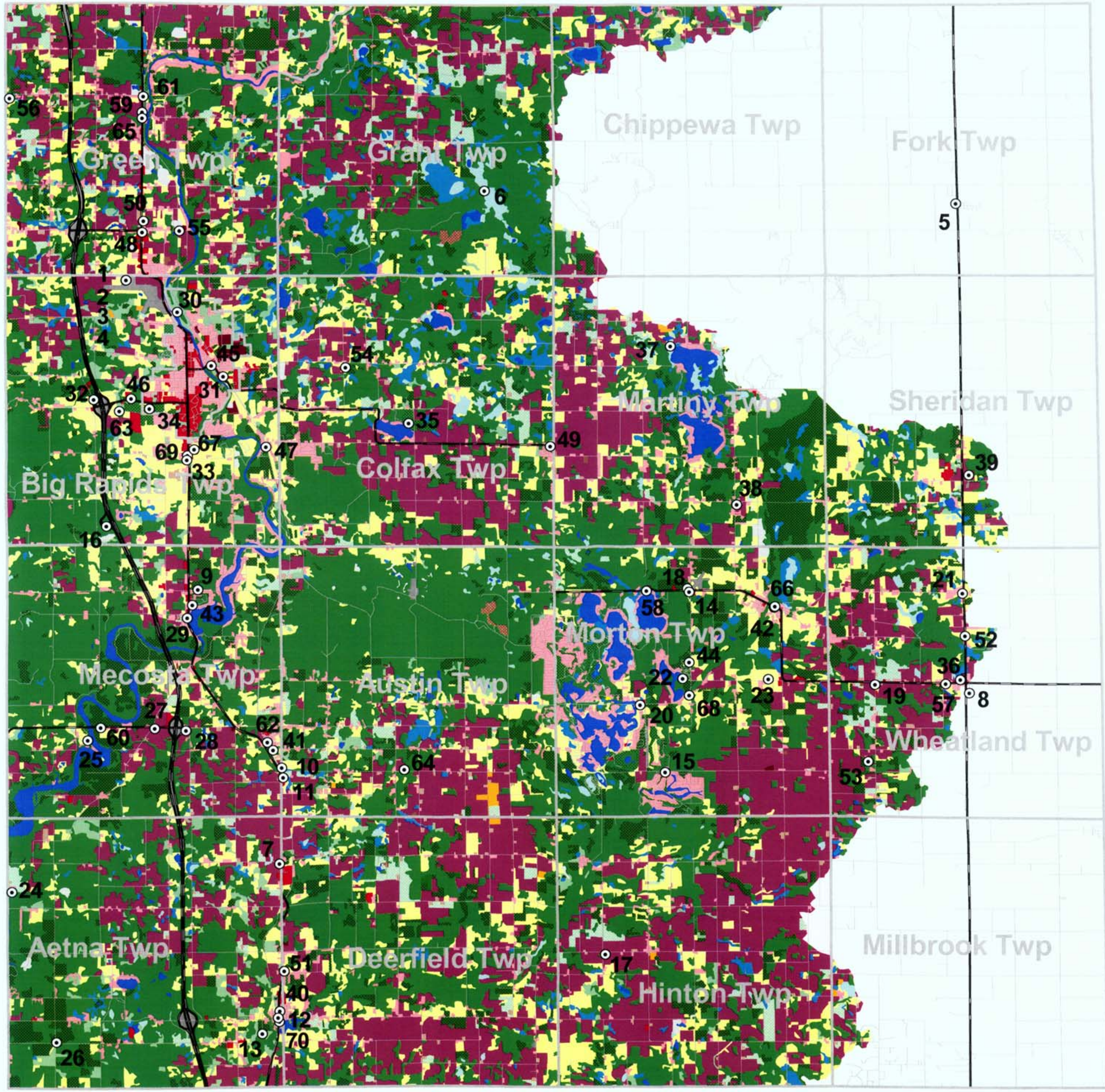
Nitrogen and phosphorus are essential nutrients for microbial growth, but high concentrations in groundwater can present environmental problems such as excessive microbial growth and algal blooms when groundwater discharges to the surface. Studies in Iowa have shown that groundwater discharge can sustain elevated levels of phosphorus in adjacent surface streams and lakes (Burkart et al. 2004). In the Mecosta County well samples, these nutrients were at quite low levels overall (Table 4). Nitrates were below detection limits in 32 of the 70 samples. Detectable nitrate levels ranged from 0.01-14.21 mg/L with an average of 1.9 mg/L. Total nitrogen (i.e., TKN + NO_3) ranged from 0.05-14.21 mg/L with an average of 1.2 mg/L. Nitrates were the most prevalent form of nitrogen in the samples. Total phosphorus (TP) was present in much lower levels with a range of 0.01-0.05 mg/L with an average of 0.02 mg/L. TP was not detected in 22 of the 70 samples. Soluble reactive phosphorus (SRP) was not detected in 54 samples, and when detected, was the most prevalent form of phosphorus.

DOC can be used to indicate the level of organic loading in a groundwater ecosystem. DOC is naturally derived from the breakdown of organic matter (plant and animal material); however, high levels of DOC can be indicative of organic (waste) pollution. The levels of DOC found in groundwater are influenced by hydrologic linkage between soils and groundwater (Baker et al. 2000), land use, rain events, and snow melts. Groundwater samples collected from Mecosta County wells had DOC levels from 0.58-4.33 mg/L (Table 4), which are typical levels for non-polluted aquifers (Chapelle 1993). No obvious spatial pattern appears to exist for DOC concentrations among the wells in the region, suggesting that concentrations are influenced more strongly by localized activities than regional influences (Figure 4).

While *E. coli* was not detected in the groundwater samples, bacteria were present in all wells at levels ranging from 10^6 to 10^7 cells per 100 ml (Table 4). These are normal levels for groundwater (Ghiorse and Balkwill 1983; Cullimore 1993) and fall below the 10^7 to 10^8 cells per 100 ml typically found in surface waters (Biddanda et al. 2001). It is generally recognized that microorganisms, especially heterotrophic bacteria, do occur naturally within shallow groundwater systems. These bacteria can provide beneficial functions such as degradation of organic matter, including breakdown of organic pollutants, which may filter into groundwater (Chapelle 1993). However, the presence of certain types of microorganisms (e.g., coliforms), and the existence of conditions promoting excessive microbial growth, are potential indicators of concern in a particular groundwater ecosystem. We compared total bacteria to DOC, nutrients, and all other parameters including land use and found no significant correlations. Indeed, the correlation coefficient for total bacteria vs. nitrate (Fig. 5) was only 0.0058, whereas that for total bacteria vs. DOC was still very small (0.0144; Fig. 6). Also, there was no observed relationship between well locations and total bacteria (Fig. 7). In surface waters, there is a positive relationship between bacterial abundance and DOC concentrations (Biddanda et al. 2001) – but no such relationship could be observed in the groundwater data set studied here. It is worth noting that the bacteria detected in this study are from groundwater samples only and do not account for the many microorganisms existing in an attached state to aquifer sediments. This is likely one of the reasons why there were no significant correlations between total bacteria and other physicochemical parameters.

A wide range of pH (5.0 to 8.5) was measured in the well samples (Table 3). These pH ranges are not uncommon for groundwater, even in pristine environments. High pH could result from natural carbonate-buffered systems associated with glacial till, whereas low pH can result from microbial processes such as the fermentation and oxidation of sulfides. Shallow aquifers containing sand also tend to have lower pH values due to limited buffering capacity and the fact that they are rapidly recharged by rainwater.


Groundwater Sample Sites
Figure 1.
Grant Twp
Chippewa Twp
Fork Twp
Green Twp
Colfax Twp
Martiny Twp
Sheridan Twp
Big Rapids Twp
Morton Twp
Mecosta Twp
Austin Twp
Wheatland Twp
Deerfield Twp
Aetna Twp
Hinton Twp
Millbrook Twp
Base Map Legend
Township Lines
Federal/State Highways
Streets
Lakes/Ponds
Rivers/Streams
Muskegon River Watershed
Groundwater Sample Locations
1 Roben-Hood Airport
2 Roben-Hood Aiport (2)
3 R-H Airport (3)
4 R-H Airport (4)
5 Hanson's Store-Standard
6 Haymarsh Game Area Cmp.
7 Borland BP- Old Sunoco
8 Wheatland Twp. Park
9 Mecosta Twp. Hall
10 Stanwood Buffalo Park
11 Northland Un. Methodist Ch.
12 Kinney Park
13 Mecosta Pines Campground
14 Country Daycare
15 Mayfair Clubhouse-Can. Lks.
16 MDOT-Big Rapids
17 Brockway Wesleyan Ch.
18 Hearts of the Lk. Plaza
19 St. Michaels Cath. Ch.
20 Antlers Lk. Side Restaurant
21 Wheatland Ch. of Christ
22 School Sec. Lk. County Pk.
23 New Hope United Meth. Ch.
24 Sarns Resort Well 2
25 Parkers Landing
26 Luther Bible School
27 Grange General Store
28 Ruddy Dux
29 Seasons Country Inn
30 Northland Riverside Park
31 Trailside BP
32 P.T. Plus
33 Daggett-Gilbert Fun. Home
34 FSU Katke Golf Course
35 Meceola Countryclub
36 Wheatland Twp. Library
37 Camp Brethren Heights
38 Mecosta Co. Senior Ctr.
39 Chippewa Hills Bus Garage
40 First Baptist Ch.
41 Stanwood Free Meth. Ch.
42 Morton Twp. Library
43 Rogers Heights Christian Ch.
44 Chapel of the Lks. Luth. Ch.
45 Currie's Amoco
46 Perry St. Mobil Mart
47 Riverside Camp
48 Bare Furniture
49 Pappy's
50 Speedway
51 American Legion 554
52 Thermo Gas Co.
53 Wheatland Music Org.
54 Stone Hill Vet Clinic
55 Rieth-Riley Construction
56 St. Anne Church
57 Crittenden-Hansen Fun. Home
58 Northern Shores
59 MOARC Workshop
60 Bucks Camping
61 Pizza in Paris
62 Corner Cafe
63 New Directions
64 Austin Twp. Hall
65 Green Twp. Hall
66 Morton Twp. Hall
67 Big Rapids Assembly of God
68 Adventure Island
69 University Cheverolet
70 Moe-Z-Inn
1 0 1 2 Miles
2 0 2 4 Kilometers
Information Services Center
Annis Water Resources Institute
Grand Valley State University
Map Prepared: Feb. 2005



1998 Land Use/Cover With Groundwater Sample Sites

Figure 2.

1998 Land Use/Cover Types

- Beach and Riverbank
- Broadleaved Forest
- Clearcut
- Commerical, Services, Institutional
- Confined Feeding
- Coniferous Forest
- Cropland
- Extractive
- Forested Wetland
- Herbaceous Rangeland
- Industrial
- Lakes
- Non-Forested Wetland
- Open and Other
- Orchard, Vineyard
- Other Agricultural
- Permanent Pasture
- Recreation, Open Use
- Reservoir
- Residential
- Shrub Rangeland
- Streams and Waterways
- Transportation
- Mixed Forest

Groundwater Sample Locations

1	Roben-Hood Airport	36	Wheatland Twp. Library
2	Roben-Hood Aiport (2)	37	Camp Brethren Heights
3	R-H Airport (3)	38	Mecosta Co. Senior Ctr.
4	R-H Airport (4)	39	Chippewa Hills Bus Garage
5	Hanson's Store-Standard	40	First Baptist Ch.
6	Haymarsh Game Area Cmp.	41	Stanwood Free Meth. Ch.
7	Borland BP- Old Sunoco	42	Morton Twp. Library
8	Wheatland Twp. Park	43	Rogers Heights Christian Ch.
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11	Northland Un. Methodist Ch.	46	Perry St. Mobil Mart
12	Kinney Park	47	Riverside Camp
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21	Wheatland Ch. of Christ	56	St. Anne Church
22	School Sec. Lk. County Pk.	57	Crittenden-Hansen Fun. Home
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30	Northland Riverside Park	65	Green Twp. Hall
31	Trailside BP	66	Morton Twp. Hall
32	P.T. Plus	67	Big Rapids Assembly of God
33	Daggett-Gilbert Fun. Home	68	Adventure Island
34	FSU Katke Golf Course	69	University Cheverolet
35	Meceola Countryclub	70	Moe-Z-Inn

1 0 1 2 Miles

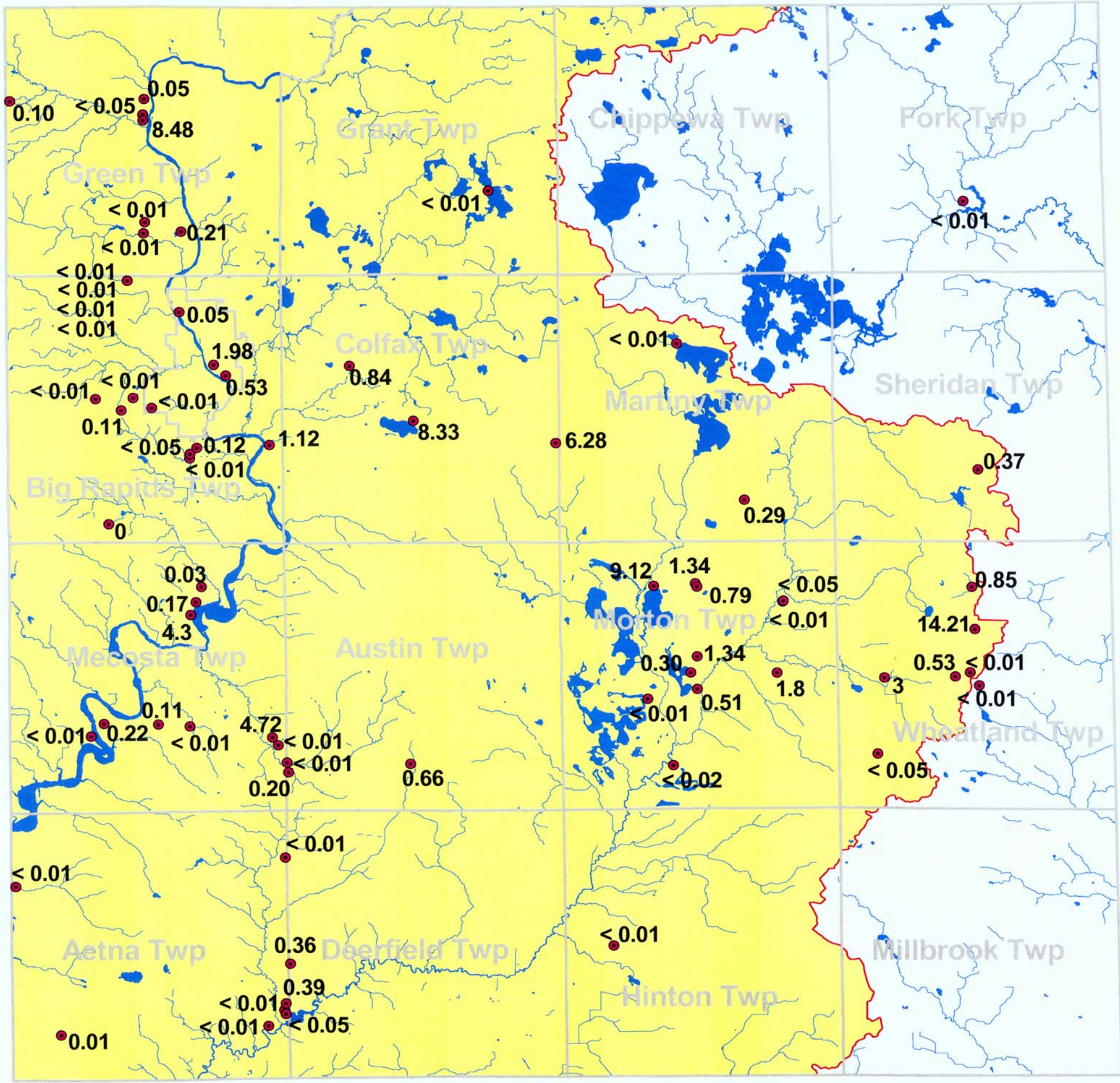
2 0 2 4 Kilometers

Information Services Center
Annis Water Resources Institute
Grand Valley State University

Map Prepared: Feb. 2005

Groundwater Nitrate-N Concentrations (mg/L)

Figure 3.



Legend

- Township Lines
- Federal/State Highways
- Streets
- Lakes/Ponds
- Rivers/Streams
- Muskegon River Watershed

1 0 1 2 Miles

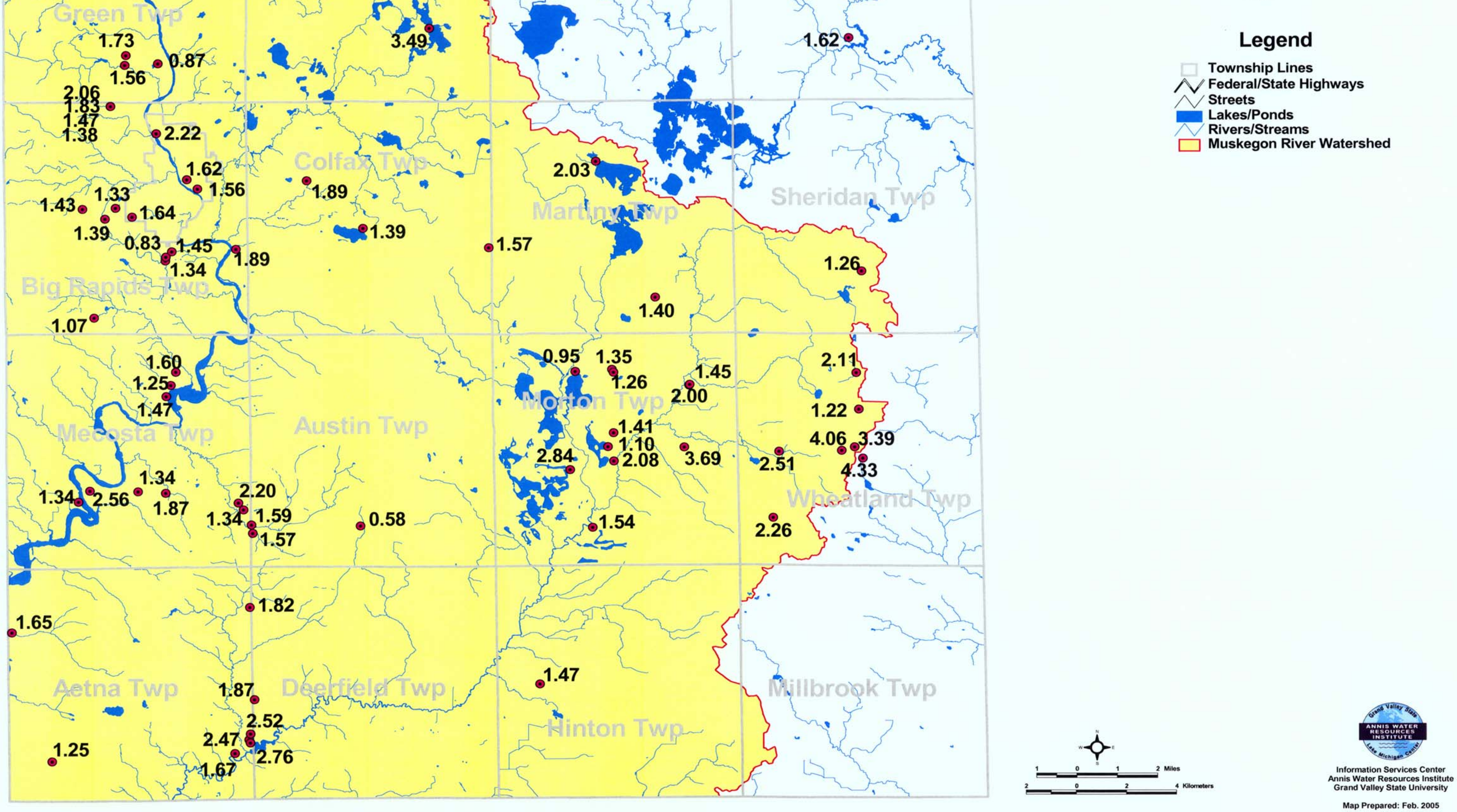
2 0 2 4 Kilometers

Information Services Center
Annis Water Resources Institute
Grand Valley State University

Map Prepared: Feb. 2005

Groundwater Dissolved Organic Carbon Concentrations (mg/L)

Figure 4.



Data from other physical and chemical parameters show normal ranges for a groundwater system. Conductivity ranged from 0.3 to 2544 μS/cm, and, not surprisingly, had a positive correlation with total dissolved solids (TDS; R^2=0.91), which ranged from 0.001 to 1.6 g/L (Table 3). Chlorides ranged from 1.5 to 3490 mg/L and sulfates ranged from 0.4 to 313 mg/L (Table 4). Mapping of nitrate (Fig. 3) and conductivity (Fig. 8) for the wells in Mecosta County revealed no distinct trends or clustering in relation to well location. High sulfate concentrations are associated with the Marshall sandstone formation and the presence of gypsum (calcium sulfate). In contrast, elevated chloride levels are typically associated with anthropogenic sources such as road salt, septic systems, and water softening. Turbidity ranged from 0 to 35 NTU (Table 3). Dissolved oxygen ranged from 1.5 to 11.1 mg/L (Table 3).

PCA was conducted on 11 chemical/physical parameters at 70 sites in Mecosta County. Principal component (PC) 1 explained 24.8% of the variability in the dataset while PC 2 explained 19.2%. Sites in the biplot of PC 1 and 2 were color-coded based on land use (Fig. 9). Land use was collapsed to 6 categories (developed, forest/rangeland, agriculture, open/other, residential, and not available) for this analysis. No clear gradient in the chemical/physical data could be identified based on land use. We also color-coded the biplot by bacterial abundance to search for patterns in bacteria that corresponded to abiotic conditions (Fig. 10). Again, no clear gradient was found.

Pearson correlations were conducted between PC scores and bacterial abundance to evaluate potential relationships between water quality and bacteria. However, no significant correlations were found. We then reduced the dataset to the 34 sites that had water temperatures of 14ºC or less. This selection was done in an attempt to eliminate sites where sample water may not have come directly from the ground but had sat in water systems long enough to warm up (in cases where water was not run long enough to completely flush the system). PCA was again used to search for gradients corresponding to land use and bacteria abundance. Sites in the biplot of PC 1 and 2 were color-coded based on bacterial abundance reduced to three categories: low ($<9x10^8$/L), medium ($9-19x10^8$/L), and high ($>19x10^8$/L). Even with this refined dataset, no clear gradients could be identified (Fig. 11) and no significant Pearson correlations were found between PC scores and bacteria abundance. While PCA analysis is a powerful multivariate analytical tool, there are several reasons why it may not have been able to detect gradients in these data: 1) the land use category for the well location may not accurately reflect all of the neighboring land uses from which groundwater was flowing; 2) the water quality could have been altered by water treatment systems (e.g., water softeners); 3) other factors that were not taken into account in the analysis may have had greater influence on the patterns (e.g., well or screen depth, lithology).

Due to constraints in how groundwater samples could be collected for this investigation, we must be cautious in assuming all samples represent groundwater solely. The samples were collected from wells that typically consist of wells, piping, pumps, and faucets. As such, the samples collected should be viewed as being from a well system (i.e., groundwater and associated well equipment) and not exclusively representative of the groundwater. In addition, in investigations that are focused specifically on the groundwater, typically accepted sampling protocols involve purging groundwater in the wells at a volume 3 times the void volume of the water in the wells. Since the void volume was not known for wells used in this investigation, water was instead purged for 5-10 minutes at full flow, resulting in 30-60 gallons of overflow (depending on flow rate). While this is the standard and customary practice specified by District #10 Health Department, it should be noted that the method does not ensure that all stagnant water was removed from each of the different wells prior to sample collection.

Groundwater is becoming an increasingly important resource due to increases in its usage over time. Although limited in scope, our 2-year study finds that the 70 Type II Non-community wells sampled within Mecosta County to be typical (based on the measured parameters) of groundwater used for drinking water purposes (i.e., with the exception of 1 well that may be worth reexamining). It should be recognized that the long term management of the groundwater resources here, and throughout the state, depend on monitoring future pumping, regulating regional development, and protecting groundwater from pollution. Only wise management with foresight will assure the undiminished quality of our ground water resource for future generations (Weist 1978).

Table 3. Hydrolab-based field measurements of Mecosta County well samples.

Sample #`	Sample Location Name	Temp (°C)	DO (mg/L)	Conductivity (µS/cm)	TDS (g/L)	Turbidity (NTU)	pH	ORP (mV)
1	Roben Hood Airport	14	1.6	332	0.21	9	8.0	198
2	Roben Hood Airport	14	1.6	335	0.23	4	8.1	110
3	Roben Hood Airport	9	2.7	310	0.20	4	8.1	84
4	Roben Hood Airport	13	2.4	312	0.20	5	8.1	75
5	Hanson Amoco	14	3.4	2*	0.00*	9	8.2	47
6	Haymarsh Lakes	15	3.0	293	0.19	16	8.0	151
7	Borland BP	18	6.3	329	0.21	4	8.6	227
8	Wheatland Township Park	13	5.2	362	0.23	17	8.2	37
9	Mecosta Township Hall	19	6.7	196	0.12	5	8.2	347
10	Stanwood Buffalo Park	12	3.5	305	0.20	7	8.4	307
11	Northland United Meth. Church	18	7.5	0.3*	0.00*	10	8.2	317
12	Kinney Park	12	4.7	485	0.31	10	7.9	186
13	Mecosta Pines Campground	13	4.9	502	0.32	6	7.9	78
14	Country Daycare	17	8.5	406	0.26	5	8.3	258
15	Mayfair Clubhouse	13	6.0	50	0.03	6	8.2	181
16	MDOT-Big Rapids	40*	3.5	342	0.22	19	8.1	218
17	Brockway Wesleyan Church	17	2.9	604	0.39	16	8.0	43
18	Hearts of the Lake Plaza	14	9.2	282	0.18	6	8.4	243
19	St. Michaels Cath. Church	17	4.6	1074	0.69	6	7.7	334
20	Antlers Lakeside Restaurant	17	2.7	0.3*	0.00*	11	8.2	294
21	Wheatland Church of Christ	13	4.7	1132	0.73	9	7.5	270
22	School Section Lake Park	19	7.3	2*	0.00*	5	8.4	319
23	New Hope United Meth. Church	20	5.6	448	0.29	5	8.1	332
24	Sarns Resort Well 2	14	9.3	701	0.46	9	8.2	162
25	Parkers Landing	23	6.5	337	0.22	5	8.3	284
26	Luther Bible School	16	3.9	200	0.13	10	8.6	27
27	Grange General Store	13	3.8	475	0.30	6	8.0	253
28	Ruddy Dux	13	5.0	345	0.22	11	8.3	1.54
29	Seasons Country Inn	12	8.7	547	0.35	6	8.0	237
30	Northland Riverside Park	12	3.9	326	0.21	1	7.7	369
31	Trailside BP	15	8.7	426	0.27	9	7.8	383
32	PT Plus	18	3.6	298	0.21	1	7.6	434
33	Dagget-Gilbert Funeral Hm	11	1.5	359	0.23	3	7.8	212
34	FSU Katke Golf Course	19	6.9	330	0.21	0	7.6	797

Table 3 cont'd. Hydrolab-based field measurements of Mecosta County well samples.

Sample #	Sample Location Name	Temp (°C)	DO (mg/L)	Conductivity (µS/cm)	TDS (g/L)	Turbidity (NTU)	pH	ORP (mV)
35	Meceola Country Club	13	8.1	569	0.36	8	7.9	198
36	Wheatland Township Library	21	5.0	2544	1.63	9	7.7	332
37	Camp Brethern Heights	14	8.0	447	0.29	6	7.8	95
38	Mecosta County Senior Center	13	11.1	364	0.23	7	8.2	303
39	Chippewa Hills Bus Garage	18	3.2	547	0.35	6	8.0	322
40	First Baptist Church	24	3.7	562	0.36	1	7.5	407
41	Stanwood Free Methodist Church	14	3.1	303	0.19	0	7.8	358
42	Morton Township Library	17	1.8	415	0.27	1	7.9	187
43	Rogers Heights Christian Church	18	4.8	335	0.21	1	7.7	480
44	Chapel of the Lakes Luth. Church	17	7.1	409	0.26	0	7.7	415
45	Currie's Amoco	15	7.8	1850	1.18	35	7.1	500
46	Perry Street Mobil Mart	12	3.4	301	0.19	0	7.9	283
47	Riverside Camp	16	9.9	425	0.27	6	7.3	47.7
48	Bare Furniture	14	4.2	458	0.29	1	7.7	27.5
49	Pappy's	20	6.5	105	0.67	2	7.4	39.9
50	Speedway	16	8.7	574	0.37	14	7.9	26.9
51	American Legion 554	16	4.6	363	0.23	4	6.7	379
52	Thermo Gas Company	15	6.0	845	0.54	1	5.0	364
53	Wheatland Music Organization	20	3.8	339	0.22	6	8.0	97
54	Stone Hill Vet Clinic	14	5.9	588	0.38	5	7.7	282
55	Reith-Riley Construction	16	4.9	460	0.29	2	6.9	173
56	St. Anne Church	14	3.4	359	0.23	14	7.8	238
57	Crittenden-Hansen Funeral Home	14	2.9	1020	0.65	8	6.3	205
58	Northern Shores	11	8.6	259	0.17	8	6.1	258
59	MOARC Workshop	14	6.9	358	0.23	25	7.8	115
60	Buck's Camping	13	6.9	493	0.32	16	5.8	316
61	Pizza in Paris	14	2.6	397	0.25	1	7.7	165
62	Corner Café	13	7.0	468	0.30	7	5.8	310
63	New Directions	16	6.4	437	0.28	3	7.6	84
64	Austin Township Hall	16	8.0	996	0.64	2	5.4	377
65	Green Township Hall	15	6.5	554	0.35	1	6.2	330
66	Morton Township Hall	14	2.0	370	0.24	2	6.6	172
67	Big Rapids Assembly of God	20	2.0	368	0.23	1	7.9	223
68	Adventure Island	16	5.3	298	0.19	16	5.9	263
69	University Chevrolet	13	2.9	351	0.23	1	7.1	141
70	Moe-Z-Inn	16	3.2	476	0.30	1	6.8	256

*Possible sensor malfunction for these parameters. These data have been excluded from statistical analyses.

Table 4. Laboratory analytical data for Mecosta County well samples.

Sample #	Sample Location Name	DOC (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3-N (mg/L)	NH_3-N (mg/L)	TKN-N (mg/L)	SRP-P (mg/L)	TP-P (mg/L)	*E. coli* (#/100 mL)	Total Bacteria (#/100 mL)
1	Roben-Hood Airport (1)	2.06	3	24	< 0.01	0.23	0.33	0.02	0.02	< 10	4,073,438
2	Roben-Hood Airport (2)	1.83	3	38	< 0.01	0.10	0.14	0.02	0.02	< 10	3,454,275
3	Roben-Hood Airport (3)	1.47	< 1	8	< 0.01	0.04	0.25	0.02	0.02	< 10	6,061,275
4	Roben-Hood Airport (4)	1.38	< 1	7	< 0.01	< 0.01	0.12	0.01	0.02	< 10	7,462,538
5	Hanson's Amoco	1.62	16	9	< 0.01	0.11	0.24	< 0.01	0.02	< 10	2,737,350
6	Haymarsh Lakes	3.49	2	8	< 0.01	0.02	0.23	< 0.01	0.01	< 10	9,254,850
7	Borland BP	1.82	17	8	< 0.01	< 0.01	0.10	0.02	0.03	< 10	2,444,063
8	Wheatland Township Park	4.33	8	0	< 0.01	0.19	0.45	< 0.01	0.05	< 10	5,670,225
9	Mecosta Township Hall	1.60	8	9	0.03	0.10	0.10	< 0.01	0.02	< 10	15,707,175
10	Stanwood Buffalo Park	1.59	6	3	< 0.01	0.22	0.31	0.02	0.02	< 10	77,102,025
11	Northland United Meth. Church	1.57	16	6	0.20	0.06	0.12	< 0.01	0.01	< 10	30,338,963
12	Kinney Park	2.47	49	15	< 0.01	0.06	0.17	< 0.01	0.01	< 10	15,902,700
13	Mecosta Pines Campground	1.67	7	14	< 0.01	0.18	0.32	< 0.01	0.02	< 10	9,776,250
14	Country Daycare	1.35	52	12	1.34	0.12	0.24	< 0.01	< 0.01	< 1	4,985,888
15	Mayfair Clubhouse	1.54	16	2	< 0.02	0.53	0.75	< 0.01	0.02	< 1	11,112,338
16	MDOT-Big Rapids	1.07	5	7	0	0.15	< 0.10	< 0.01	0.02	< 1	5,083,650
17	Brockway Wesleyan Church	1.47	12	55	< 0.01	0.09	0.18	< 0.01	< 0.01	< 1	18,900,750
18	Hearts of the Lake Plaza	1.26	29	8	0.79	0.03	0.19	< 0.01	< 0.01	< 1	12,057,375
19	St. Michaels Cath. Church	2.51	143	22	3	< 0.01	< 0.10	< 0.01	0.01	< 1	4,985,888
20	Antlers Lakeside Restaurant	2.84	31	4	< 0.01	< 0.01	< 0.10	0.02	0.02	< 1	9,711,075
21	Wheatland Church of Christ	2.11	163	18	0.85	< 0.01	< 0.10	< 0.01	< 0.01	< 1	10,884,225
22	School Section Lake Park	1.10	11	13	0.30	< 0.01	< 0.10	< 0.01	0.02	< 1	16,880,325
23	New Hope United Meth. Church	3.69	32	19	1.8	< 0.01	< 0.10	< 0.01	< 0.01	< 1	11,340,450

Table 4 cont'd. Laboratory analytical data for Mecosta County well samples.

Sample #	Sample Location Name	DOC (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3-N (mg/L)	NH_3-N (mg/L)	TKN-N (mg/L)	SRP-P (mg/L)	TP-P (mg/L)	*E. coli* (#/100 mL)	Total Bacteria (#/100 mL)
24	Sarns Resort Well 2	1.65	139	314	< 0.01	0.06	0.18	0.08*	0.01	< 1	7,690,650
25	Parkers Landing	1.34	2	10	< 0.01	0.05	0.12	0.01	0.03	< 1	10,949,400
26	Luther Bible School	1.25	8	3	0.01	0.13	0.24	0.01	0.03	< 1	5,996,100
27	Grange General Store	1.34	24	8	0.11	0.05	0.17	< 0.01	0.01	< 1	10,688,700
28	Ruddy Dux	1.87	7	2	< 0.01	0.28	0.42	0.01	0.02	< 1	5,735,400
29	Seasons County Inn	1.47	44	12	4.3	0.13	0.19	< 0.01	0.01	< 1	5,605,050
30	Northland Riverside Park	2.22	16	6	0.05	< 0.01	0.33	< 0.01	< 0.01	< 1	7,201,838
31	Trailside BP	1.56	63	13	0.53	< 0.01	0.30	< 0.01	< 0.01	< 1	6,159,038
32	PT Plus	1.43	3	5	< 0.01	0.04	0.38	< 0.01	0.02	< 1	4,497,075
33	Dagget-Gilbert Funeral Hm	1.34	2	8	< 0.01	0.09	0.40	< 0.01	0.02	< 1	7,364,775
34	FSU Katke Golf Couse	1.64	6	11	< 0.01	< 0.01	0.32	0.04	0.05	< 1	4,855,538
35	Meceola Country Club	1.39	34	26	8.33	0.02	< 0.10	< 0.01	0.01	< 1	11,698,913
36	Wheatland Township Library	3.39	568	52	< 0.01	0.02	0.10	< 0.01	0.02	< 1	22,289,850
37	Camp Brethren Heights	2.03	28	18	< 0.01	< 0.01	< 0.10	< 0.01	0.02	< 1	8,635,688
38	Mecosta County Senior Center	1.40	32	10	0.29	0.03	< 0.10	< 0.01	0.01	< 1	4,268,963
39	Chippewa Hills Bus Garage	1.26	49	23	0.37	0.03	< 0.10	< 0.01	< 0.01	< 1	26,623,988
40	First Baptist Church	2.52	64	17	0.39	< 0.01	< 0.10	< 0.01	0.01	< 1	24,408,038
41	Stanwood Free Methodist Church	1.34	13	4	< 0.01	0.15	0.14	< 0.01	0.02	< 1	9,482,963
42	Morton Township Library	2.00	45	15	< 0.01	0.35	0.34	< 0.01	0.03	< 1	15,642,000
43	Rogers Heights Christian Church	1.25	13	17	0.17	< 0.01	< 0.10	0.01	0.01	< 1	6,452,325
44	Chapel of the Lakes Luth. Church	1.41	41	13	1.34	< 0.01	< 0.10	< 0.01	< 0.01	< 1	4,203,788
45	Currie's Amoco	1.62	349	17	1.98	< 0.01	< 0.10	< 0.01	< 0.01	< 1	5,376,938
46	Perry Street Mobil Mart	1.33	16	5	< 0.01	0.04	< 0.10	< 0.01	0.01	< 1	3,356,513

* Note: SRP data for this sample (well # 24) appears to be compromised – possibly due to laboratory contamination.

Table 4 cont'd. Laboratory analytical data for Mecosta County well samples.

Sample #	Sample Location Name	DOC (mg/L)	Cl (mg/L)	S0$_4$ (mg/L)	N0$_3$-N (mg/L)	NH$_3$-N (mg/L)	TKN-N (mg/L)	SRP-P (mg/L)	TP-P (mg/L)	*E. coli* (#/100 mL)	Total Bacteria (#/100 mL)
47	Riverside Camp	1.89	33	8	1.12	< 0.01	< 0.10	< 0.01	< 0.01	< 1	8,537,925
48	Bare Furniture	1.56	17	17	< 0.01	0.05	0.11	< 0.01	0.02	< 1	8,928,975
49	Pappy's	1.57	173	18	6.28	< 0.01	< 0.10	< 0.01	0.01	< 1	5,735,400
50	Speedway	1.73	68	8	< 0.01	0.05	< 0.10	< 0.01	0.02	< 1	5,572,463
51	American Legion 554	1.87	37	10	0.36	0.03	< 0.10	< 0.01	< 0.01	< 1	3,780,150
52	Thermo Gas Company	1.22	51	31	14.21	< 0.02	< 0.10	< 0.01	< 0.01	< 1	9,950,050
53	Wheatland Music Organization	2.26	28	22	< 0.05	0.05	< 0.10	< 0.01	< 0.01	< 1	5,735,400
54	Stone Hill Vet Clinic	1.89	35	14	0.84	< 0.02	< 0.10	< 0.01	< 0.01	< 1	5,865,750
55	Reith-Riley Construction	0.87	1861	29	0.21	0.16	0.1	< 0.01	< 0.01	< 1	14,599,200
56	St. Anne Church	1.87	11	13	0.10	0.03	< 0.01	< 0.01	0.01	< 1	6,387,150
57	Crittenden-Hansen Funeral Home	4.06	120	40	0.53	0.03	0.1	< 0.01	< 0.01	< 1	25,157,550
58	Northern Shores	0.95	17	21	9.12	< 0.02	< 0.10	< 0.01	< 0.01	< 1	9,341,750
59	MOARC Workshop	0.98	364	11	< 0.05	0.19	0.1	< 0.01	0.03	< 1	3,258,750
60	Buck's Camping	2.56	43	65	0.22	0.08	< 0.10	< 0.01	< 0.01	< 1	6,647,850
61	Pizza in Paris	1.18	18	4	0.05	0.85	0.5	< 0.01	0.02	< 1	948,000
62	Corner Café	2.20	3491	62	4.72	0.03	0.2	< 0.01	< 0.01	< 1	2,607,000
63	New Directions	1.39	36	10	0.11	0.07	< 0.10	< 0.01	0.01	< 1	10,558,350
64	Austin Township Hall	0.58	6	10	0.66	< 0.02	< 0.10	< 0.01	< 0.01	< 1	2,911,150
65	Green Township Hall	2.28	108	19	8.48	< 0.02	< 0.10	< 0.01	< 0.01	< 1	12,470,150
66	Morton Township Hall	1.45	9	14	< 0.05	0.03	< 0.10	< 0.01	0.01	< 1	1,998,700
67	Big Rapids Assembly of God	1.45	27	8	0.12	0.12	< 0.10	0.01	0.02	< 1	4,953,300
68	Adventure Island	2.08	33	14	0.51	0.04	< 0.10	0.01	0.01	< 1	11,861,850
69	University Chevrolet	0.83	40	11	< 0.05	0.10	0.2	< 0.01	0.02	< 1	3,084,950
70	Moe-Z Inn	2.76	41	14	< 0.05	< 0.02	< 0.10	0.01	0.01	< 1	7,690,650

Figure 5. Scatter plot of nitrate and total bacteria in Mecosta County wells. Note the absence of a significant relationship between the two parameters.

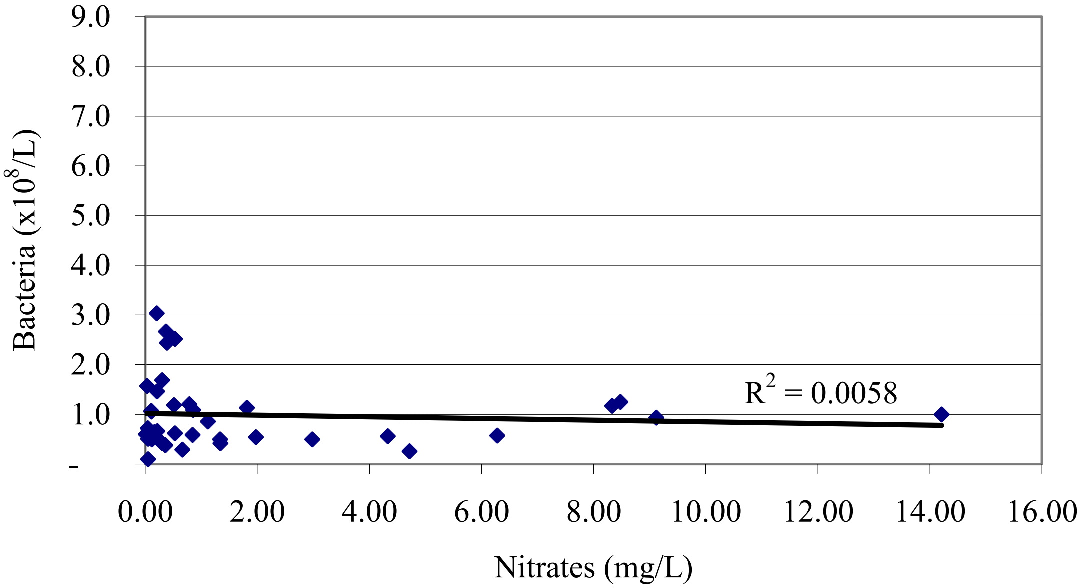
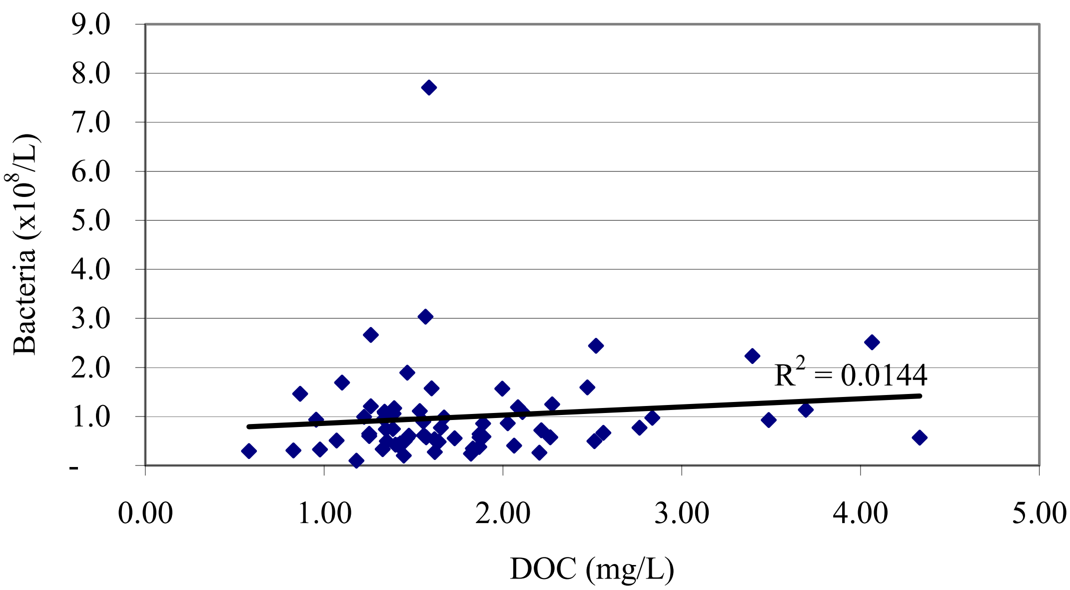
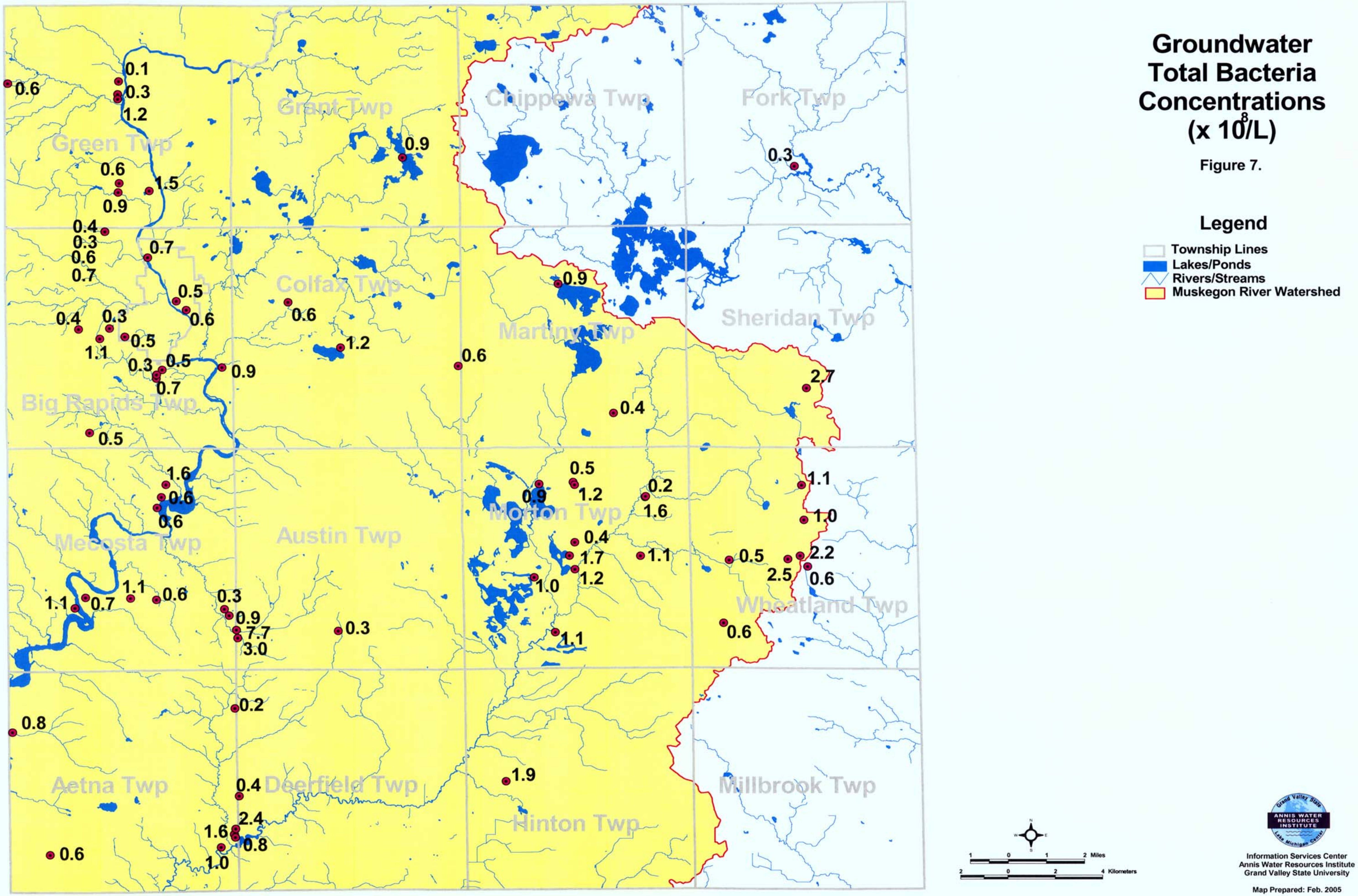


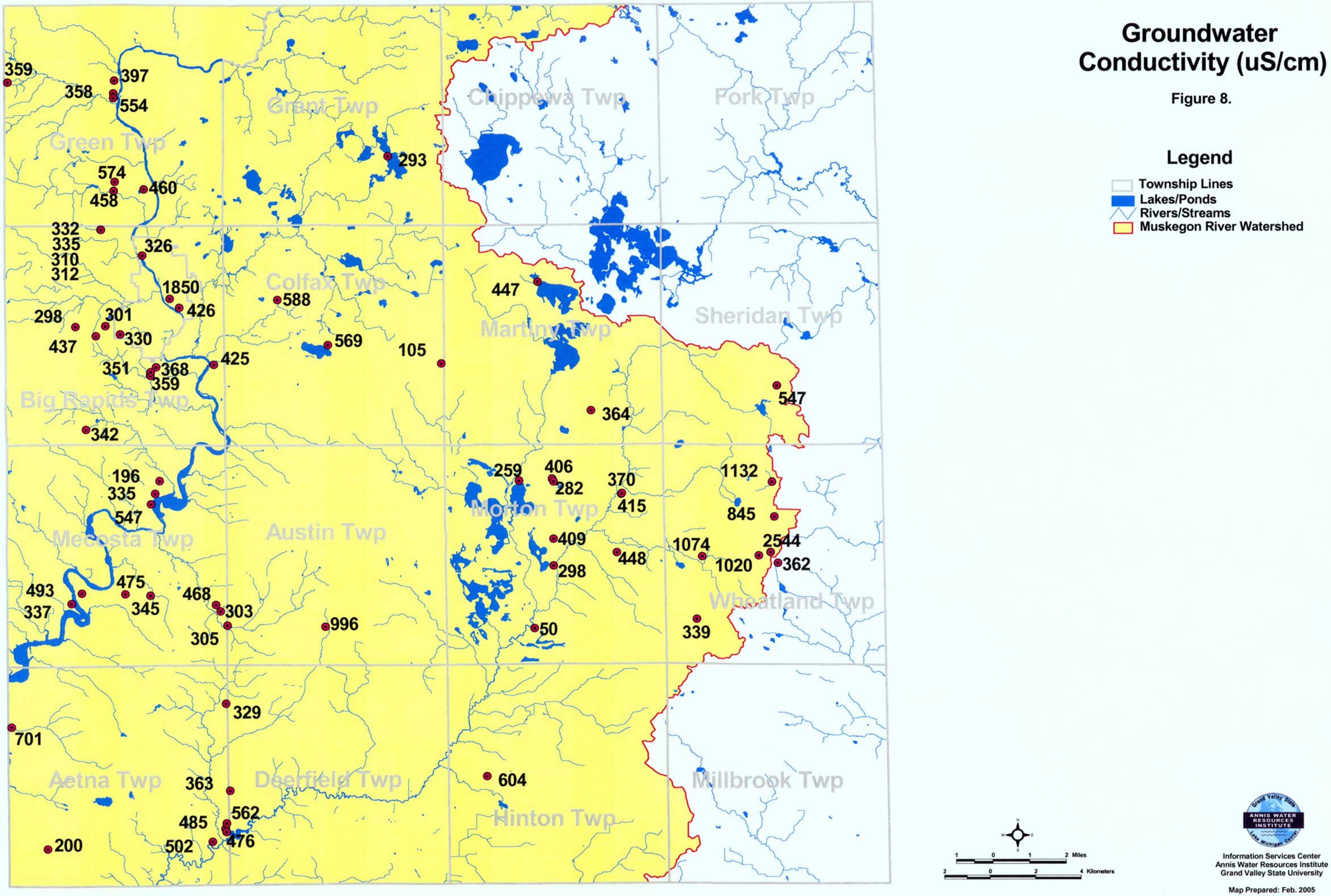
Figure 6. Scatter plot of dissolved organic carbon and total bacteria in Mecosta County wells showing little if any relationship between the two parameters.





Groundwater Total Bacteria Concentrations ($\times 10^8$/L)

Figure 7.



Groundwater Conductivity (uS/cm)

Figure 8.

Figure 9. PCA of chemical/physical parameters sampled from well water at 70 sites in Mecosta County, color-coded by land use. Codes to the site labels can be found after Figure 11, and correspond to site numbers in Tables 3 and 4.

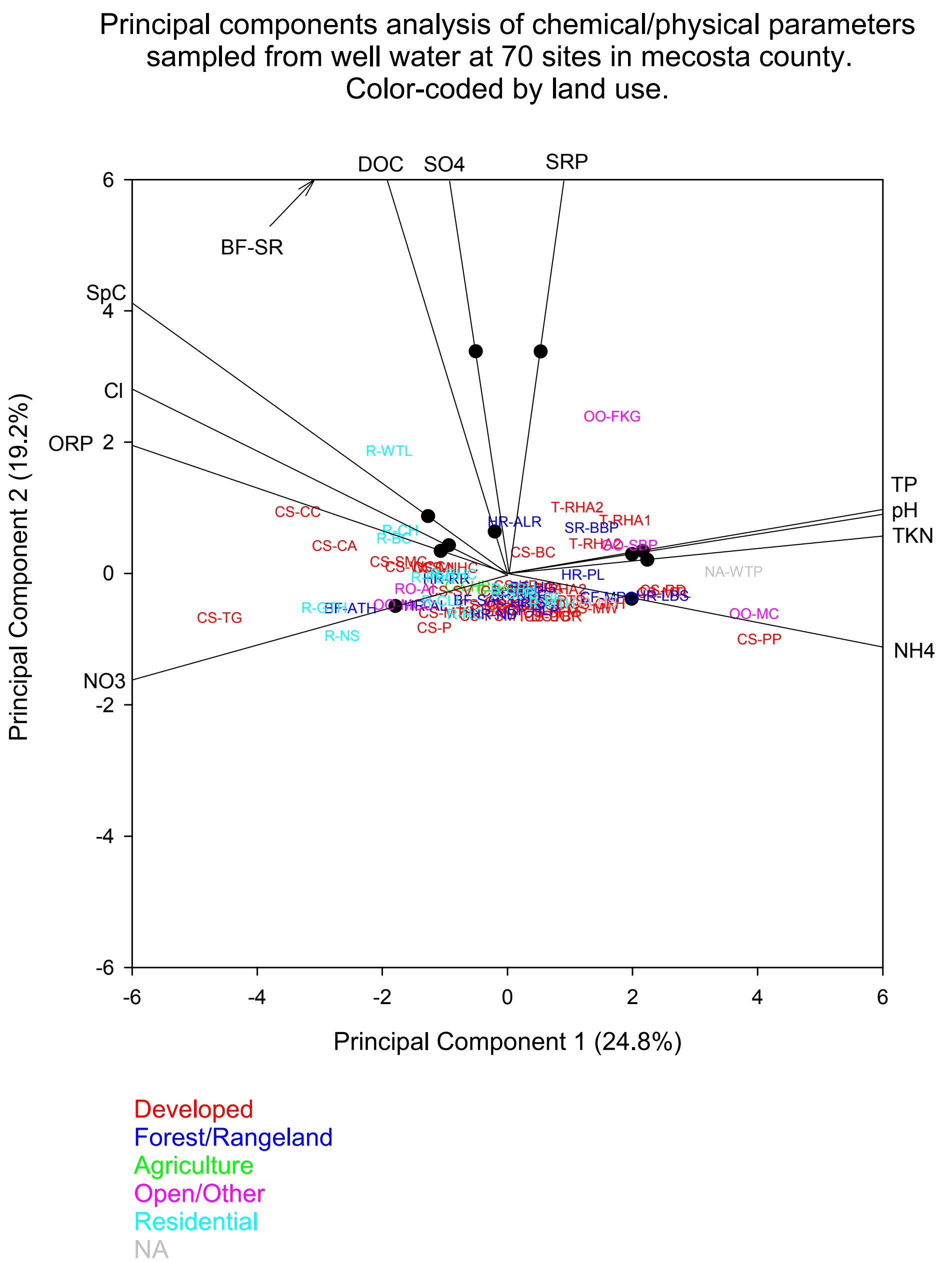


Figure 10. PCA of chemical/physical parameters sampled from well water at 70 sites in Mecosta County, color-coded by bacterial abundance. Codes to the site labels can be found after Figure 11, and correspond to site numbers in Tables 3 and 4.

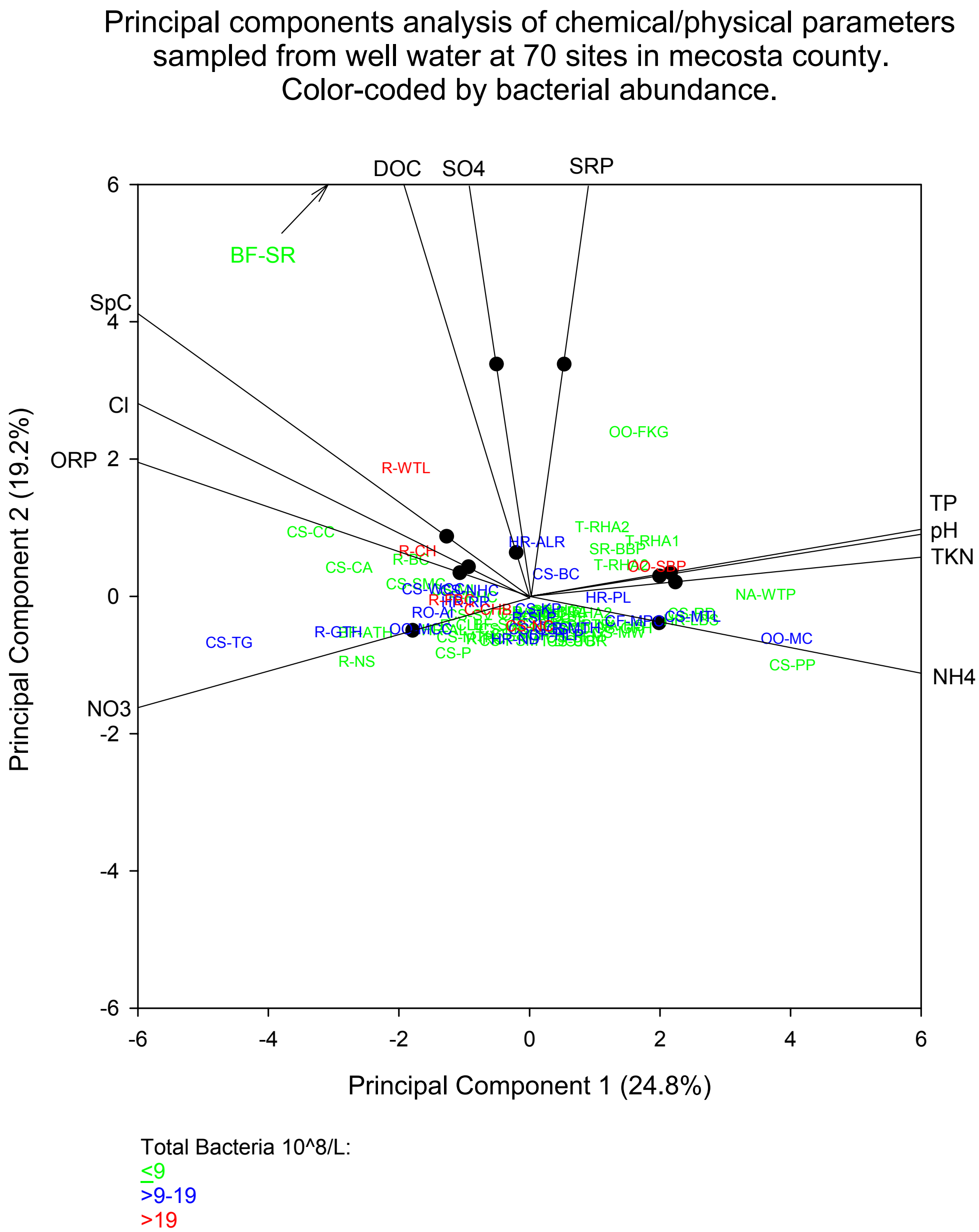
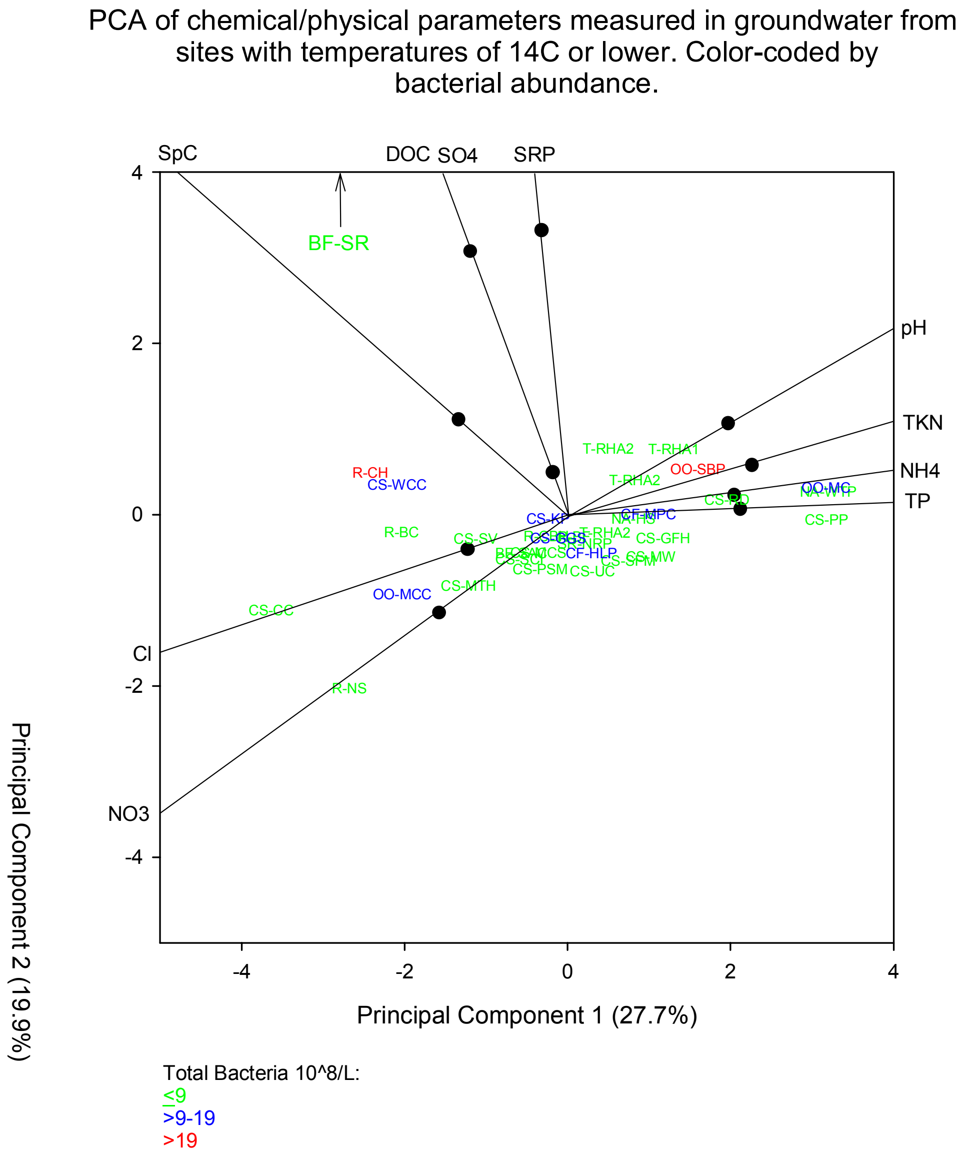


Figure 11. PCA of chemical/physical parameters measured in groundwater (i.e., sites with water temperatures ≤14°C) at sites in Mecosta County, color-coded by bacterial abundance. Codes to the site labels can be found following this figure, and correspond to site numbers in Tables 3 and 4.



Label codes for PCA in Figures 9 and 10.

#	PCA Codes	#	PCA Codes	#	PCA Codes	#	PCA Codes	#	PCA Codes
1	T-RHA1	15	OO-MC	29	CS-SCI	43	R-RHC	57	R-CH
2	T-RHA2	16	T-DOTBR	30	SR-NRP	44	R-CLL	58	R-NS
3	T-RHA2	17	CS-BC	31	CS-TBP	45	CS-CA	59	CS-MW
4	T-RHA2	18	CF-HLP	32	CS-PTP	46	CS-PSM	60	R-BC
5	NA-HS	19	CS-SMC	33	CS-GFH	47	R-RC	61	CS-PP
6	BF-HG	20	HR-ALR	34	OO-FKG	48	R-BF	62	CS-CC
7	SR-BBP	21	CS-WCC	35	OO-MCC	49	CS-P	63	HR-ND
8	NA-WTP	22	R-SLP	36	R-WTL	50	HR-S	64	BF-ATH
9	R-MTH	23	CS-NHC	37	R-CBH	51	HR-AL	65	R-GTH
10	OO-SBP	24	BF-SR	38	CS-MCS	52	CS-TG	66	CS-MTH
11	CS-NC	25	HR-PL	39	C-CHB	53	C-WMO	67	CS-BRA
12	CS-KP	26	HR-LBS	40	R-FBC	54	CS-SV	68	RO-AI
13	CF-MPC	27	CS-GGS	41	CS-SFM	55	HR-RR	69	CS-UC
14	CS-CD	28	CS-RD	42	CS-MTL	56	BF-SAC	70	CS-MI

Label codes for PCA in Figure 11.

#	PCA Codes	#	PCA Codes	#	PCA Codes	#	PCA Codes
1	T-RHA1	15	OO-MC	35	OO-MCC	58	R-NS
2	T-RHA2	18	CF-HLP	37	R-CBH	59	CS-MW
3	T-RHA2	21	CS-WCC	38	CS-MCS	60	R-BC
4	T-RHA2	24	BF-SR	41	CS-SFM	61	CS-PP
5	NA-HS	27	CS-GGS	46	CS-PSM	62	CS-CC
8	NA-WTP	28	CS-RD	48	R-BF	66	CS-MTH
10	OO-SBP	29	CS-SCI	54	CS-SV	69	CS-UC
12	CS-KP	30	SR-NRP	56	BF-SAC		
13	CF-MPC	33	CS-GFH	57	R-CH		

Task 4: Develop conceptual groundwater model for the unconfined aquifer system

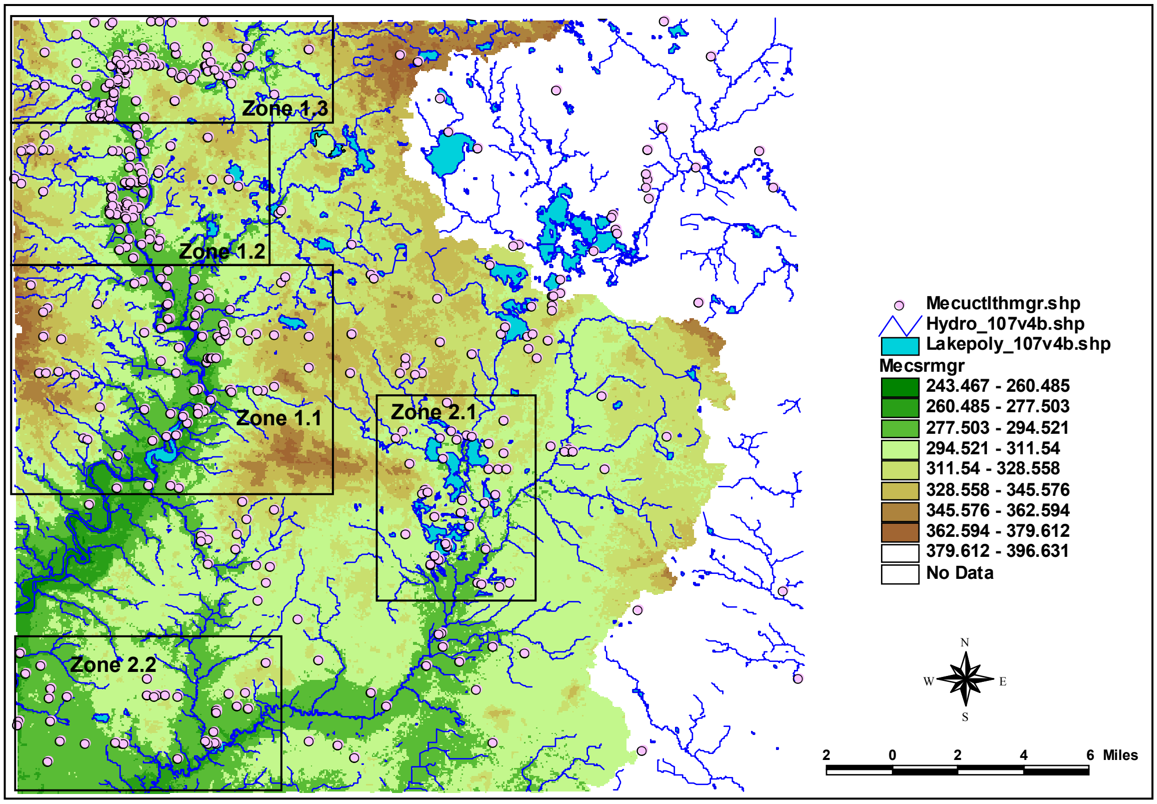
This task focused on analyzing, conceptualizing, and visualizing the distribution of various geologic materials, unconfined aquifers, and the groundwater flow system based on the available well log data (e.g., material types, layers, and static water levels) in the GIS database developed as part of this study. Specifically, the following work has been completed:

- Analysis of all borehole data and development of a Groundwater Modeling System (GMS) borehole information system.
- Development of three-dimensional stratigraphy models to visualize the distribution of various geologic materials and the unconfined aquifers.
- Grouping of the static water level data chronologically and generation of a series of three-dimensional surface maps and contour maps of the unconfined groundwater levels. These materials provide fundamental information on the groundwater distribution and flow patterns (flow direction and gradient) during different time periods.
- Generation of three-dimensional surface maps of the unconfined groundwater depths and water level changes, which reveal the shallow groundwater storage changes during the corresponding time intervals.

4a. Borehole Data Analyses and Development of GMS Borehole Information System

The analysis of the groundwater system was based on 470 unconfined wells in the Mecosta portion of the Muskegon River watershed. Figure 12 shows the study area and the watershed boundary (note that the boundary of the shallow groundwater system is not coincident with the watershed boundary). These wells include 441 domestic wells, 8 P2B type II public wells, 5 P3 type III public wells, 3 P0 type II public wells, 5 irrigation wells, and 8 other wells. Comparison of Figs. 2 and 12 reveal that most of the wells are located in residential and industrial areas along major stream channels.

Figure 12. Study area and well distribution of Muskegon River watershed within Mecosta County. Colors refer to elevation based on USGS digital elevation model (brown = higher; green = lower). See text for explanation of sub-zones.



By using the GMS software (Groundwater Modeling System, 2004), we analyzed the available well log data and developed a GMS borehole information system, which provided all basic information on the unconfined wells, such as ID numbers, locations (x and y coordinates), static water levels, material codes, layers, horizons, and borehole segment graphs. An interface display is shown in Fig. 13, while a representative 3-dimensional image of sediment types from boreholes is shown in Fig. 14. The corresponding soil codes and materials are shown in Table 5.

Figure 13. Typical interface displaying GMS borehole information system.

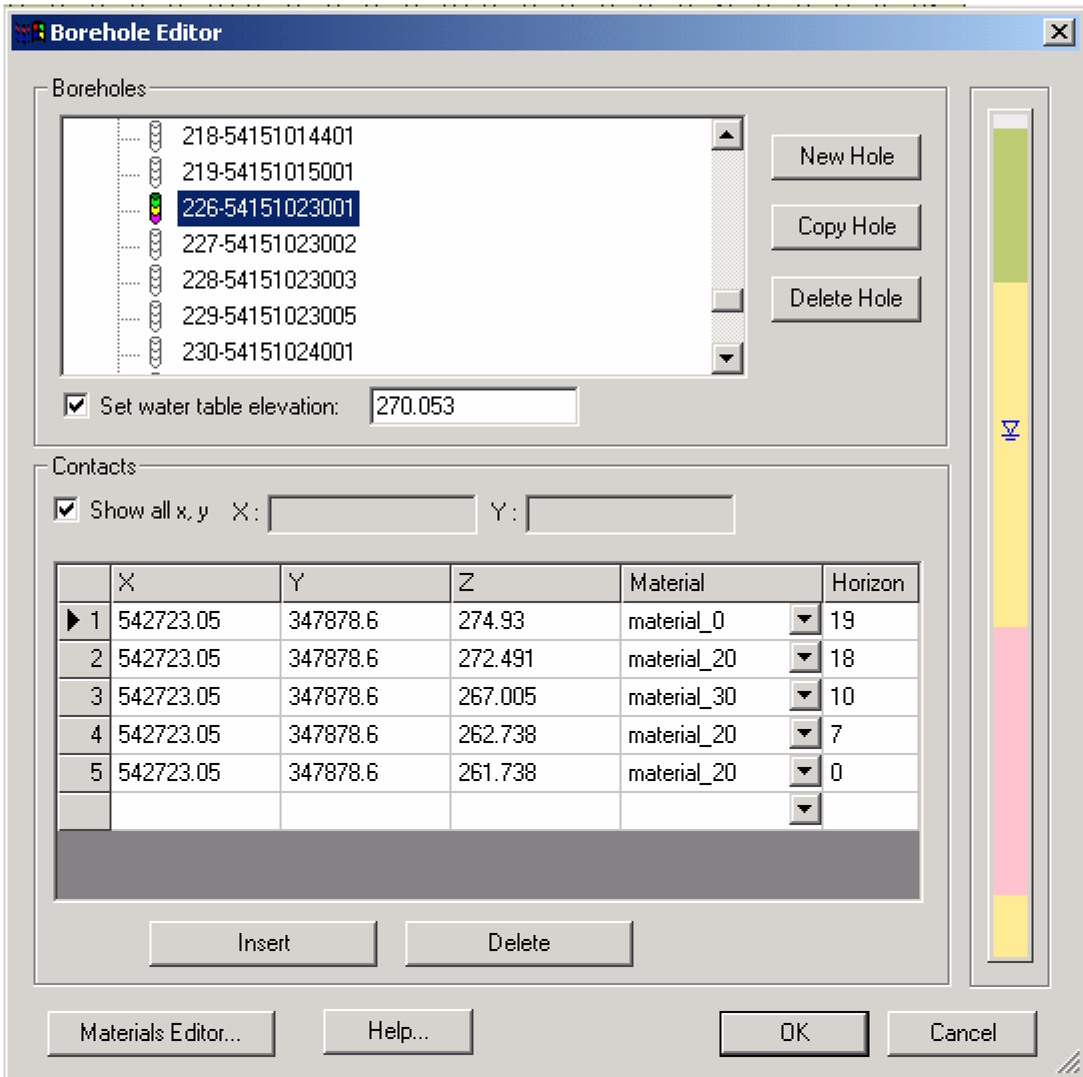
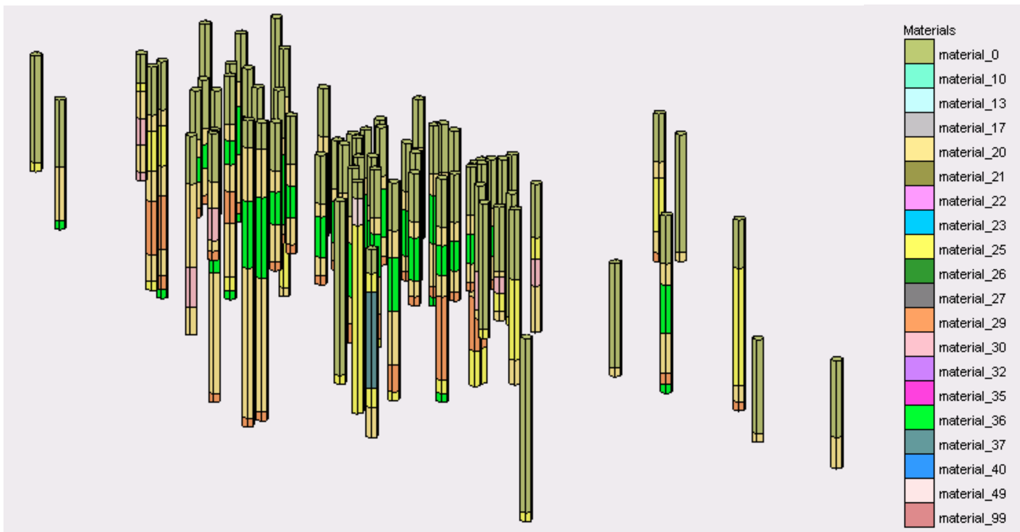


Figure 14. Three-dimensional distribution of soil materials within boreholes from Zone 1.2 (see Fig. 12 for location). See Table 5 to relate material type to actual soil type and Attachment 1 for more details.



4b. Development of Three-Dimensional Stratigraphy Models

In order to visualize the spatial distribution of various geologic materials, we further generated a set of three-dimensional stratigraphy models based on the developed GMS borehole database. We first divided the entire domain into two major zones (Zone 1 and Zone 2), which are further divided into five sub-zones (Zones 1.1, 1.2, 1.3, 2.1, and 2.2, see Figure 12). Then, horizons representing the top of each stratigraphic unit (soil layer) were defined and numbered. Finally, the solid module of GMS was used to create the three-dimensional stratigraphy models for all sub-zones. Solid and cross-section examples are shown in Figures 15 and 16, respectively. Please also refer to Attachment 1 for details.

Figure 15. Three-dimensional distribution of different layers, sampled from within Zone 1.2. See Attachment 1 for additional details.

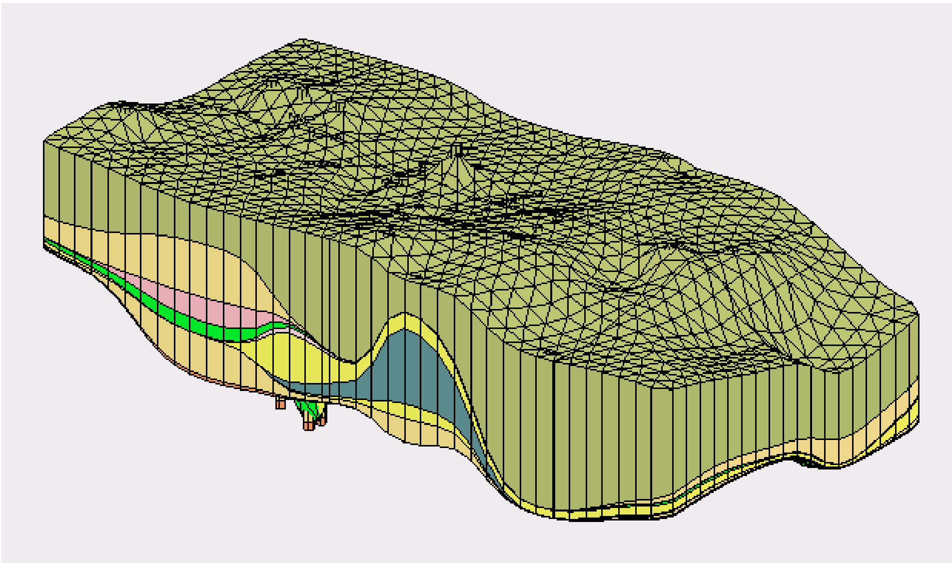
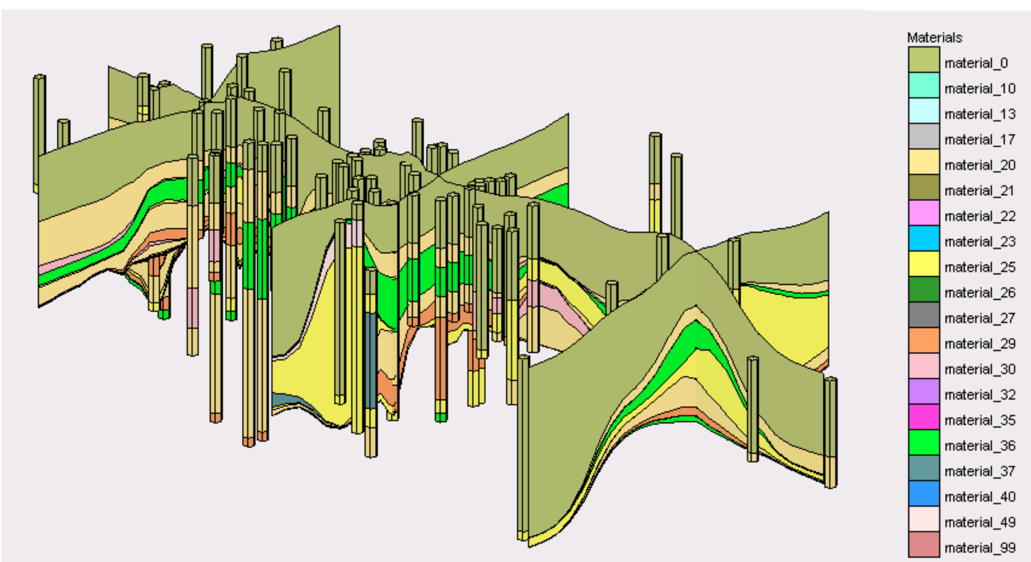


Figure 16. Cross sections showing depth-distribution of different layers (based on Figure 15). See Table 1 to relate material symbol to actual soil type.



4c. Visualization of Groundwater Flow, Distribution, and Changes over Time

Static groundwater levels of the 470 wells were used for analyzing the shallow groundwater flow system and mapping the groundwater distribution and changes. In the analysis, the wells were further classified into four groups according to their time periods: 1990-1999 wells (153), 1986-1995 wells (142), 1976-1985 wells (115), and 1966-1975 wells (144). Then, the following three types of groundwater maps were generated for the entire time period (1966-1999) and for the four sub-time periods.

(1) Three-dimensional surface maps and two-dimensional contour/vector maps of the unconfined groundwater levels: these maps help us understand the spatial distribution and flow conditions (flow direction and gradient) of the shallow groundwater. Examples of the surface, contour, and vector maps (for the time period of 1990-1999) are shown in Figures 17, 18, and 21, respectively.

    The vector map (Fig. 21) shows the conceptualized direction of groundwater flow in the Muskegon River watershed portion of Mecosta County. Generally, the unconfined groundwater flow directions are determined by the distribution of groundwater levels. Governed by the principles of mass balance, groundwater levels change with variations in recharge/source and discharge/sink. The specific magnitude of water level changes also depends on the properties of the geologic materials and groundwater flow conditions (including boundary conditions). Thus, there are many factors, including groundwater withdrawals, that may affect shallow groundwater levels and hence the corresponding flow directions. A pumping well may alter the local groundwater flow conditions at certain operation times. Pumping from a number of wells may temporarily or permanently change the regional flow condition. This study, however, does not provide any local distributions of groundwater levels and flow directions due to the limitations of the data we used.

    Basically, the overall flow pattern in the study area matches the related surface water system of the watershed. That is, the shallow groundwater flow directions are consistent with the topographic features of the watershed, although the boundaries of the two flow systems are not identical. As shown in Fig. 21, the eastern boundary of the study area is also the boundary of the Muskegon River Watershed, which is clearly not the boundary of the regional shallow groundwater system (the groundwater boundary would be perpendicular to the contour lines and parallel to flow directions). Since we do not have any groundwater pumping and level monitoring data, it is impossible to determine how pumping may have influenced the groundwater levels and flow directions during the three decades under consideration in this study. Also, because all the information provided herein is limited to the *unconfined* aquifer, no inferences can be made from the contour and vector maps on the impacts of urban wells that withdraw groundwater from the underlying *confined* aquifers.

(2) Three-dimensional surface maps of the unconfined groundwater depths: these maps show the depths of the water table, as well as their spatial and temporal variability during the three decades. An example for the time period of 1990-1999 is shown in Fig. 19.

(3) Three-dimensional surface maps of the unconfined groundwater level changes: we tried to utilize the limited data to outline the overall trend in groundwater level changes and the corresponding storage changes over a long time period (10, 20, or 30 years). An example of this type of map is shown in Fig. 20. Clearly, the quantitative interpretation of these maps is limited due to lack of data. To gain an insight into the detailed groundwater storage changes over years, a complete mass balance analysis should be performed, which requires much more data including groundwater pumping and monitoring data.

Please refer to Attachment 2 for details on the three types of groundwater maps. It should be pointed out that these groundwater maps (surface maps and/or contour maps of the groundwater levels, depths, and level changes) were generated by using the available static water level data that were grouped for different time periods. Thus, the maps only reflect average features about groundwater distributions during the indicated time periods and they do not represent the real spatial distributions at any specific time. Additionally, uneven distributions of the available wells in both space and time may result in disparate shapes in the maps for different time periods, or even improper interpolations. However, the maps do provide an overall understanding of groundwater distribution, which can be of use in evaluating impacts of future withdrawals from this region.

Table 5. Identity of different soil codes and their soil types (materials).

No.	Soil Code	Materials
1	0	Surface
2	10	Clay
3	13	Sandy Clay
4	17	Clay & Gravel
5	20	Sand
6	21	Fine Sand
7	22	Medium Sand
8	23	Coarse Sand
9	25	Sand & Gravel
10	26	Sand/Stone/Gravel
11	27	Sand & Clay
12	29	Water Sand
13	30	Gravel
14	32	Gravel & Sand
15	35	Coarse Gravel
16	36	Water Gravel
17	37	Gravel & Cobbles
18	40	Topsoil
19	49	Fill
20	99	Water Material

Summary: The water quality data indicate that most of the sampled wells within the Muskegon River watershed portion of Mecosta County do not have significant environmental problems. There are no obvious patterns between the bacterial numbers and the physical/chemical attributes measured, which may be a result of bacterial numbers being within too narrow a numeric range (due to their low values) or our sampling being at too coarse a scale to detect patterns. Additional monitoring may be needed in the future, especially in locations where the Health Department may suspect potential contamination due to specific land uses (cf. Trojan et al. 2003).

The conceptual groundwater flow model revealed no major surprises. Glacial drift sediments cover nearly all of the bedrock basin of the southern peninsula of Michigan. From about 1.8 million years ago, until the eventual disappearance of the ice approximately 10,000 years ago, glaciers re-worked and deposited vast layers of sand, clay, and gravel over the ancient bedrock surface of the Michigan Basin. The melt water from the retreating glaciers flowed down pre-existing channels in the bedrock, etching paths, that today constitute Michigan's many rivers and streams.

In Mecosta County, the Muskegon and Little Muskegon Rivers follow some of these remnant glacio-fluvial valleys to form the predominant surface water drainages in our project area. These rivers and their many tributaries send surface and ground water along their main stems in a south-westerly direction to Lake Michigan. The sub-surface groundwater flow, and especially the flow within the unconfined or "free water table" aquifer, is thought to essentially mimic these flow paths established by the surface water drainage. The conceptual modeling of the unconfined sub-surface system confirms this premise by describing the conceptualized directions of groundwater flow along paths that surface water would similarly travel (Fig. 21). The small arrow-like flow vectors within the map describe the direction of groundwater flow, intersecting the contoured unconfined groundwater isopleth depths at right angles. These flow vectors mark similar paths that surface water would potentially take along the land surface. The three-dimensional surface map of the unconfined groundwater levels (Fig. 17) strikingly illustrates this concept by projecting these flows paths as a continuous and undulating surface, showing the high and low areas within the water table. These changes in the sub-surface water topography are directly correlated with the undulations in elevation present at the surface in the project area.

Finally, the data suggest there are portions of the study region that are experiencing groundwater declines over time (Fig. 20). One must be cautious in interpreting these data, as they are aggregated over large spatial and temporal scales; however, they do suggest that these regions (within the Muskegon River valley of the watershed in the county) merit watching in the future.

Figure 17. Three-dimensional surface map of the unconfined groundwater levels (1990-1999) within the entire county. The more blue the surface, the higher the absolute elevation of the water table. Bottom center corner represents southwestern corner of Mecosta County (bottom left corner in Figure 12). Note that the groundwater level distribution is generally consistent with overall topographic features of the watershed (relate to Figure 12). Units are in meters.

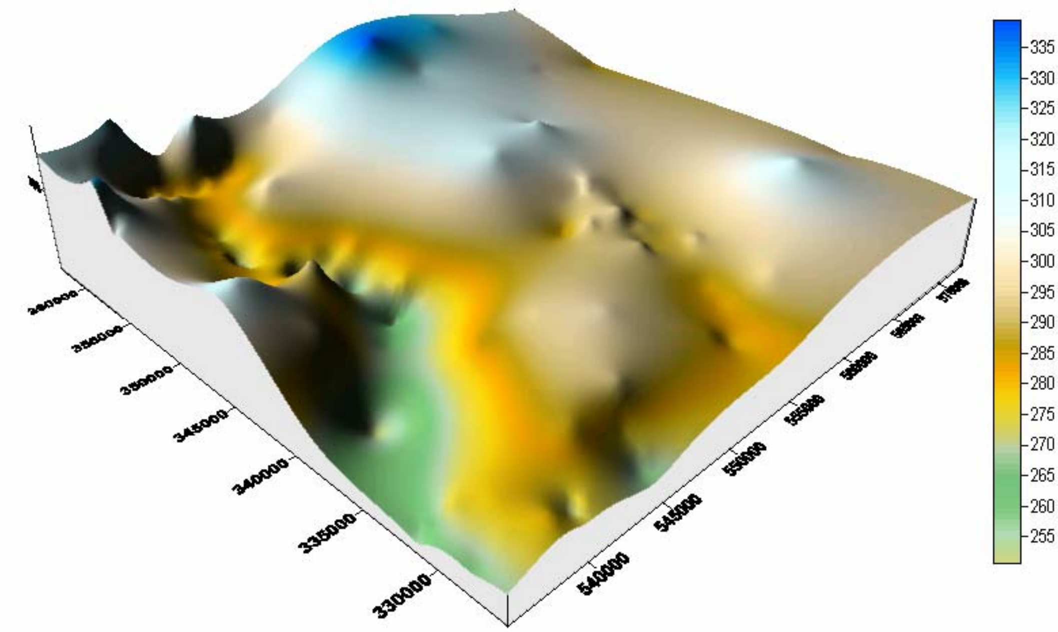


Figure 18. Two-dimensional contour map of the unconfined groundwater elevations (1990-1999) for the portion of the Muskegon River Watershed within Mecosta County. Units are in meters.

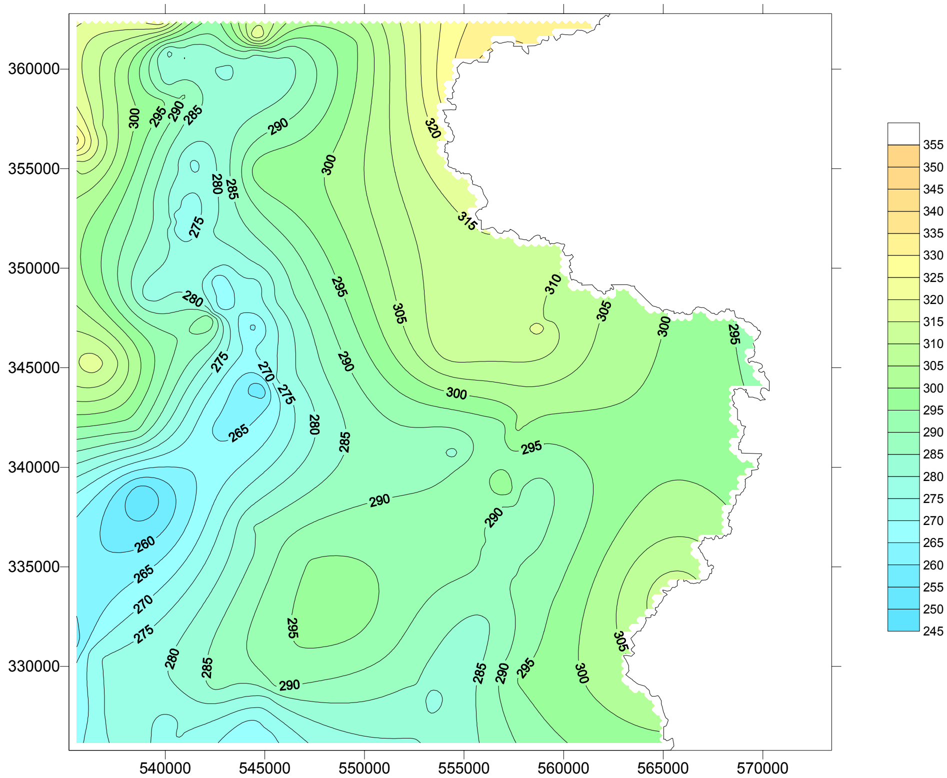


Figure 19. Three-dimensional surface map of the unconfined groundwater depths (1990-1999). The more blue the surface, the closer the water table is to the ground surface. Bottom center corner corresponds to southwestern corner of Mecosta County (bottom left corner in Figure 12). Units are in meters.

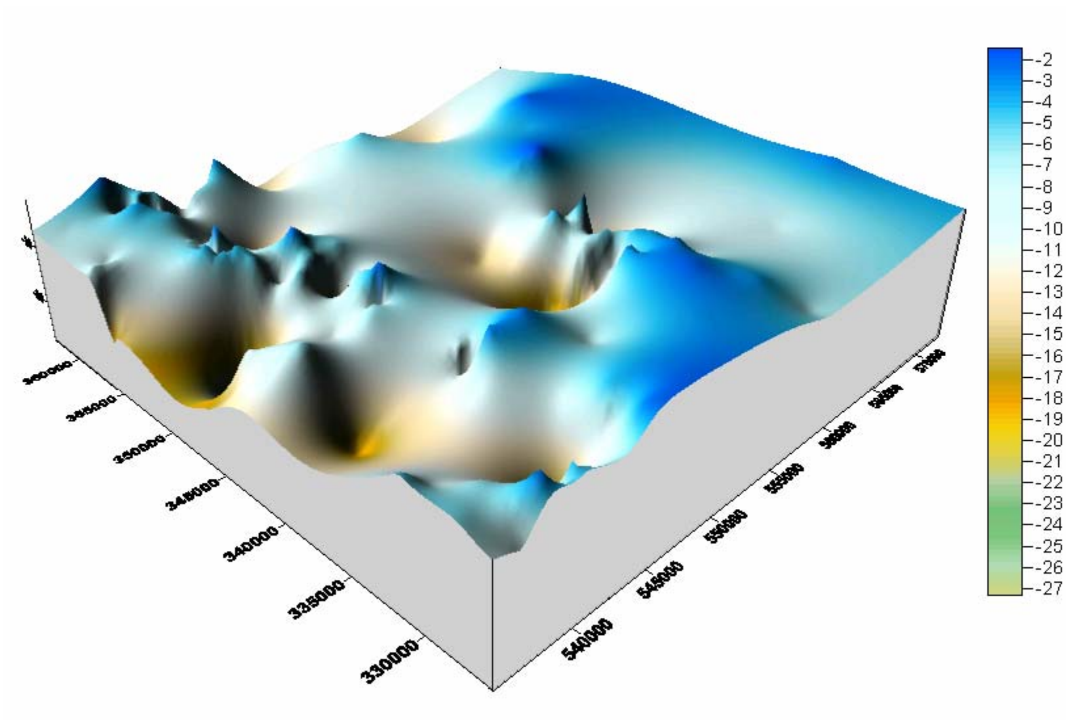


Figure 20. Three-dimensional surface map of the groundwater level changes between the time periods of 1966-1975 (past) and 1990-1999 (recent). Specific locations may not reflect real water level change due to uneven distribution of well data in both space and time (see special note in Attachment 1). Blue surfaces represent a net increase in groundwater level; green surfaces represent a net decrease in groundwater level. Bottom center corner corresponds to southwestern corner of Mecosta County (bottom left corner in Figure 12). Units are in meters.

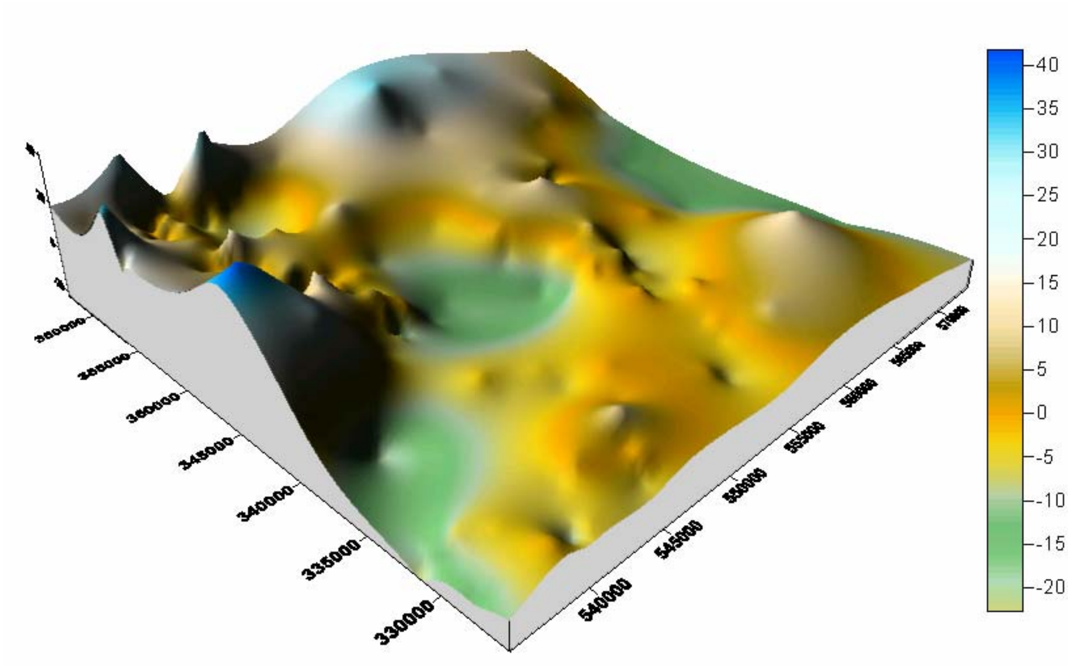
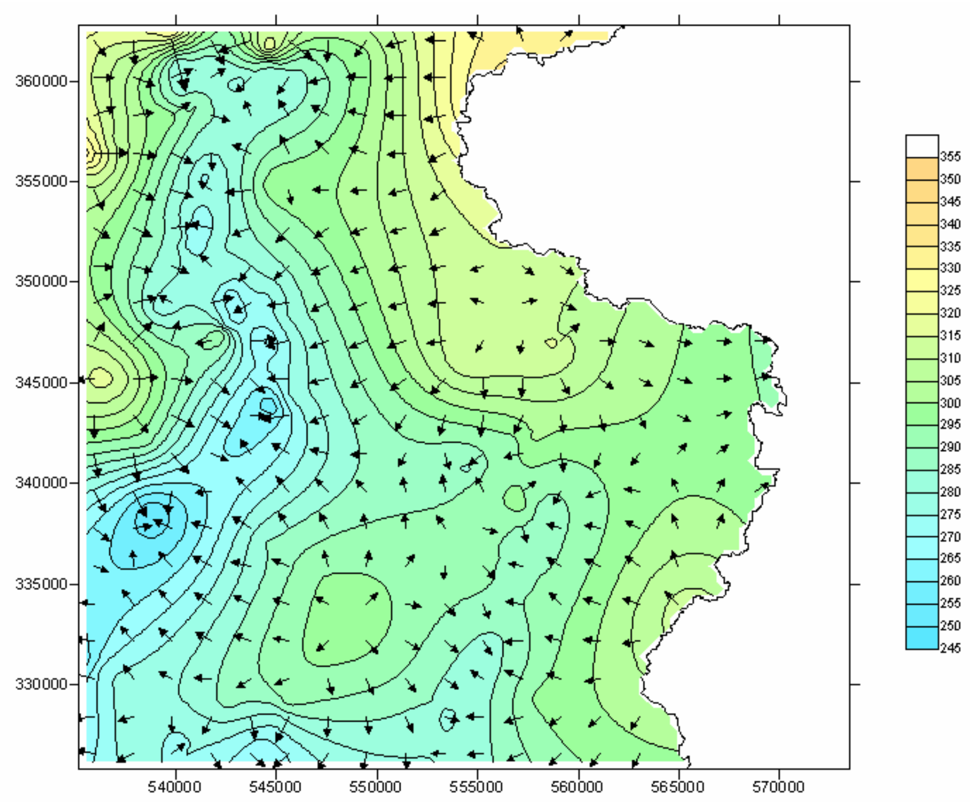


Figure 21. Vector diagram showing conceptualized direction of groundwater flow (for 1990-1999 period) for the portion of the Muskegon River Watershed within Mecosta County. Units are in meters.



Task 5: Host workshop in Big Rapids at Ferris State University

The workshop to be hosted by the AWRI to distribute data and train project partners is scheduled for May, 2005. Participants of the workshop will have "hands on" training in the use of all the GIS data layers assembled for the Mecosta County groundwater project. The workshop will be held at a geographic information system laboratory at Ferris State University (FSU). Dr. Yaron A. Felus, an Assistant Professor in the Surveying Engineering department at FSU, has generously allowed the AWRI staff to use his facility to teach the workshop. At present, anticipated participants include (in addition to the trainers, Kurt Thompson and Jonathon Ginka from AWRI):

- Gary Noble - Executive Director - Muskegon River Watershed Assembly
- Terry Stilson - Executive Assistant - Muskegon River Watershed Assembly
- Ron Schumacher - Supervising Sanitarian -District #10 Health Department
- Mark Hill - Sanitarian -District #10 Health Department
- Donald Greiner, P.E. - City Engineer/Utilities Director - City of Big Rapids, Mecosta County
- Christina Curell - Mecosta-Montcalm Groundwater Agent- Michigan State University Extension
- Charmaine Lucas - Mecosta County Conservation District

Task 6: Final report

This task is completed, as evidenced by this report.

References

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2. Refer to the original grant request from your organization and compare your results to the goals and objectives described in the proposal.

All goals and objectives have been attained except for Task 5, which after discussion with personnel from the Fremont Area Community Foundation, it was agreed that the final workshop could be held in May, 2005.

3. **Again relating to the goals in the request, what are the specific outcomes of the project or program? What impact did your project/program have on the population served? What were the benefits of the program? Are you doing any long term tracking of participants?**

There have been a number of specific outcomes. These include a number of presentations, a GIS-based model that will be of assistance to the local Health Department sanitarians, and baseline information on groundwater quality and flow patterns.

- Presentation to the MDEQ Groundwater Conservation Advisory Council: January, 2005.
- Project highlighted in AWRI 2004 Year in Review (enclosed)

4. **Was anything NOT accomplished as planned; or were there any unanticipated problems encountered with this project?**

The most significant unanticipated problem was the uncertainty associated with the well log data; filtering out inappropriate or obviously erroneous records was more time-consuming than originally anticipated. In addition, the resulting number of wells, on which the mapping and flow models were based, were not as well populated as we would have preferred.

Budget

1. Please itemize specifically how FACF's grant funds were utilized, and also funds from other sources. Make sure your report corresponds with the budget in your grant proposal.

We have attached our itemized budget (Table 2).

2. Please include your most recent audit or annual report if not previously submitted.

This was submitted previously.

3. If specific items were purchased, please include copies of paid invoices.

Not applicable

Table 2. Year 2 budget for the Mecosta County Well Water project.

Mecosta County Well Project 4-26541
Year 2 Budget - 4/1/04-4/30/05

A. Salaries & Wages	FACF Funds	In Kind Match	Total Proj Costs	Expended 6/30/2004	7/1/04 to 4/15/2005	Total Expended	Balance
Alan Steinman	0	4,427.50	4,427.50	1,492.40	4,258.66	5,751.06	(1,323.56)
Rick Rediske	0	3,013.78	3,013.78	1,032.96	3,250.58	4,283.54	(1,269.760)
Kurt Thompson	5118	0.00	5,117.50	1,732.49	2,784.71	4,517.20	600.300
John Koches	0	2,953.18	2,953.18	1,701.52	1,615.92	3,317.44	(364.259)
Michael Chu	0	4,312.00	4,312.00	1,453.43	3,313.77	4,767.20	(455.200)
Bopi Biddanda	0	4,312.00	4,312.00	1,453.50	3,313.76	4,767.26	(455.260)
Janet Vail	0	1,354.70	1,354.70	555.15	1,605.12	2,160.27	(805.570)
Tonya Cnossen	1405	0.00	1,405.25	387.08	1,052.45	1,439.53	(34.280)
Student AS	4034	0.00	4,034.19	1,831.50	1,570.50	3,402.00	632.193
Student JG	2025	0.00	2,024.60	1,338.76	1,413.68	2,752.44	(727.845)
Student SK	0	0.00	0.00	0.00	981.00	981.00	(981.000)
Total Salaries & Wages	**12582**	**20,373.16**	**32,954.70**	**12,978.79**	**25,160.15**	**38,138.94**	**(5,184.241)**
B. Fringe Benefits							
Alan Steinman	0	1,500.92	1,500.92	524.82	1,489.23	2,014.05	(513.128)
Rick Rediske	0	1,021.67	1,021.67	360.59	1,196.51	1,557.10	(535.429)
Kurt Thompson	1735	0.00	1,734.83	606.70	1,029.75	1,636.45	98.383
John Koches	0	1,001.13	1,001.13	596.81	600.61	1,197.42	(196.292)
Michael Chu	0	1,461.77	1,461.77	509.38	1,224.66	1,734.04	(272.272)
Bopi Biddanda	0	1,461.77	1,461.77	508.36	1,222.85	1,731.21	(269.442)
Janet Vail	0	459.24	459.24	194.35	592.99	787.34	(328.097)
Tonya Cnossen	544	0.00	543.83	167.74	492.97	660.71	(116.878)
Student #1	323	0.00	322.74	145.80	125.01	270.81	51.925
Student #2	162	0.00	161.97	102.42	30.43	132.85	29.118
Student #3	0	0.00	0.00	0.00	78.09	78.09	(78.090)
Total Fringe Benefits	**2763**	**6,906.50**	**9,669.87**	**3,716.97**	**8,083.10**	**11,800.07**	**(2,130.201)**
TOTAL SALARIES AND FRINGE	**15345**	**27,279.66**	**42,624.57**	**16,695.76**	**33,243.25**	**49,939.01**	**(7,314.442)**
C. Travel							
4 trips @ 300 miles/trip (0.36/mi)	432	0.00	432.00	285.83	32.25	318.08	113.920
2 trips @ 100 miles/trip (0.36/mi)	72	0.00	72.00	0.00	0.00	0.00	72.000
Total Travel	**504**	**0.00**	**504.00**	**285.83**	**32.25**	**318.08**	**185.920**
D. Office Supplies							
plotter paper, ink	2050	0.00	2,050.00	1,025.00	1,657.55	2,682.55	(632.55)
postage	100	0.00	100.00	0.00	0.00	0.00	100.00
printing, copying	400	0.00	400.00	1.44	1.40	2.84	397.16
Total Office Supplies	**2550**	**0.00**	**2,550.00**	**1,026.44**	**1,658.95**	**2,685.39**	**(135.39)**
E. Materials							
$80/sample for all parameters (2(	1600	0.00	1,600.00	0.00	1,909.79	1,909.79	(309.79)
Total Materials	**1600**	**0.00**	**1,600.00**	**0.00**	**1,909.79**	**1,909.79**	(309.79)
Year 2 Expenses	19999	27,279.66	47,278.57	18,008.03	36,844.24	54,852.27	(7,573.70)

Publicity

1. **Attach any printed materials relating to your program; press or newsletters, brochures, photographs, etc.**

AWRI's 2004 Year in Review is included, in which a story on this project is presented on pp. 5-6.

2. **If appropriate and confidentiality is not an issue, please include two photographs suitable for use in the Foundation's periodicals or annual report.**

Figures of laboratory analyses of groundwater samples and GIS data files were included in the mid-year report. Map images are included in the attachments of this report.

Attachments

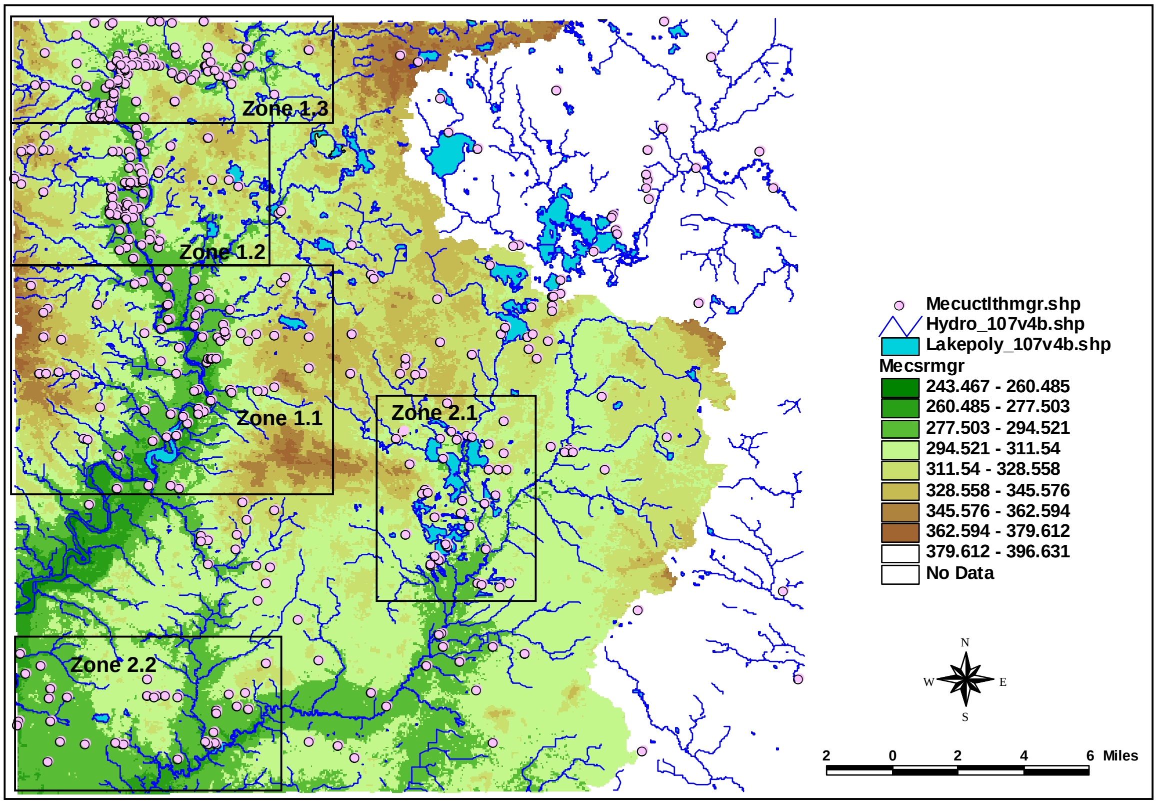
Attachment 1. Borehole data analysis and three-dimensional stratigraphy models.

Attachment 2. Mapping of groundwater flow and distribution.

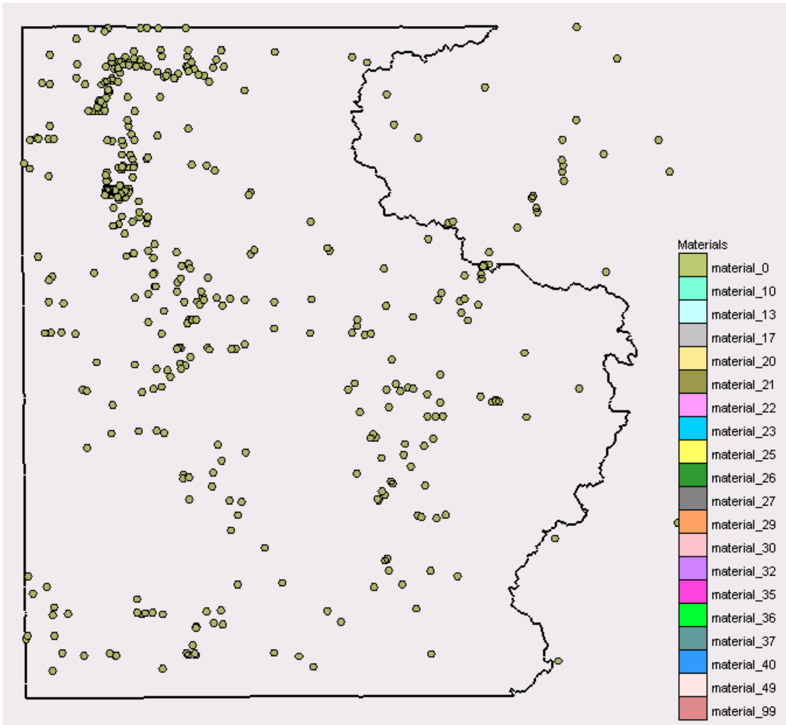
Attachment 1

Borehole Data Analysis and Three-Dimensional Stratigraphy Models

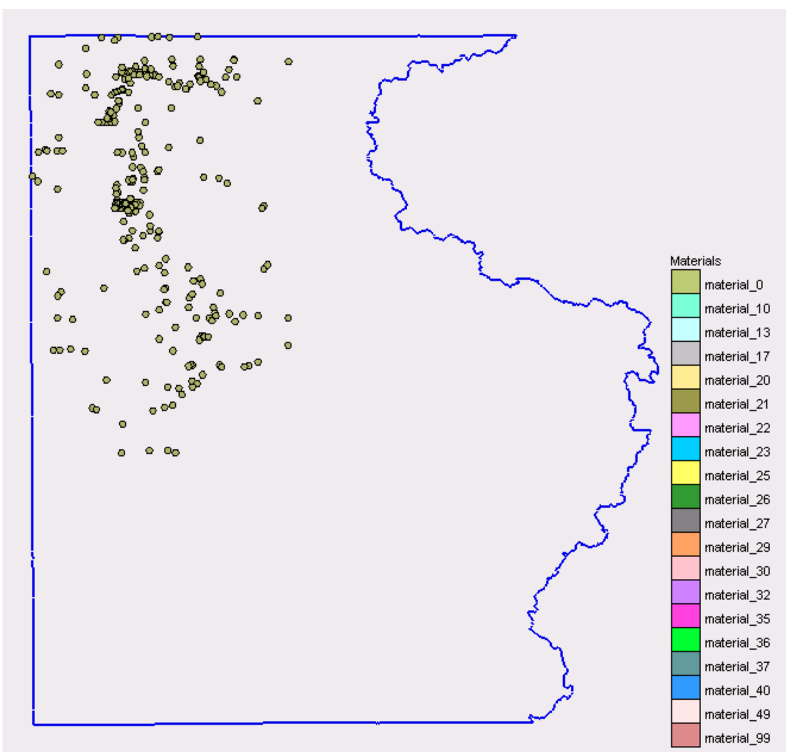
Location of Zones and Distribution of Boreholes



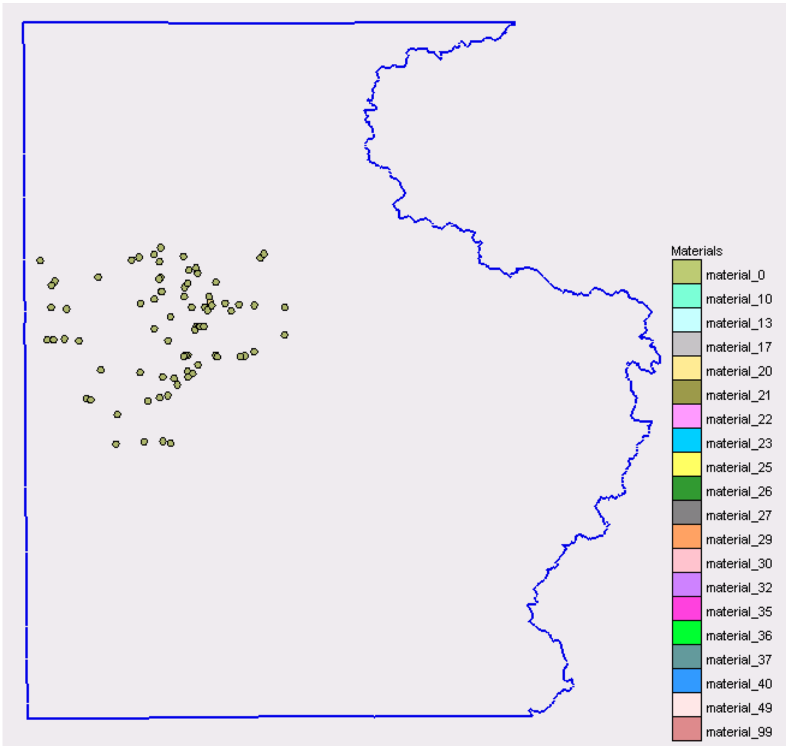
Distribution of All Boreholes



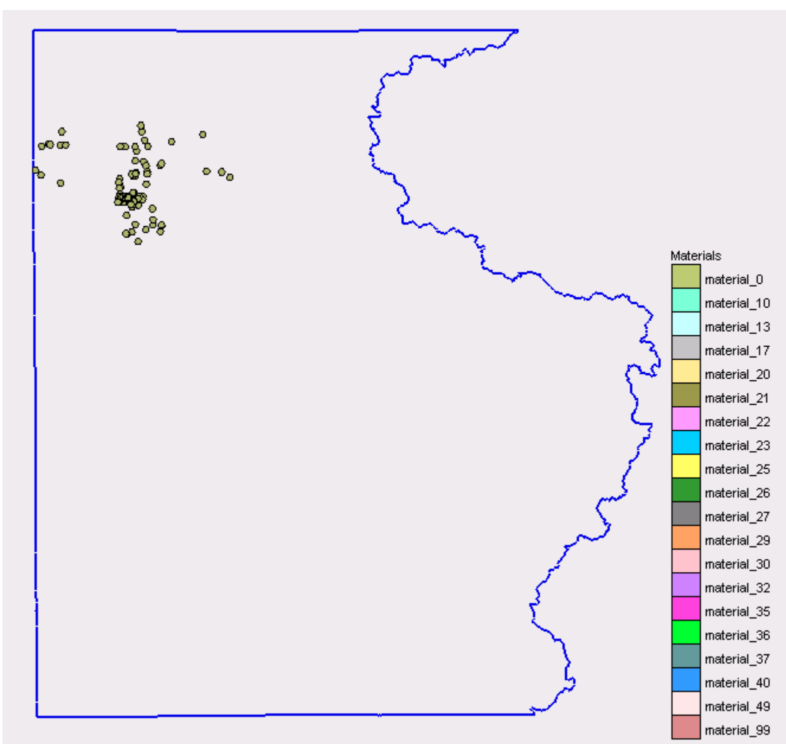
Boreholes in Zone 1



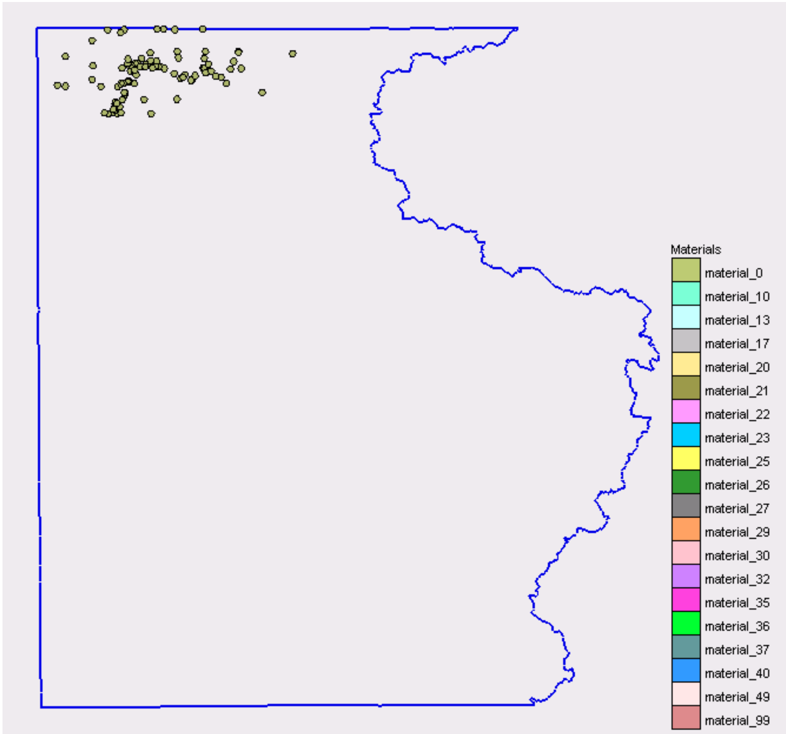
Boreholes in Zone 1.1



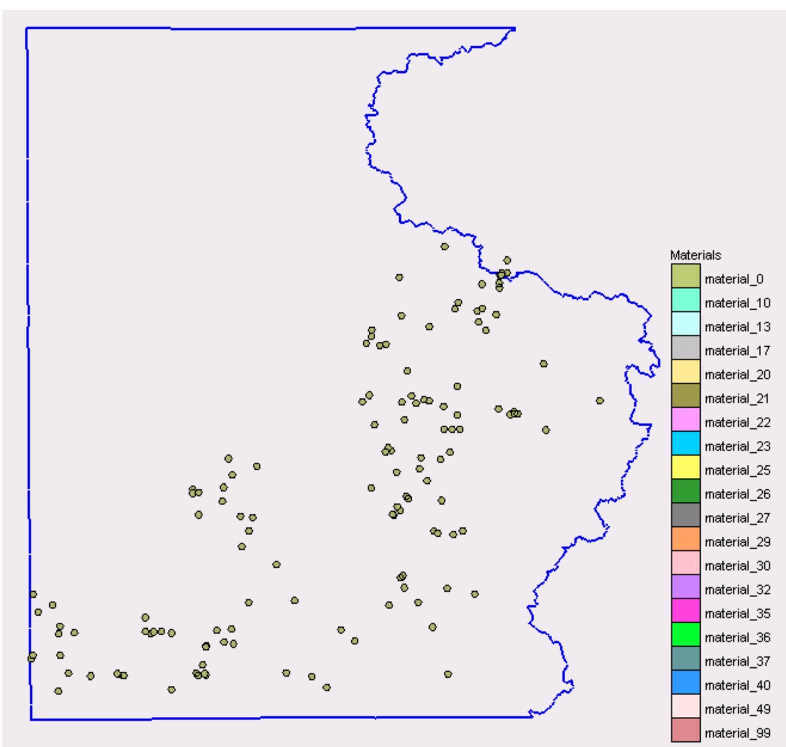
Boreholes in Zone 1.2



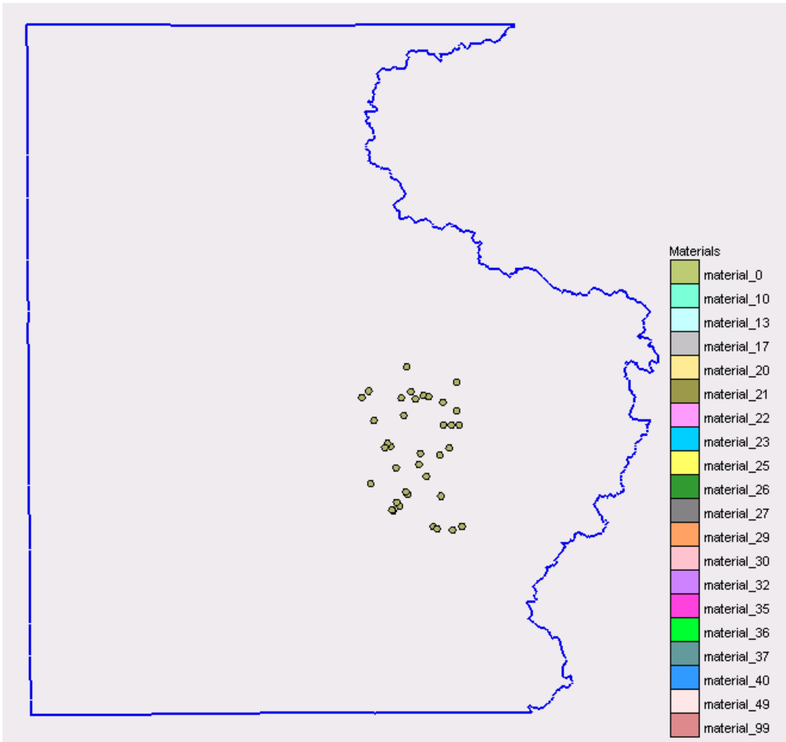
Boreholes in Zone 1.3



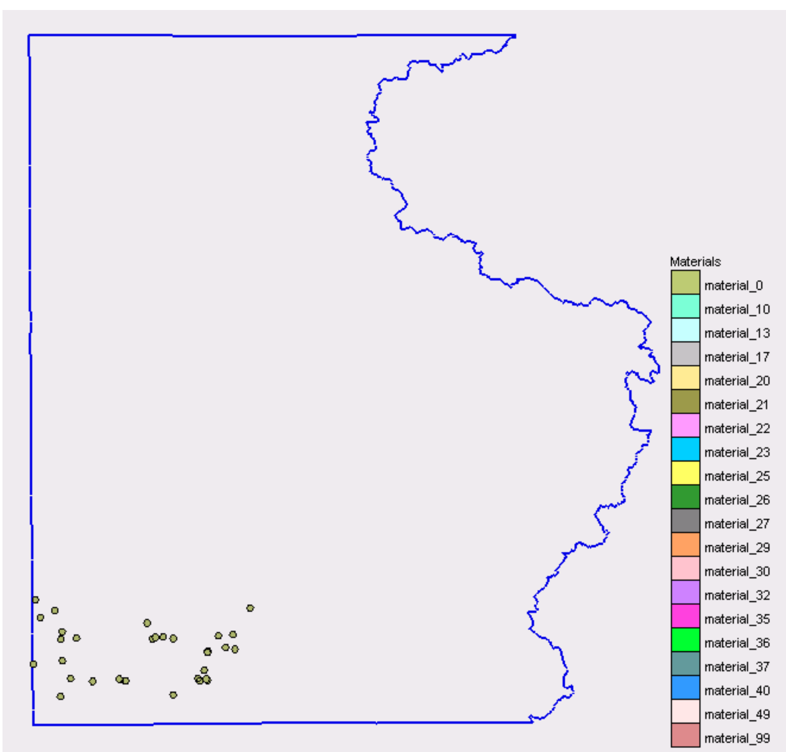
Boreholes in Zone 2



Boreholes in Zone 2.1



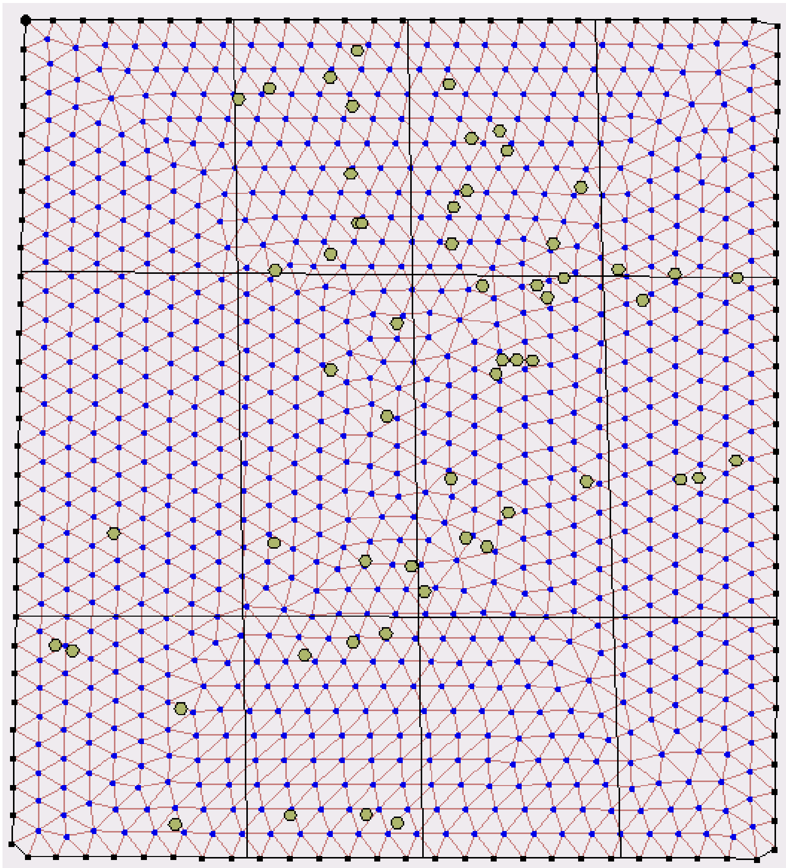
Boreholes in Zone 2.2

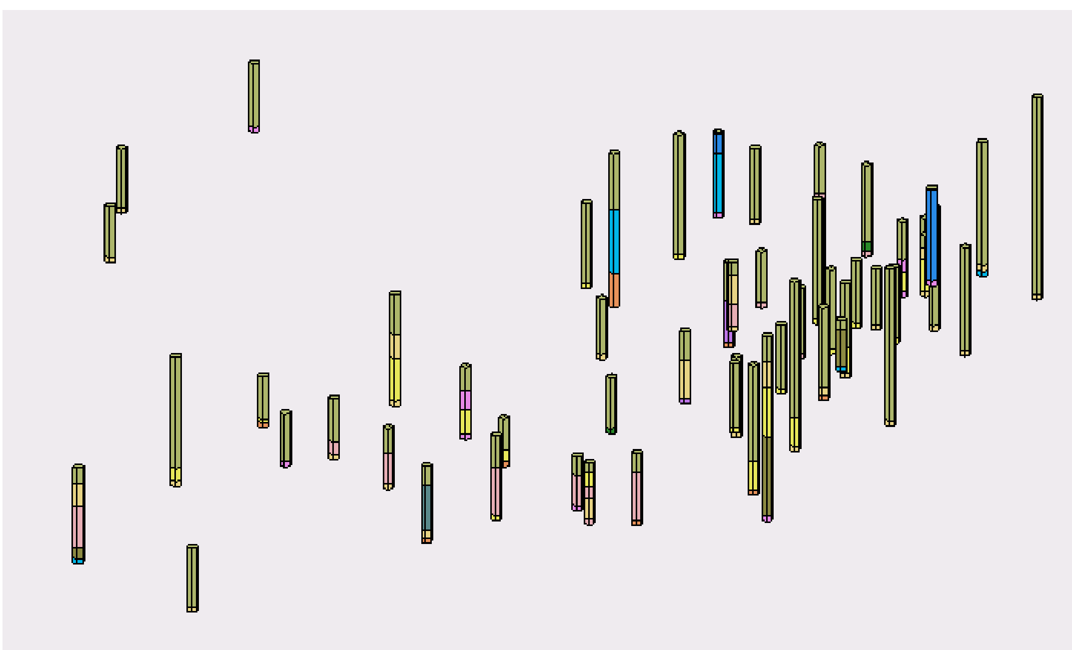


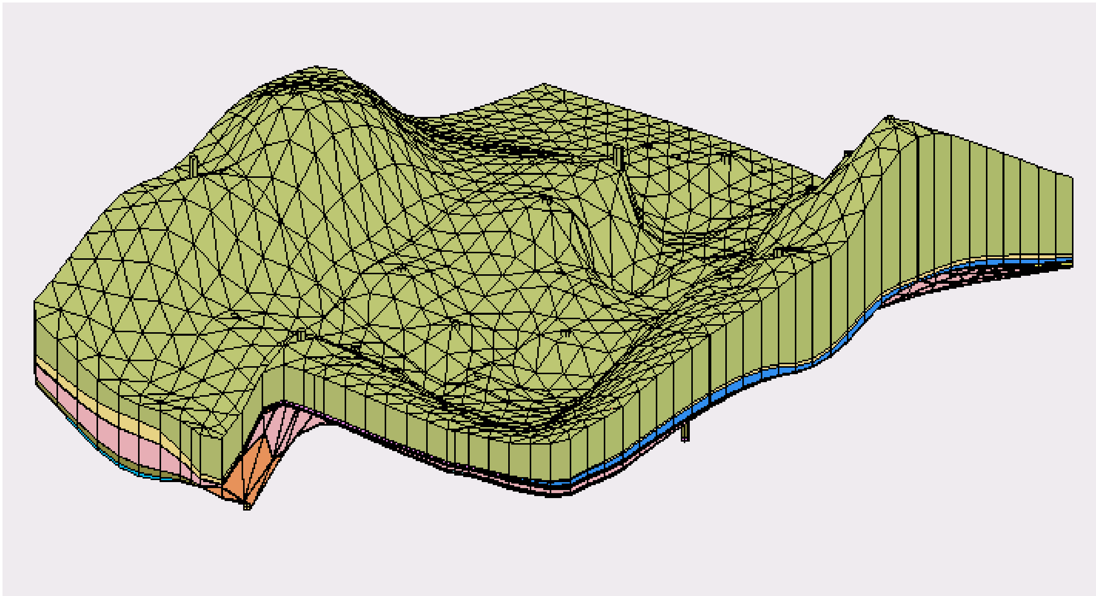
Soil Code and Material Table

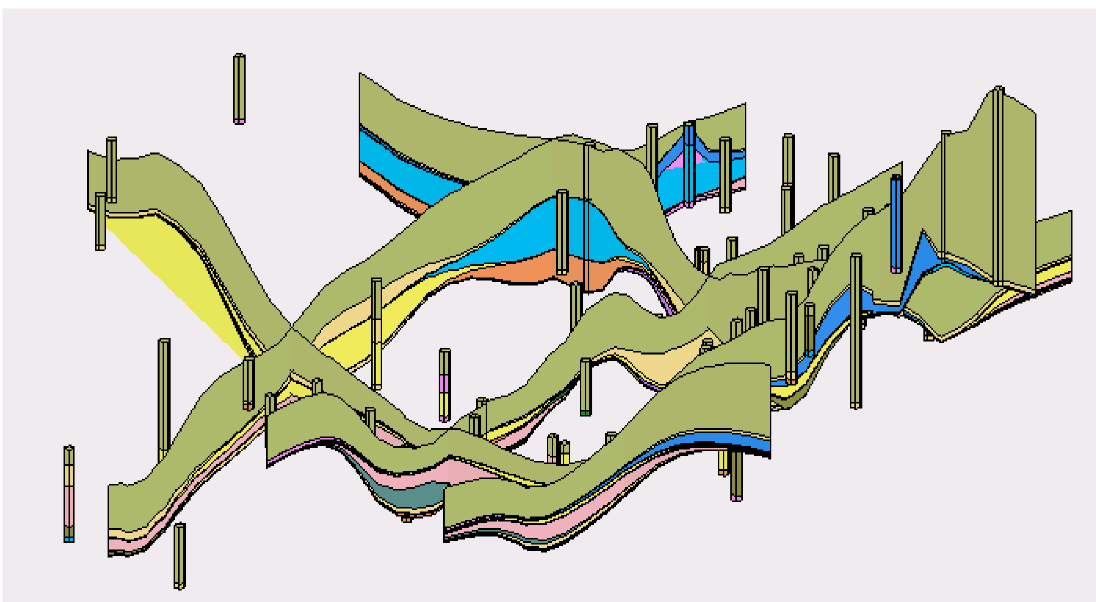
No.	Soil Code	Materials
1	0	Surface
2	10	Clay
3	13	Sandy Clay
4	17	Clay & Gravel
5	20	Sand
6	21	Fine Sand
7	22	Medium Sand
8	23	Coarse Sand
9	25	Sand & Gravel
10	26	Sand/Stone/Gravel
11	27	Sand & Clay
12	29	Water Sand
13	30	Gravel
14	32	Gravel & Sand
15	35	Coarse Gravel
16	36	Water Gravel
17	37	Gravel & Cobbles
18	40	Topsoil
19	49	Fill
20	99	Water Material

Stratigraphy Model for Zone 1.1

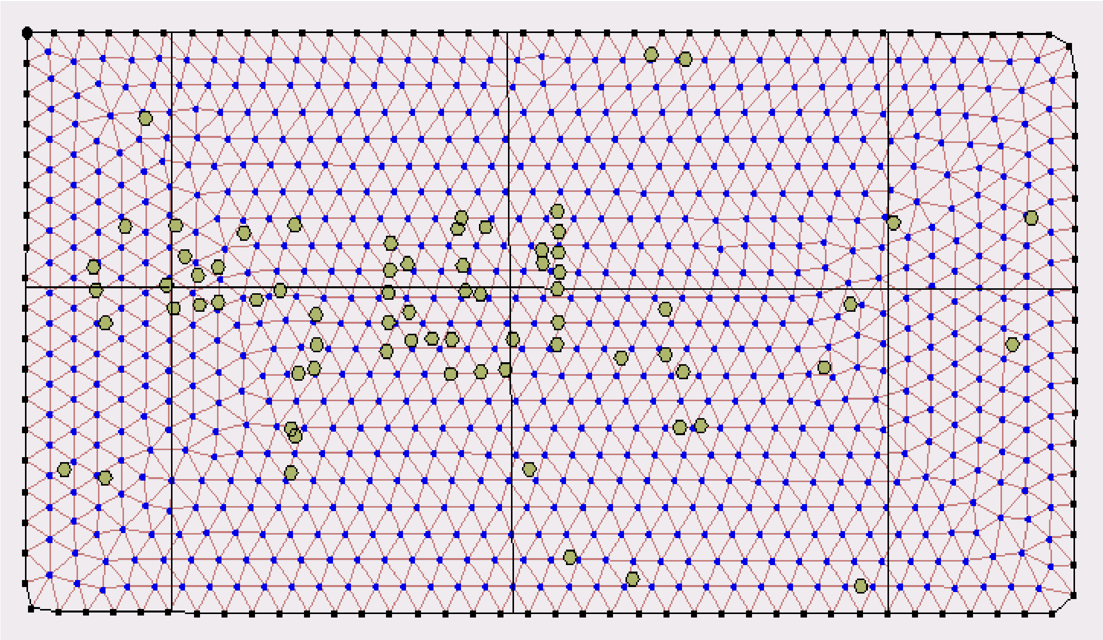


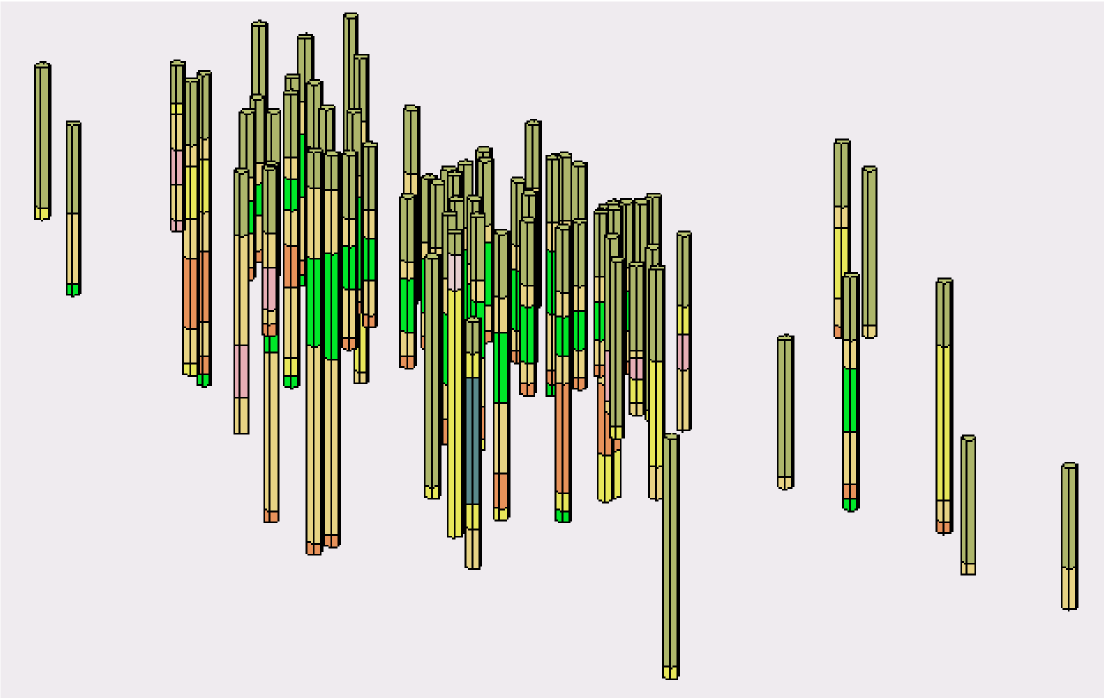


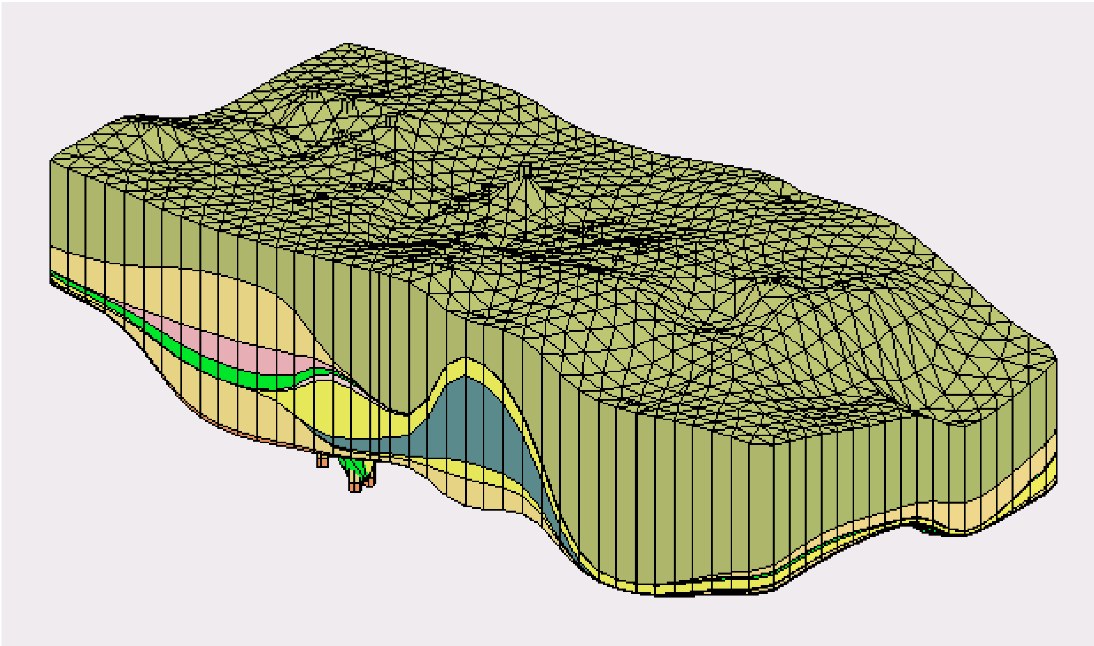


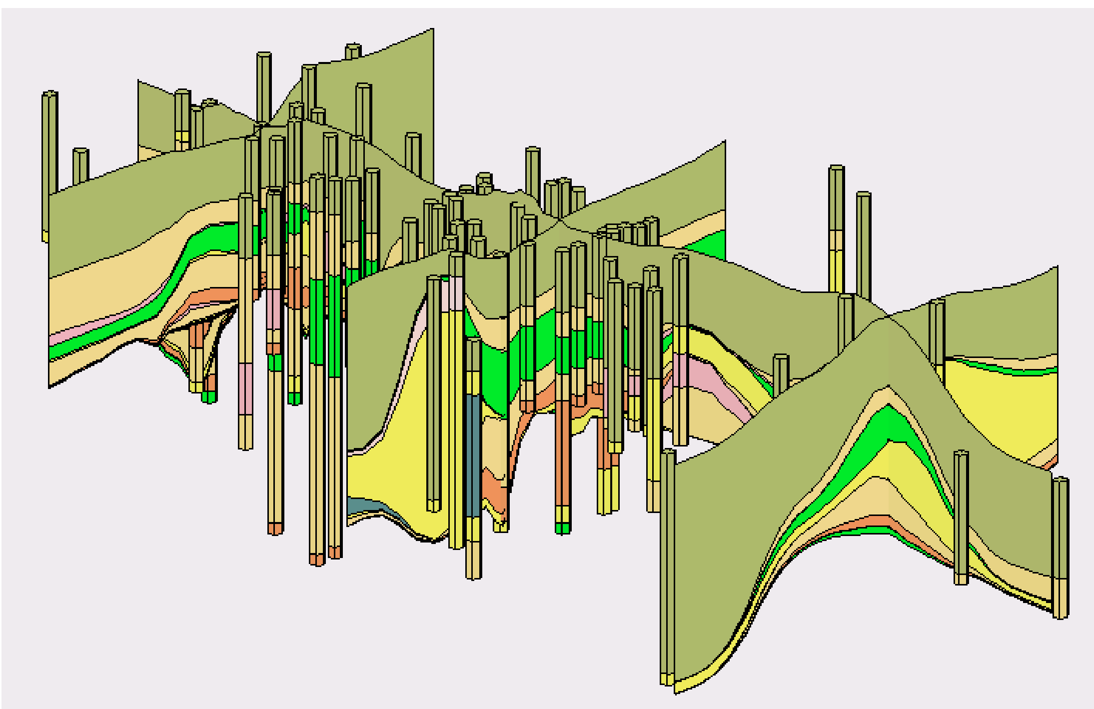


Stratigraphy Model for Zone 1.2-1

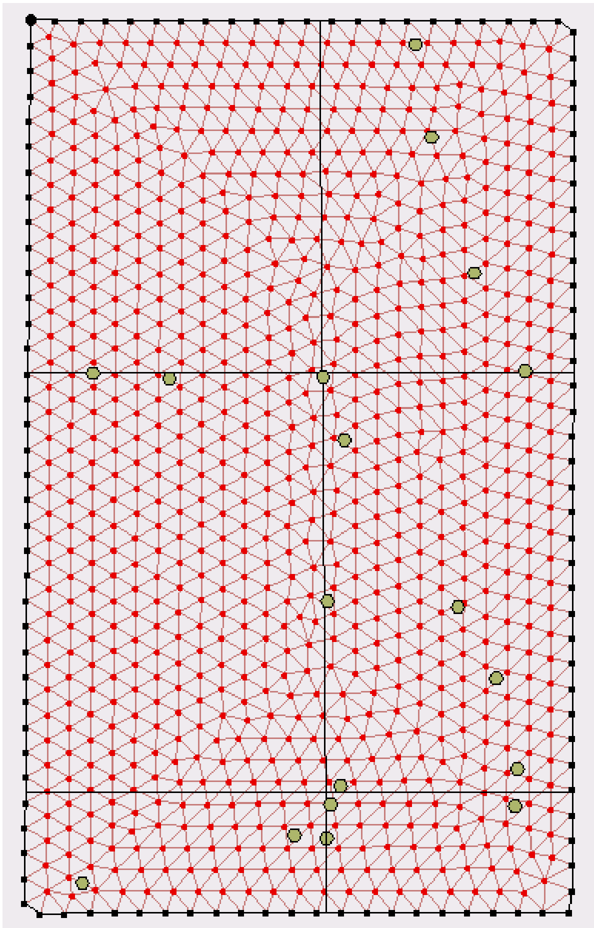


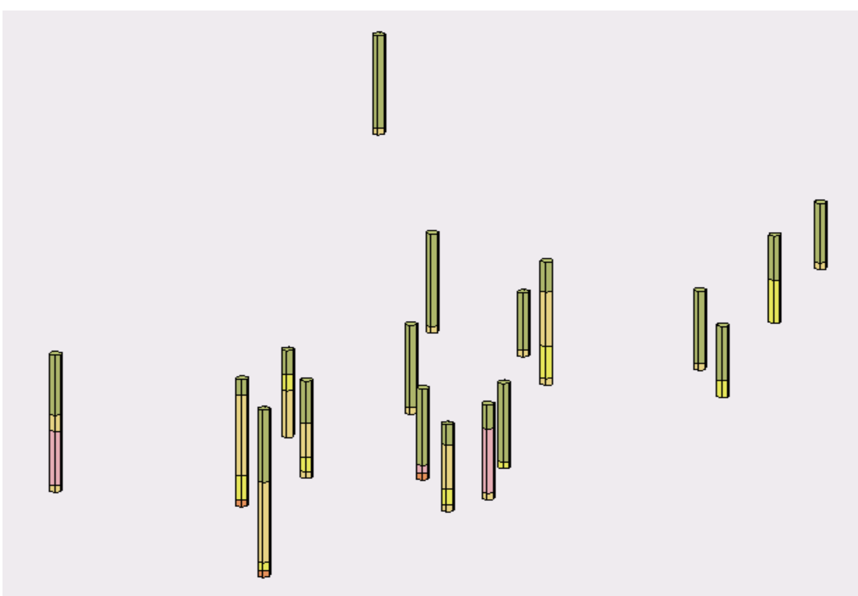


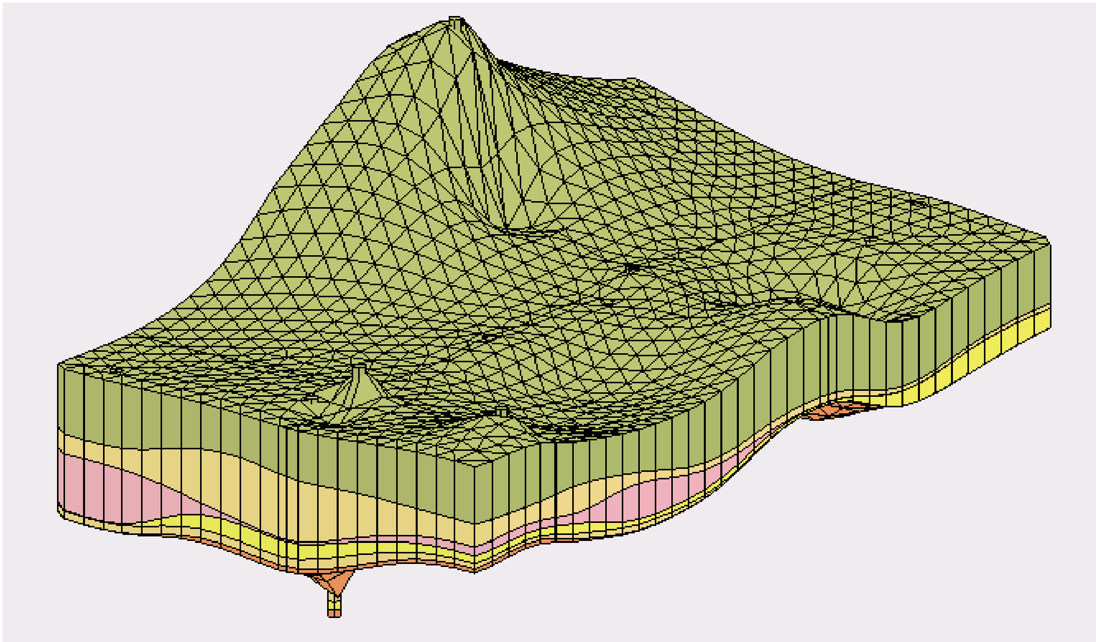


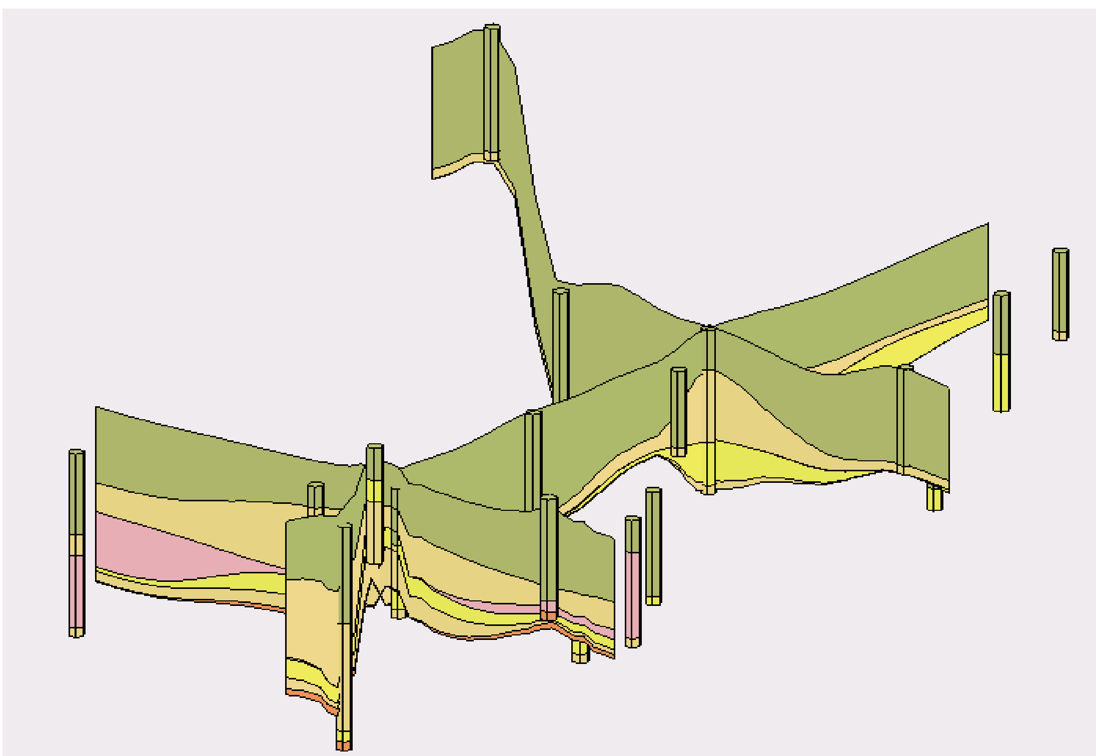


Stratigraphy Model for Zone 1.2-2

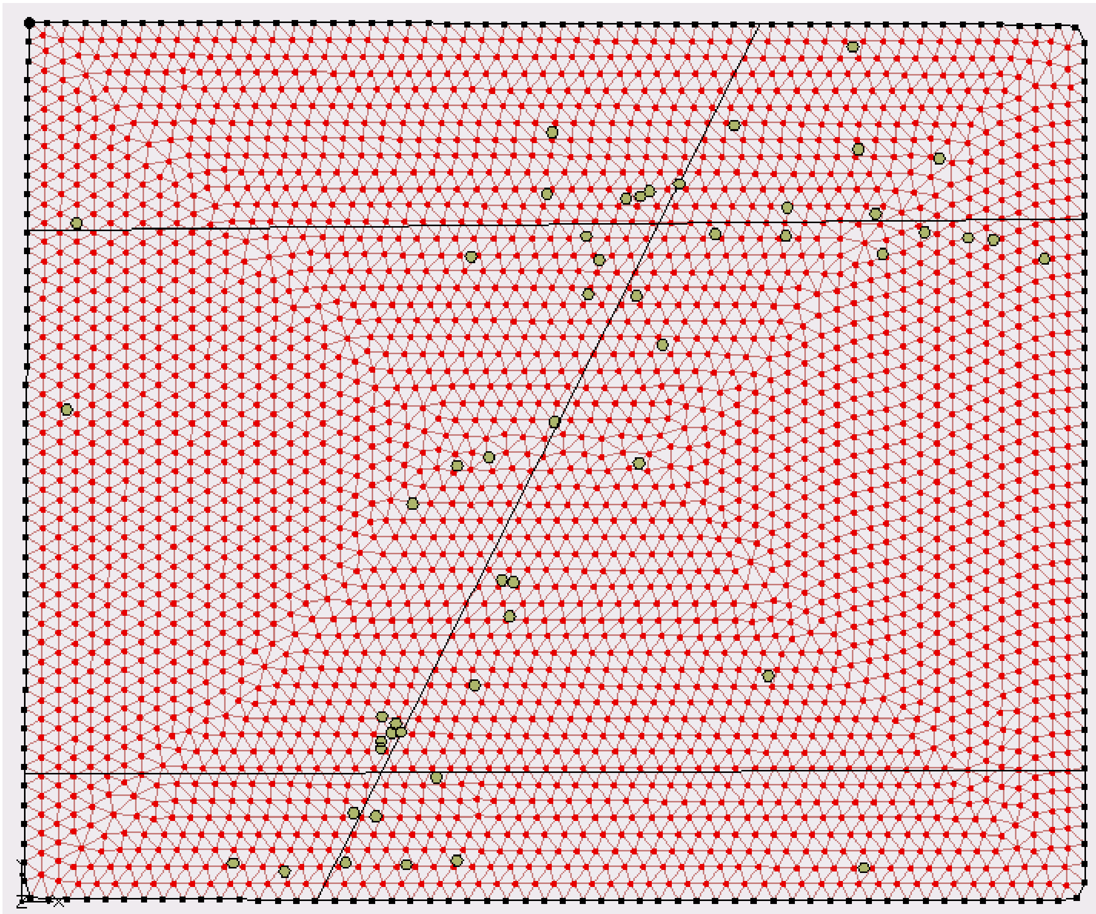


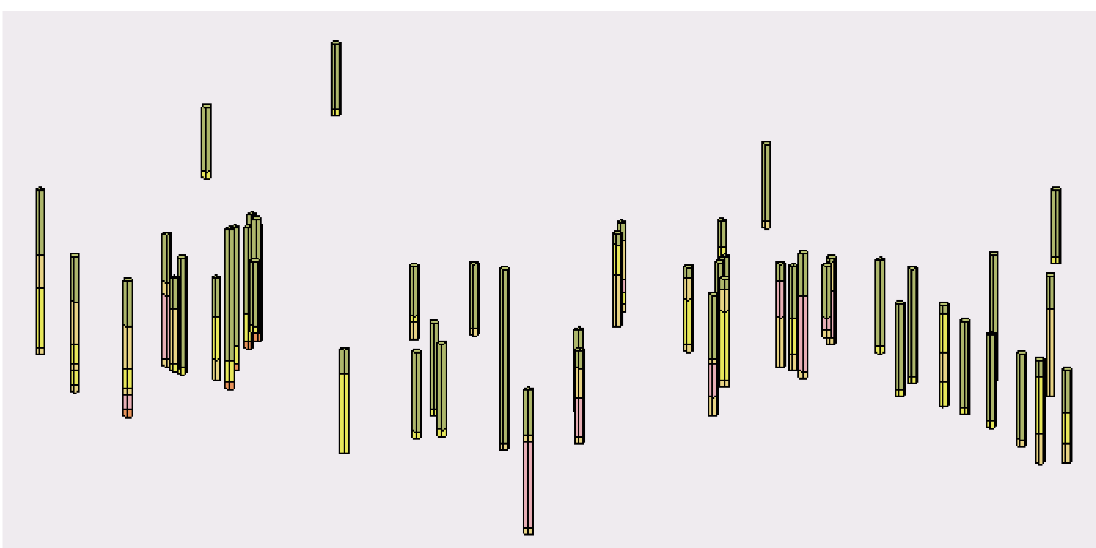


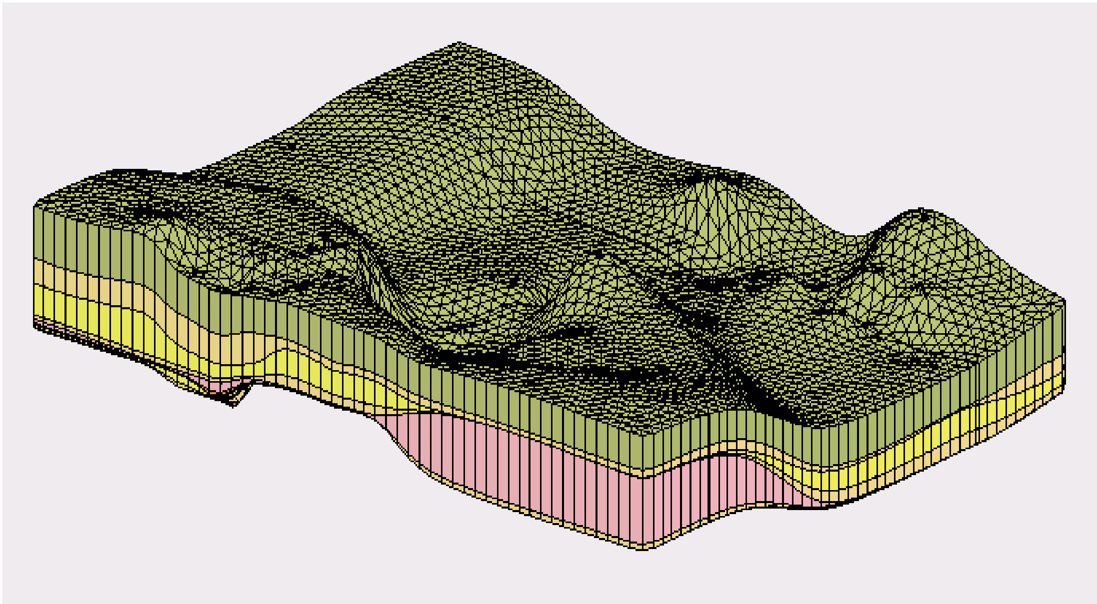


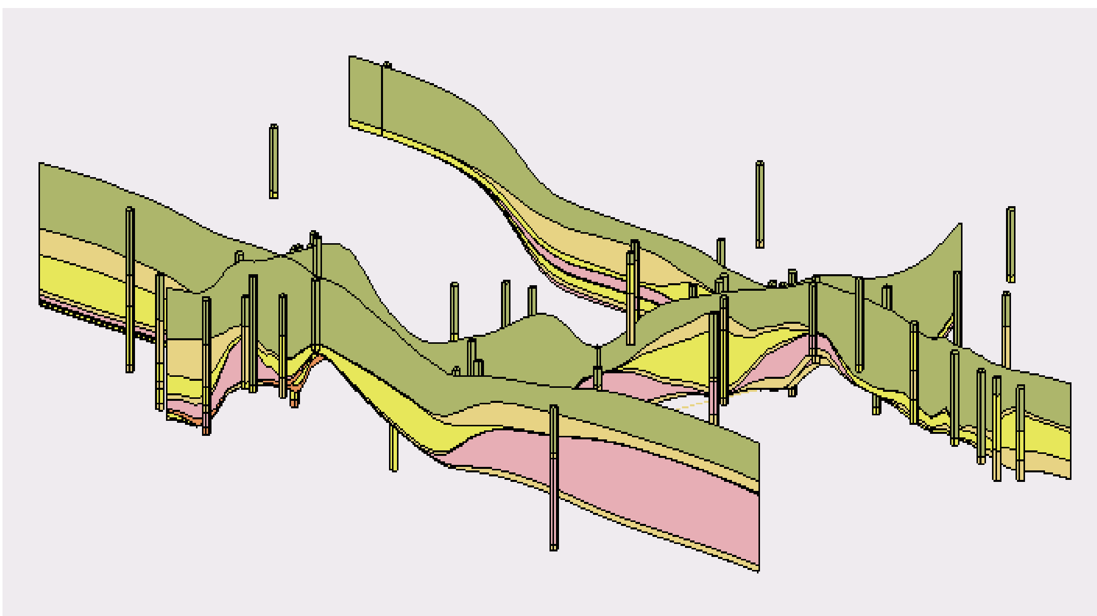


Stratigraphy Model for Zone 1.3-1

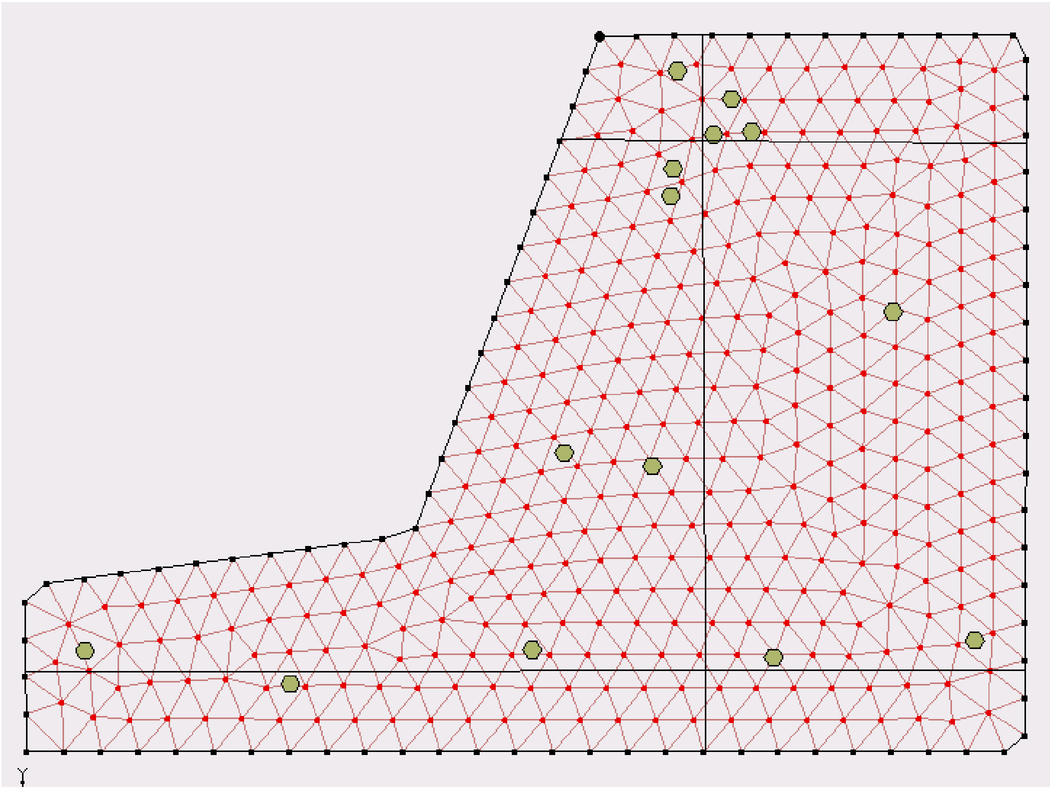


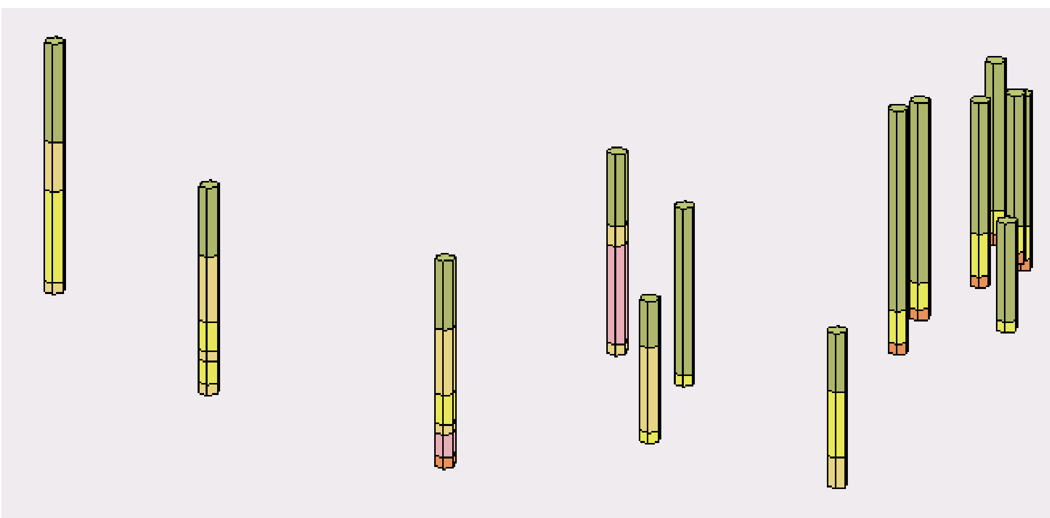


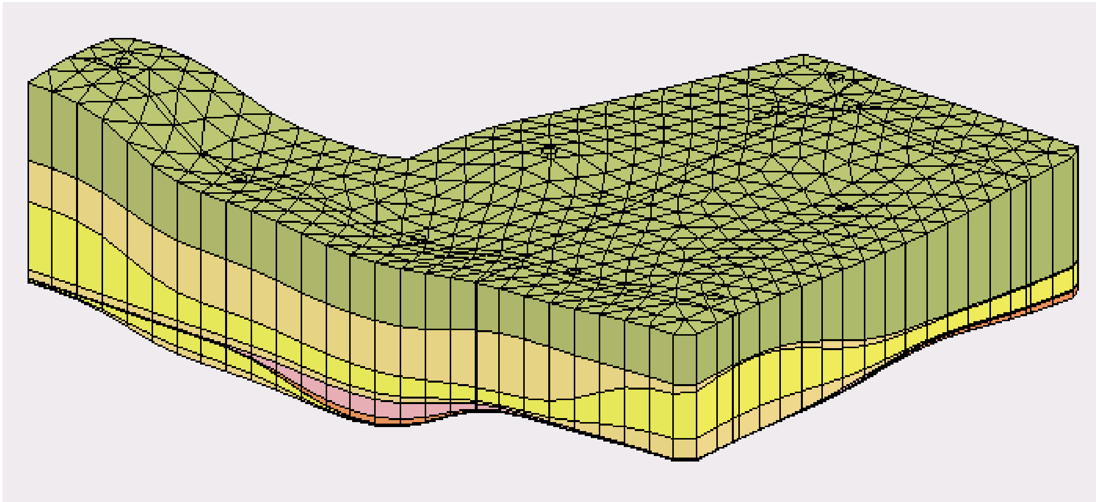


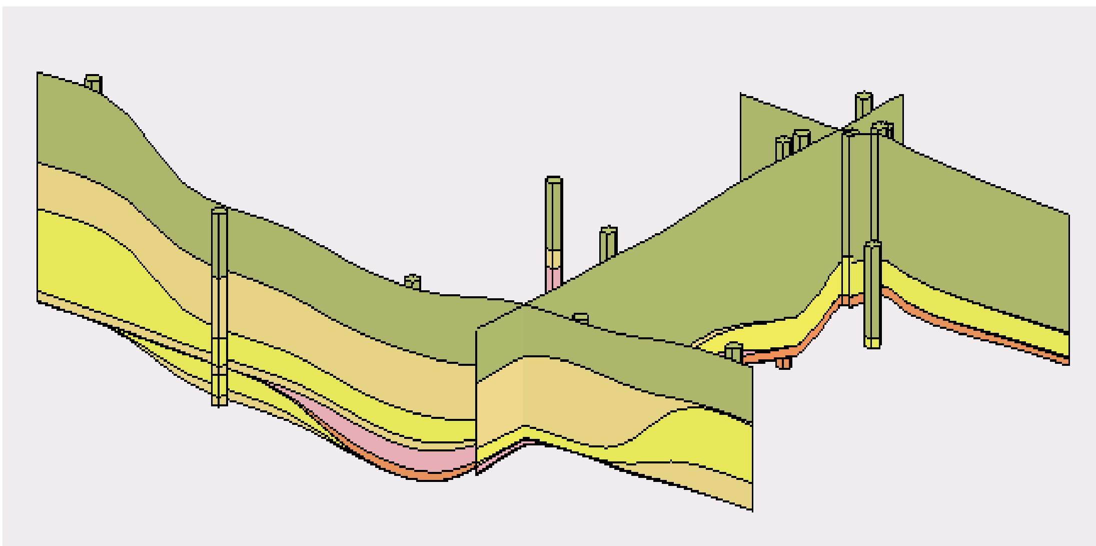


Stratigraphy Model for Zone 1.3-2

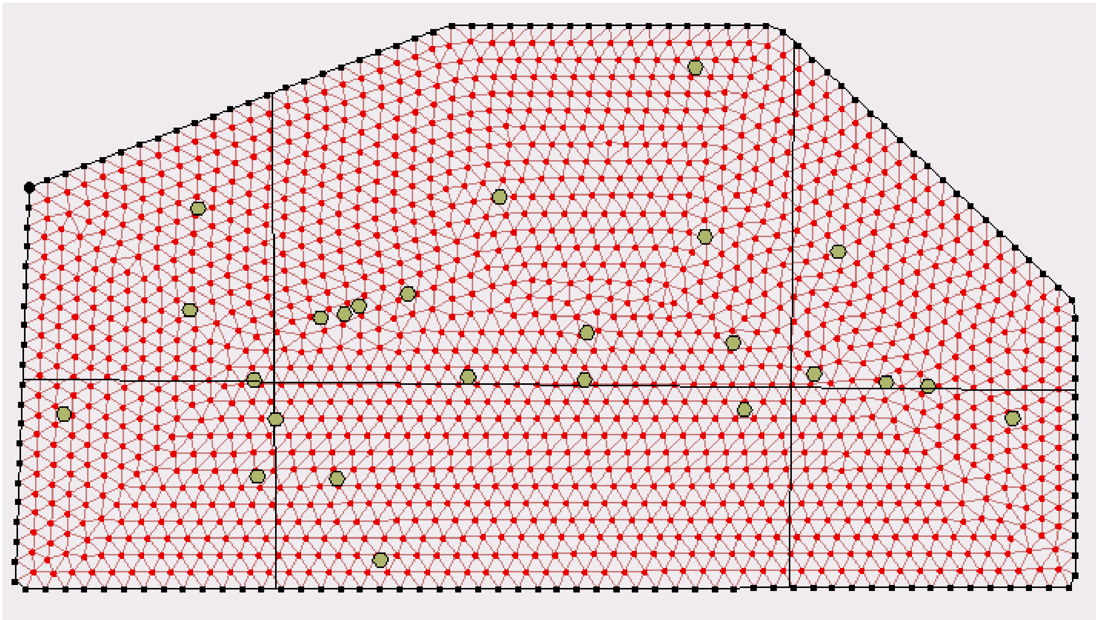


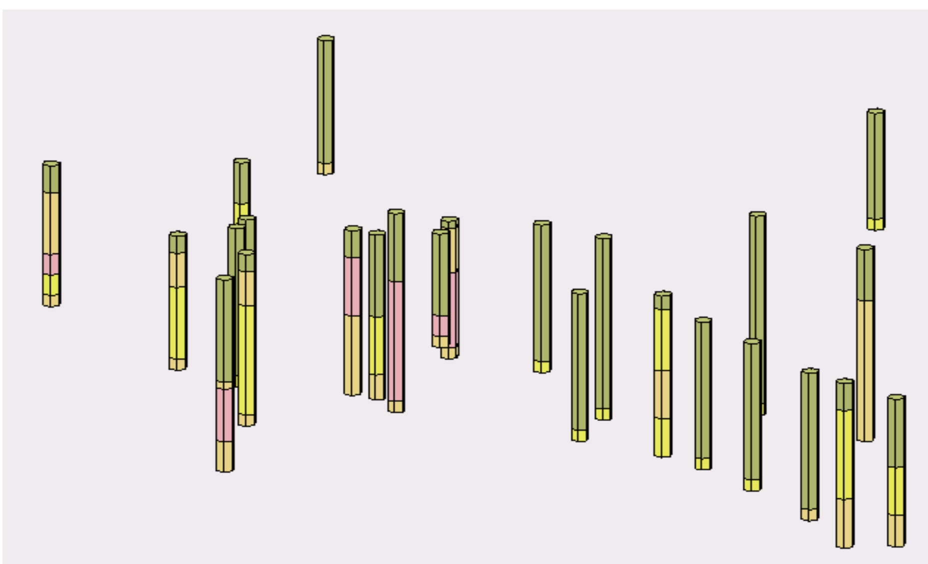


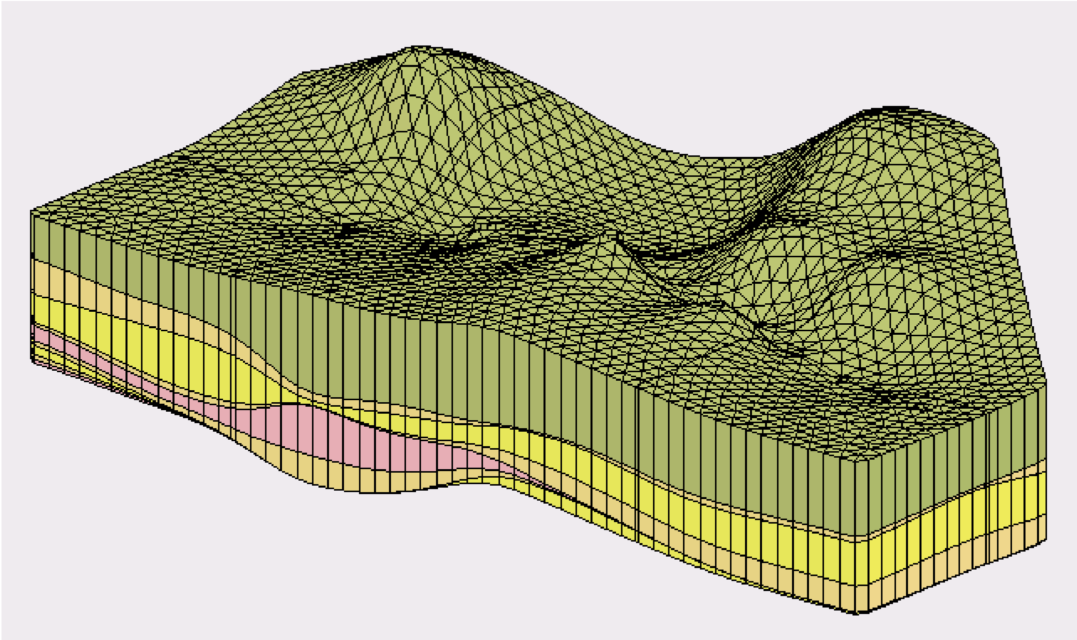


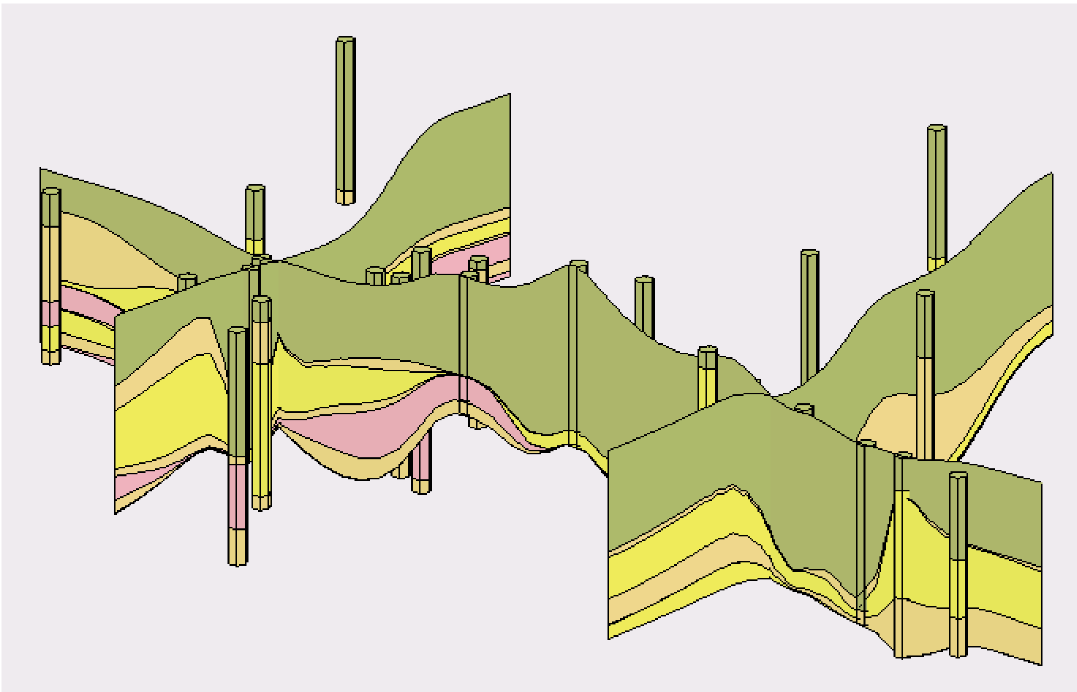


Stratigraphy Model for Zone 1.3-3

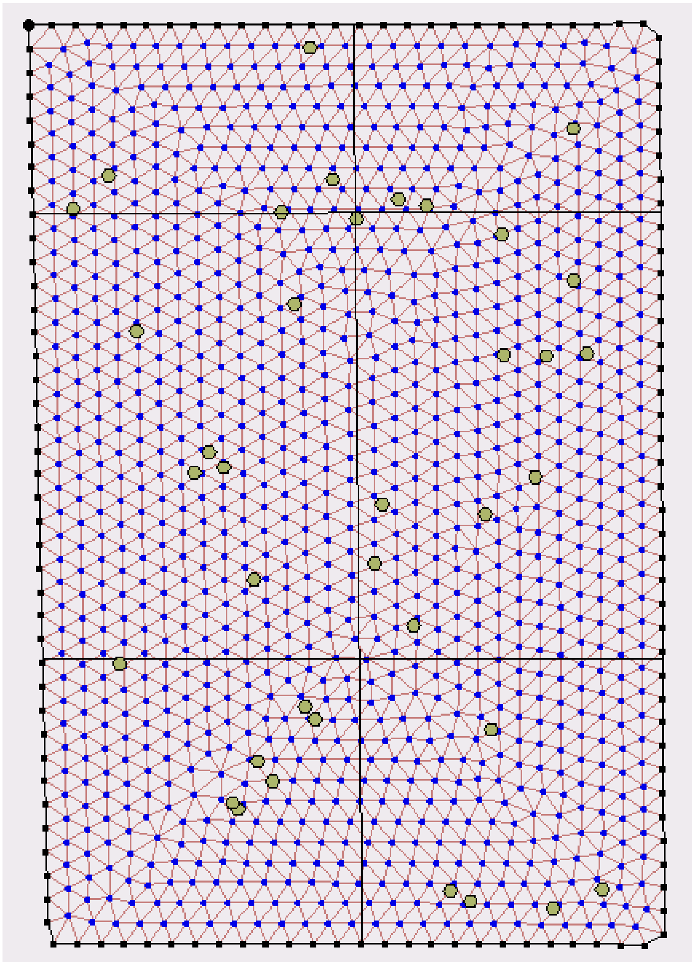


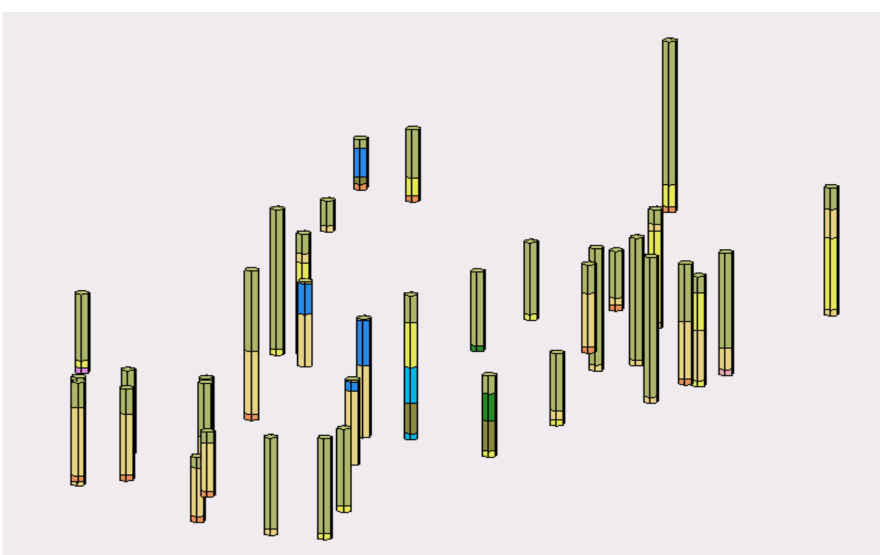


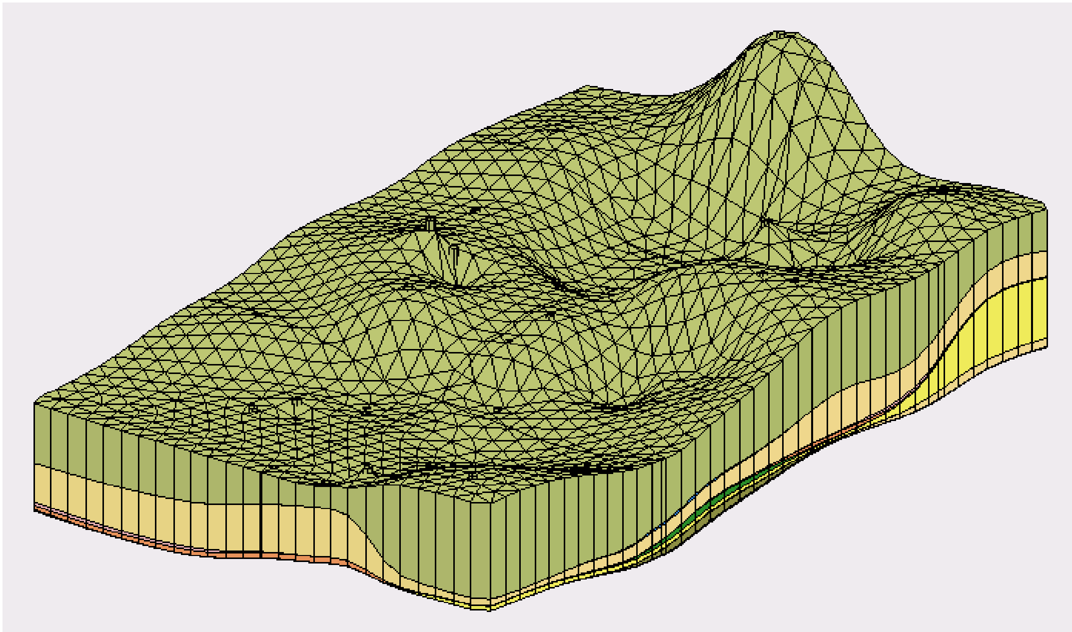


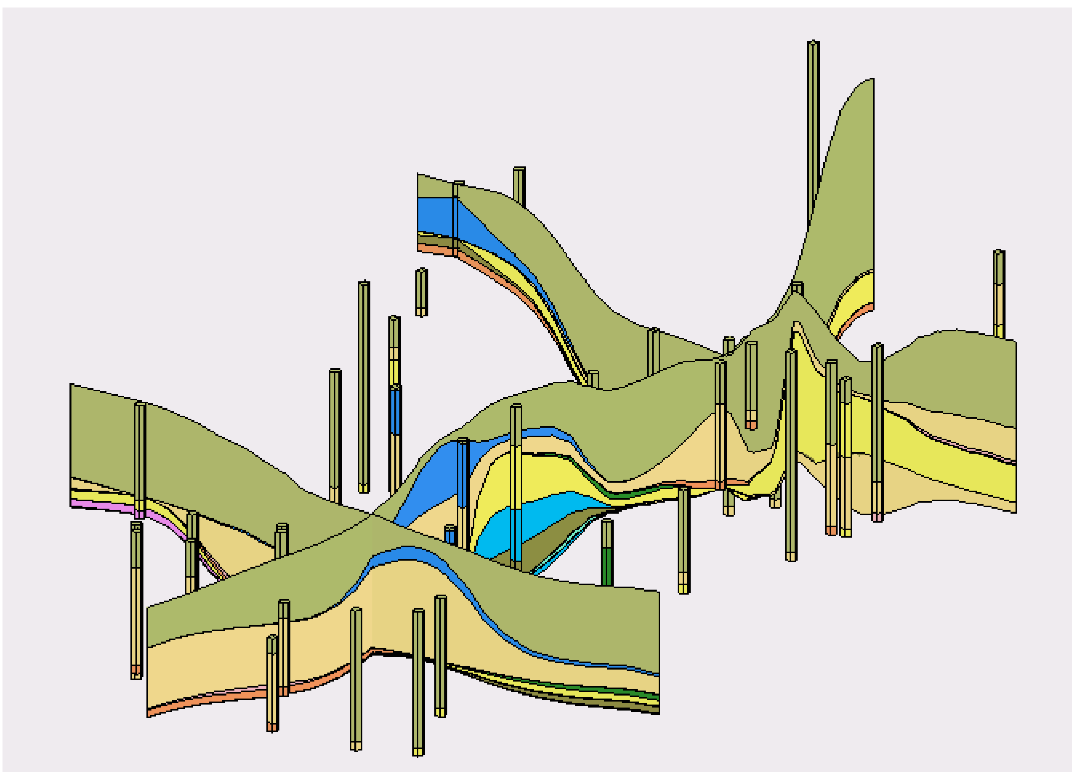


Stratigraphy Model for Zone 2.1

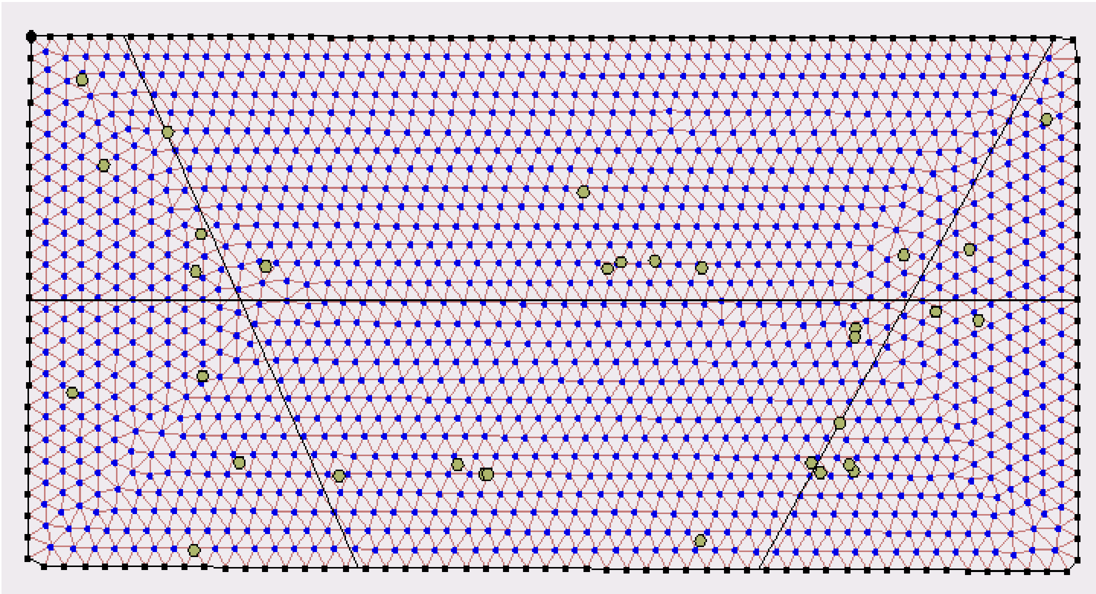


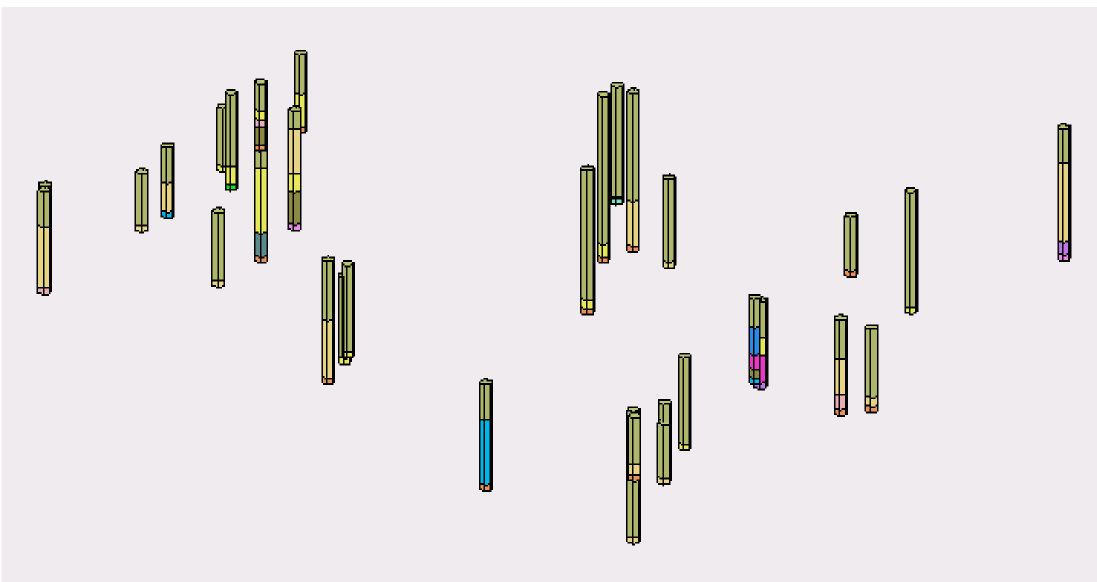


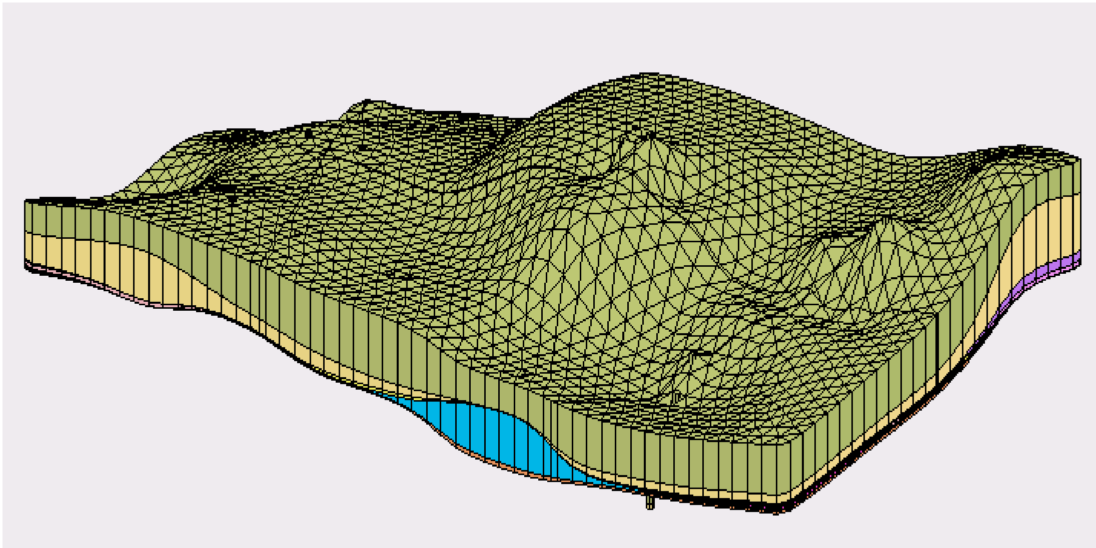


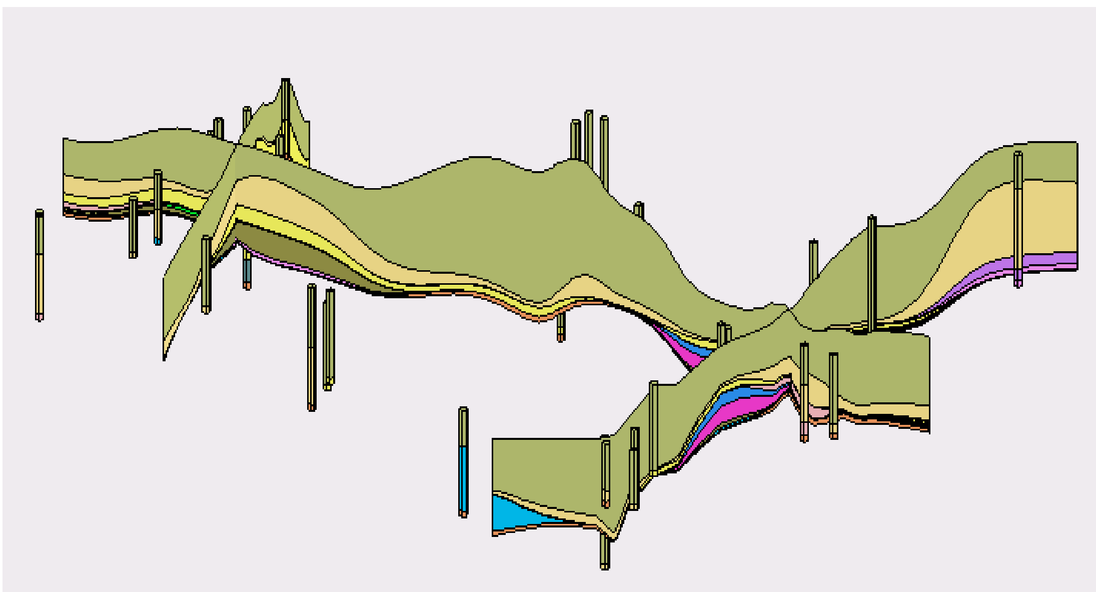


Stratigraphy Model for Zone 2.2







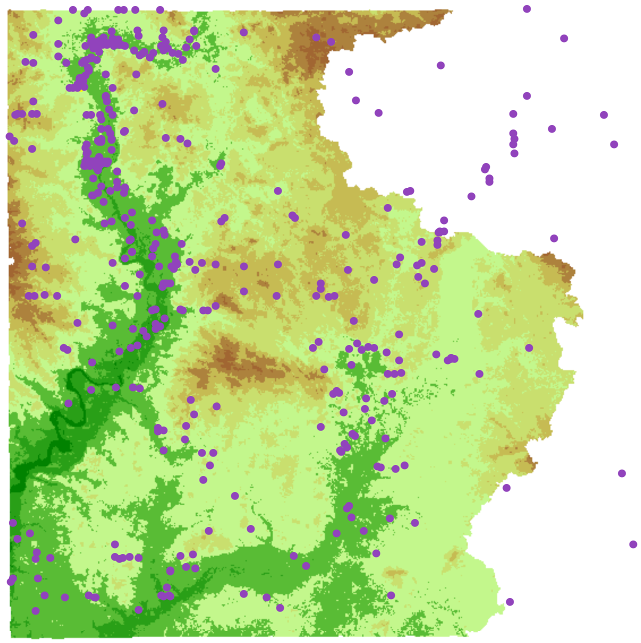


Attachment 2

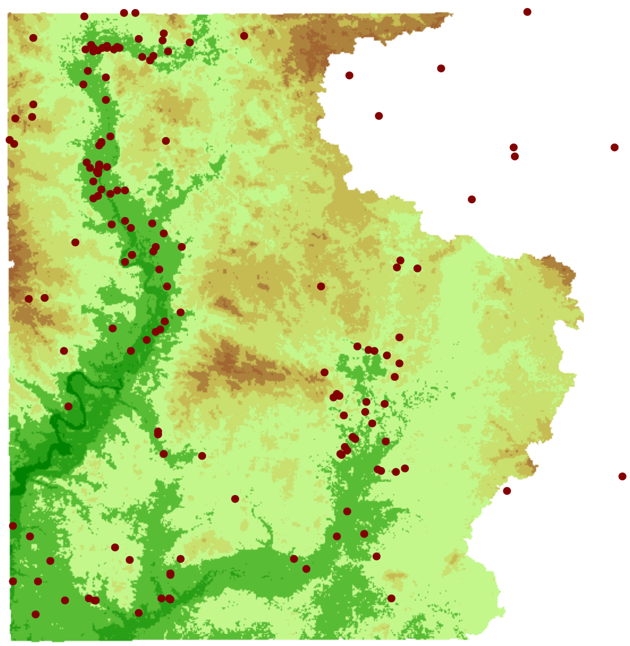
Mapping of Groundwater Flow and Distribution

Number and Distribution of Wells for Different Time Periods

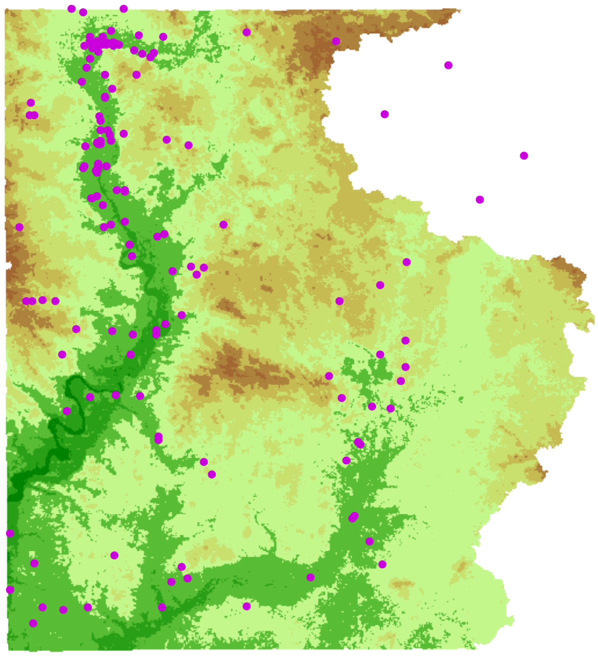
1966-1999 wells (total 470 wells)



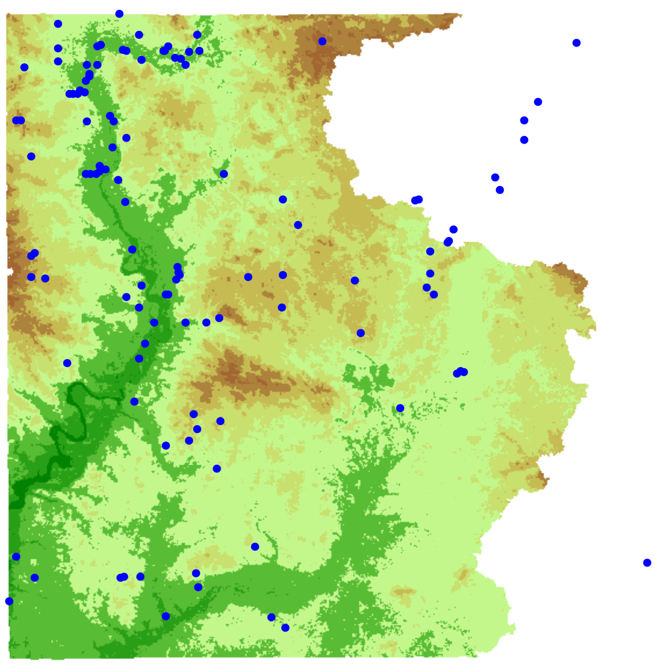
1990-1999 wells (153 wells)



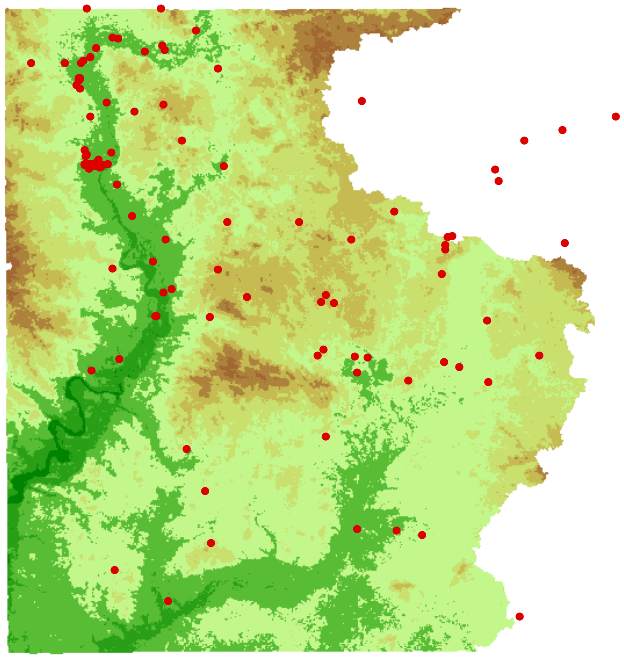
1986-1995 wells (142 wells)



1976-1985 wells (115 wells)



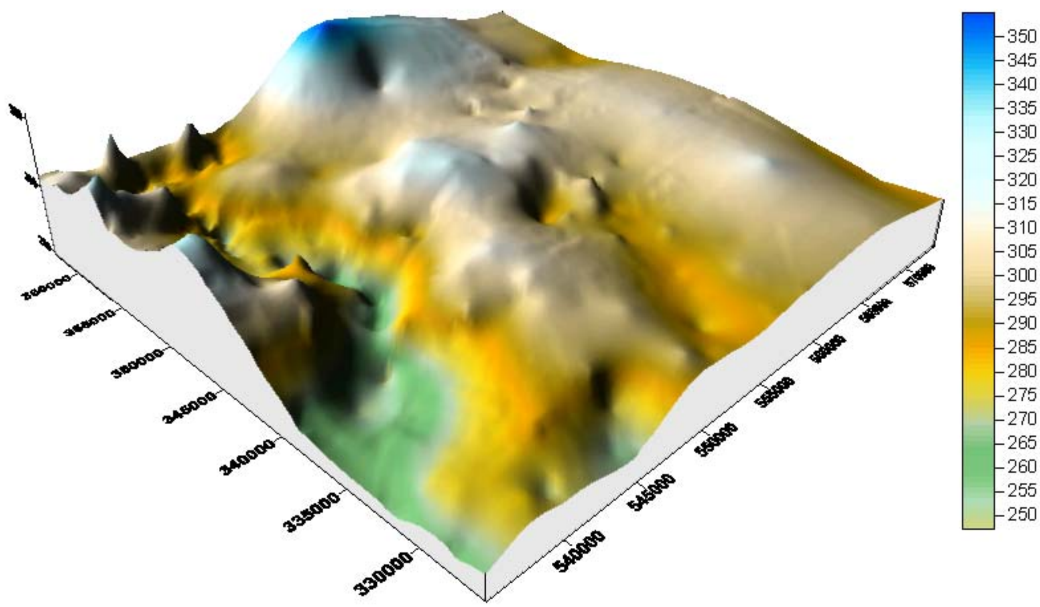
1966-1975 wells (144 wells)



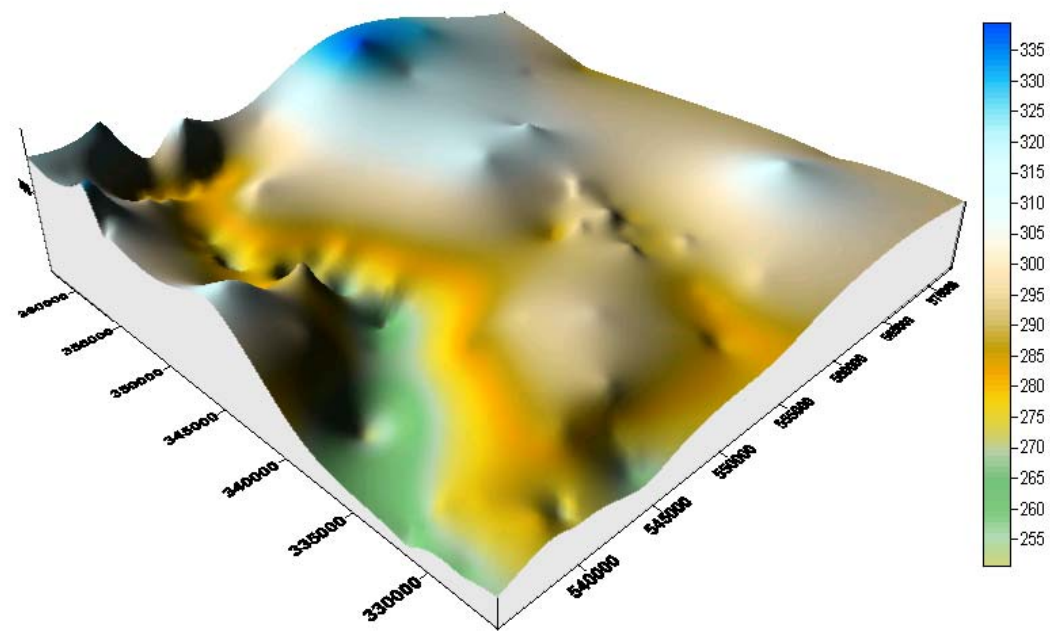
Three-Dimensional Surface Maps and Contour Maps of the Unconfined Groundwater Levels

Special Notes: (1) All surface and contour maps of the unconfined groundwater levels are generated by using the available static water level data for certain time periods. Thus, these maps only reflect average groundwater distributions during the indicated time periods and they do not represent the real groundwater levels and their spatial distributions at any specific times. Additionally, uneven distributions of the available wells in both space and time may result in disparate shapes in the maps for different time periods. (2) The unit for all maps is meter.

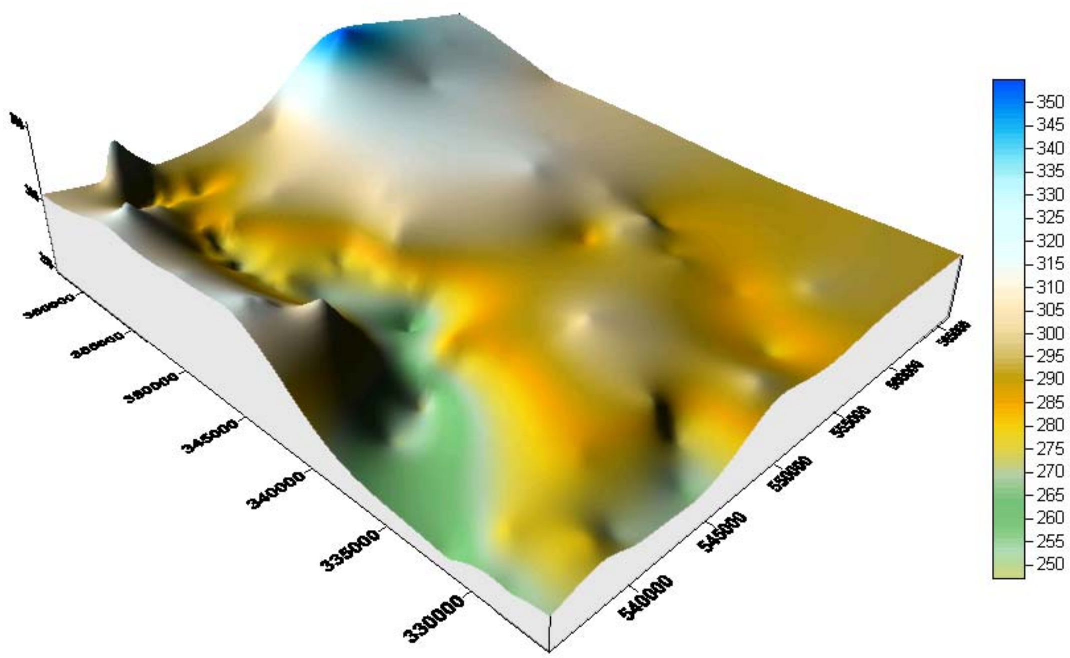
1966-1999 Three-Dimensional Surface Map of Groundwater Levels



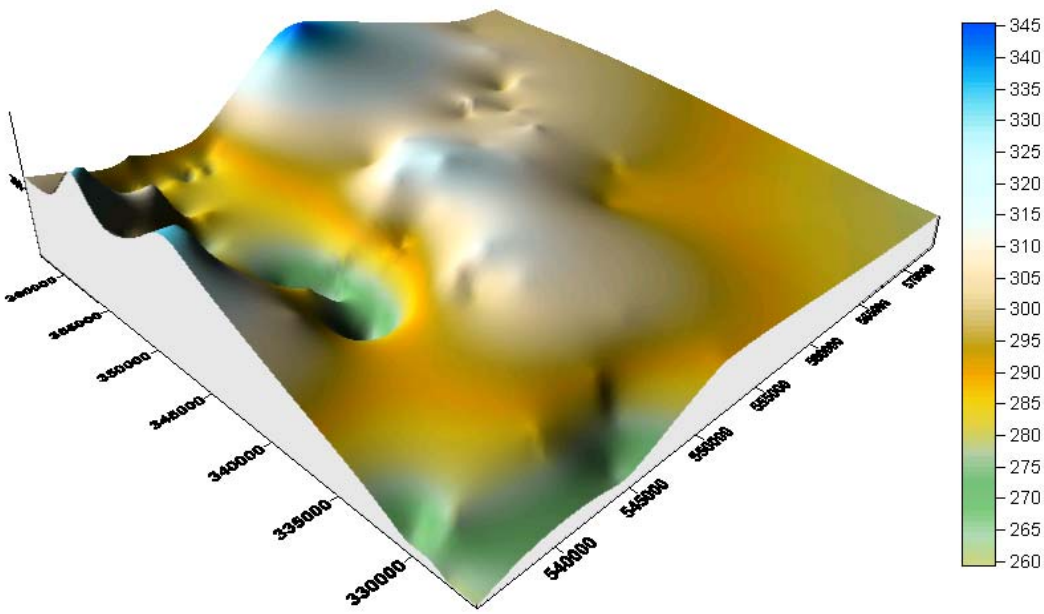
1990-1999 Three-Dimensional Surface Map of Groundwater Levels



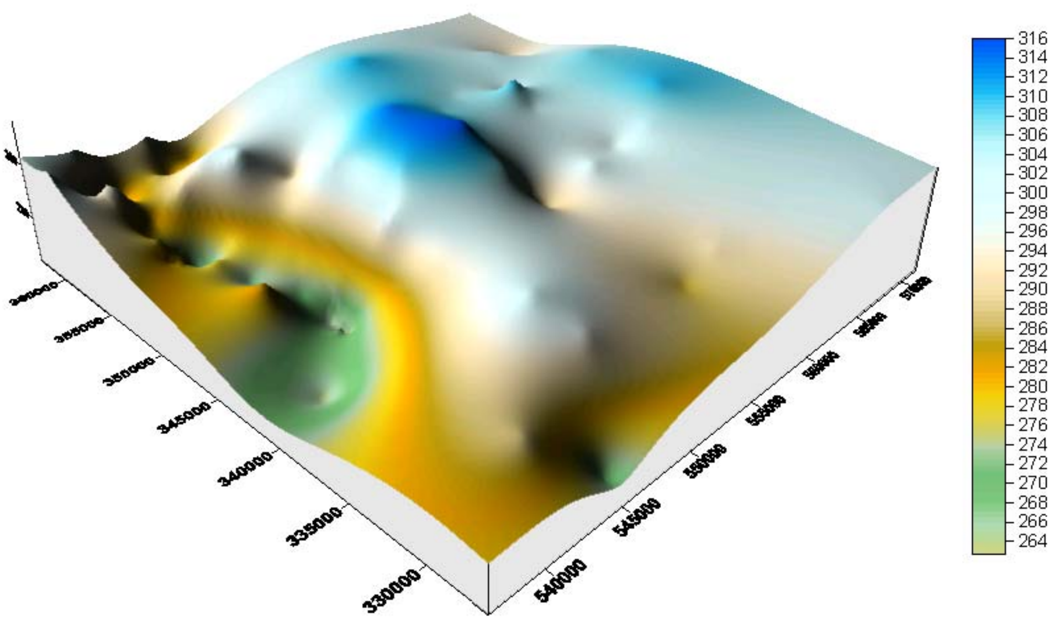
1986-1995 Three-Dimensional Surface Map of Groundwater Levels



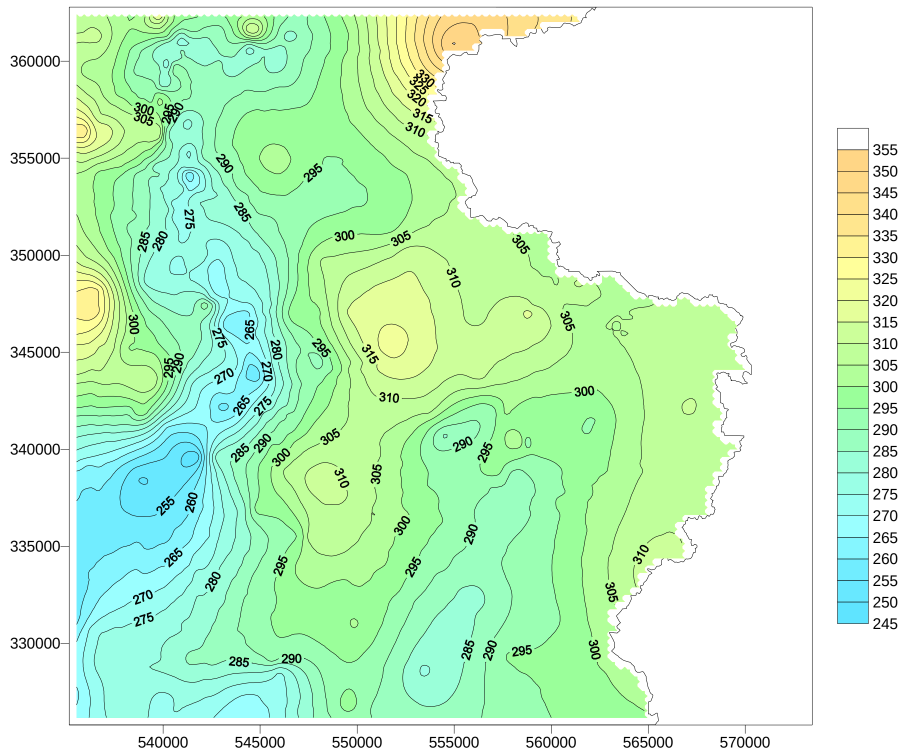
1976-1985 Three-Dimensional Surface Map of Groundwater Levels



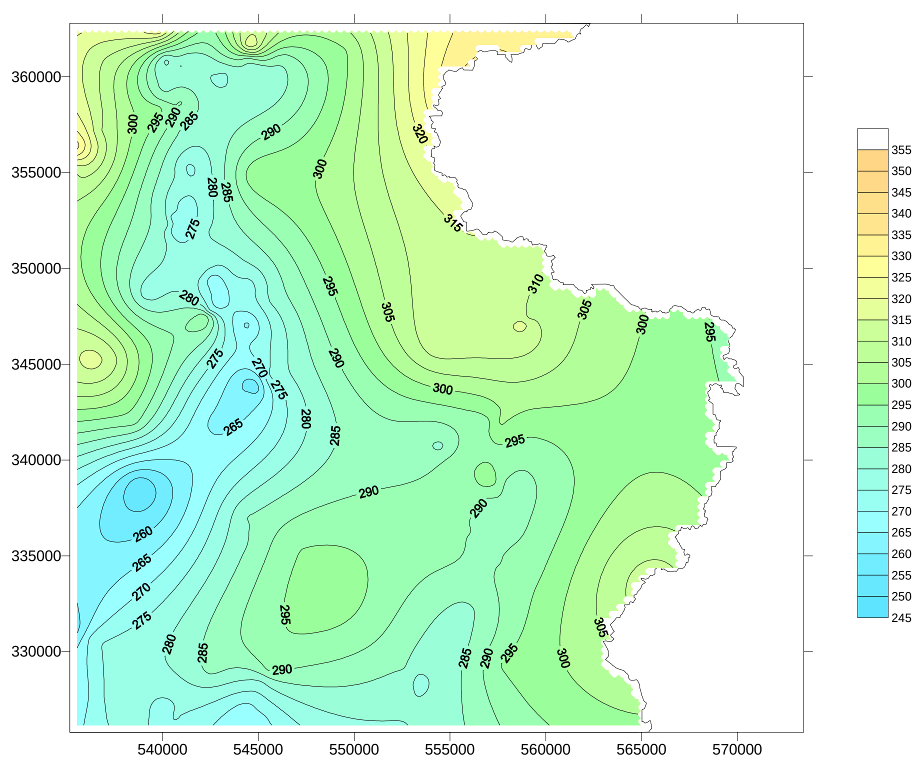
1966-1975 Three-Dimensional Surface Map of Groundwater Levels



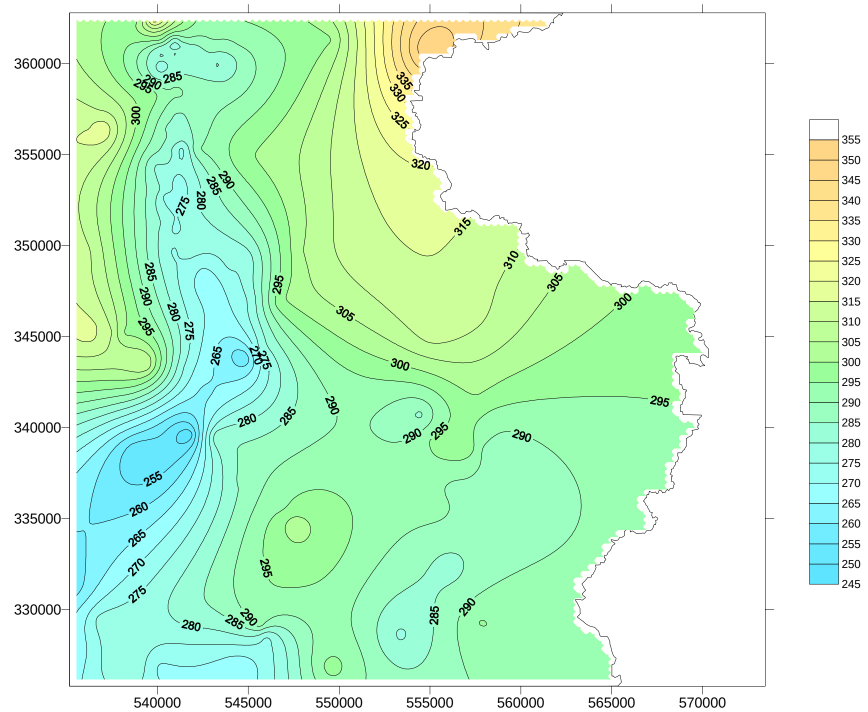
1966-1999 Average Groundwater Level Contour Map



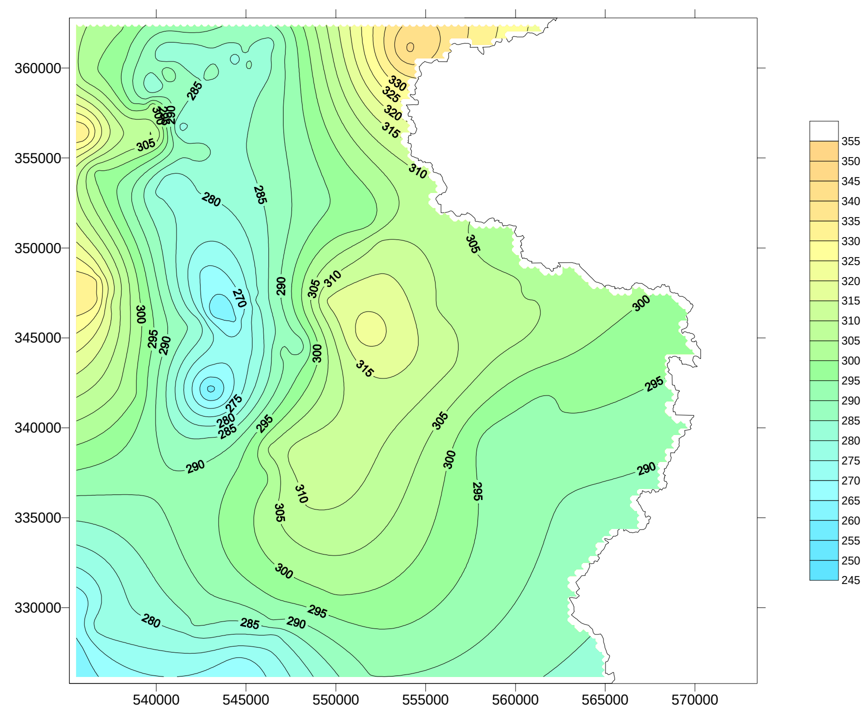
1990-1999 Average Groundwater Level Contour Map



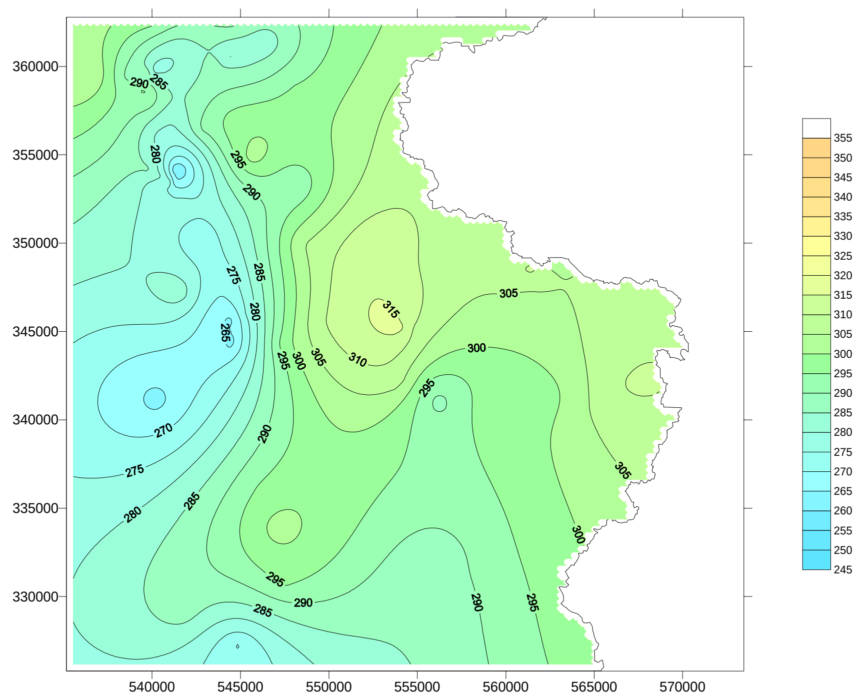
1986-1995 Average Groundwater Level Contour Map



1976-1985 Average Groundwater Level Contour Map



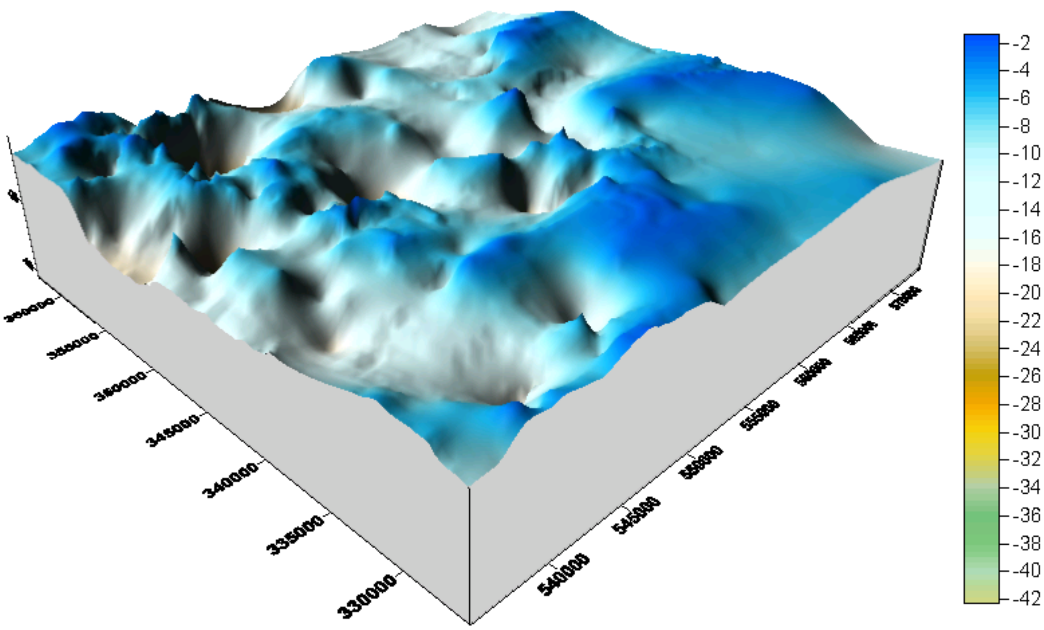
1966-1975 Average Groundwater Level Contour Map



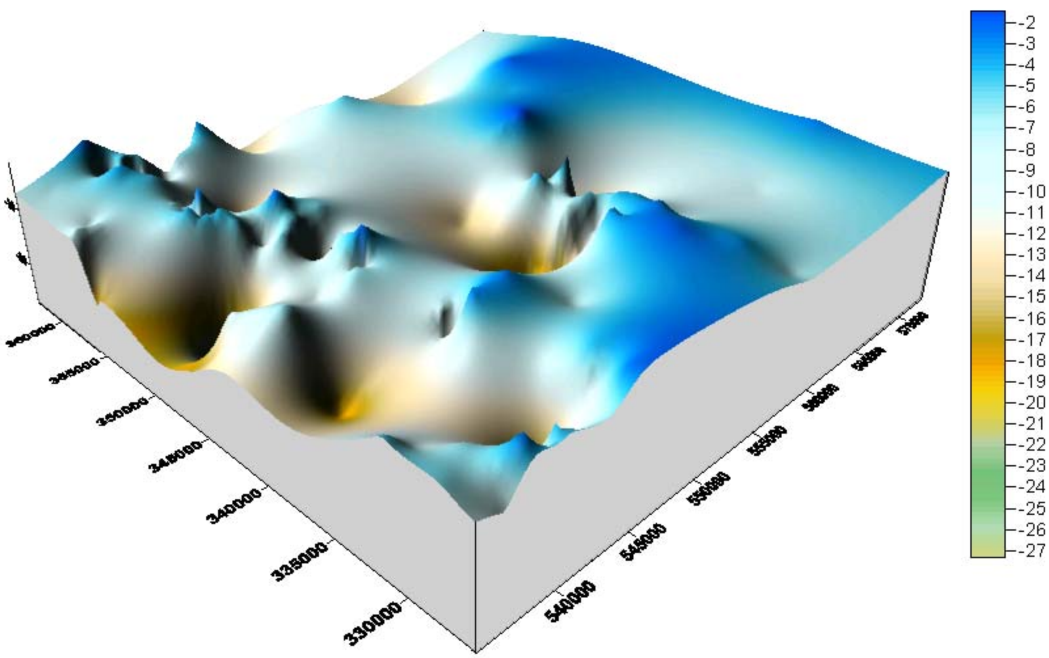
Three-Dimensional Surface Maps of the Unconfined Groundwater Depths

Special Notes: (1) All surface maps of depths of the water table are generated by using the available static water level data for certain time periods. Thus, these maps only reflect some average features during the indicated time periods and they do not represent the real depths of the water table and their spatial distributions at any specific times. Additionally, uneven distributions of the available wells in both space and time may result in disparate shapes in the maps for different time periods. (2) The unit for all maps is meter.

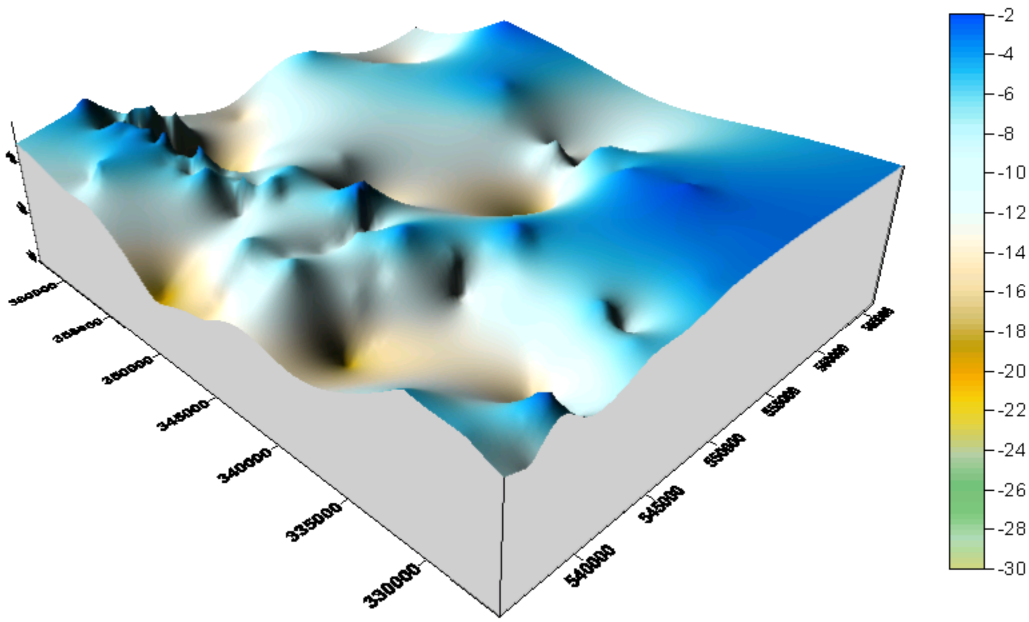
1966-1999 Three-Dimensional Surface Maps of Groundwater Depths



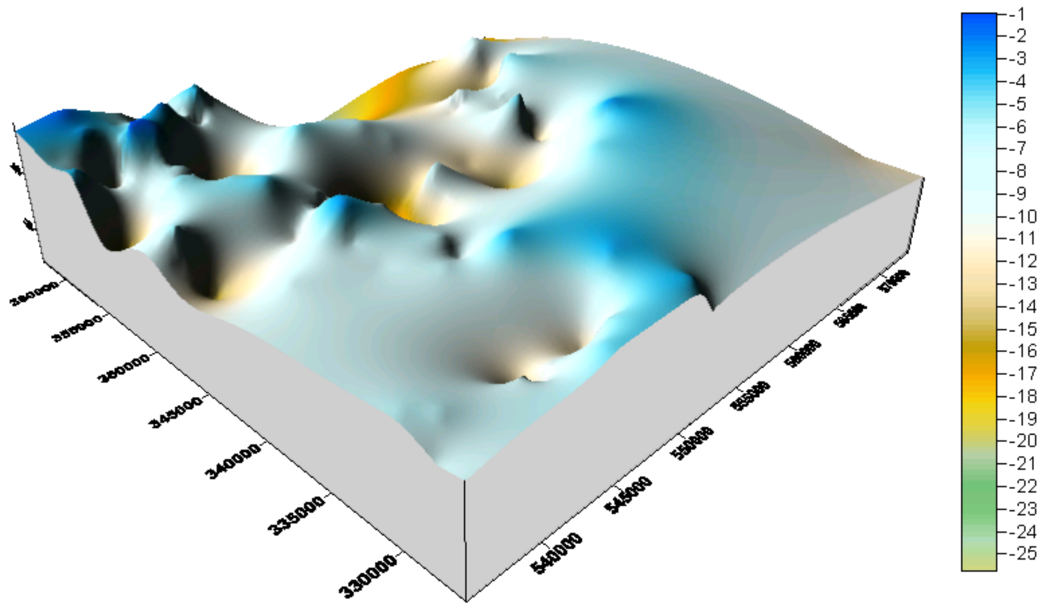
1990-1999 Three-Dimensional Surface Maps of Groundwater Depths



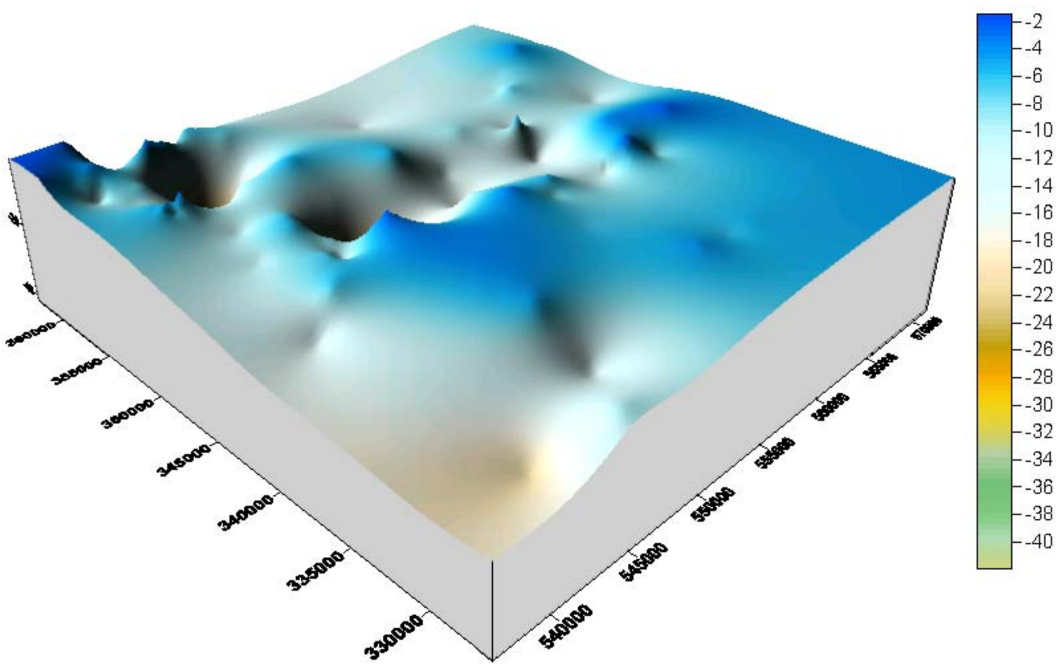
1986-1995 Three-Dimensional Surface Maps of Groundwater Depths



1976-1985 Three-Dimensional Surface Maps of Groundwater Depths



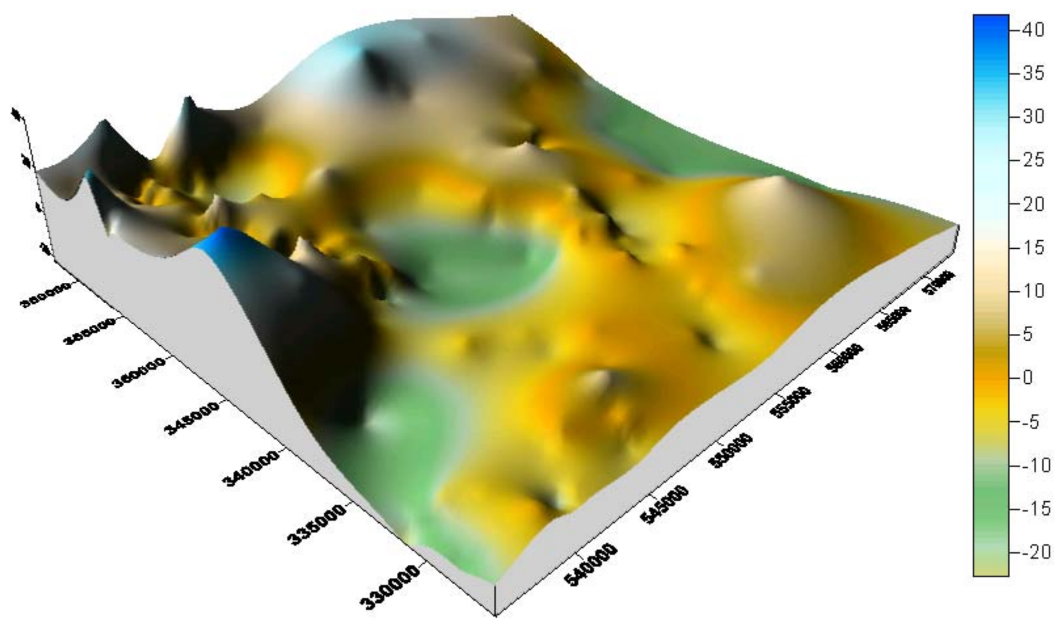
1966-1975 Three-Dimensional Surface Maps of Groundwater Depths



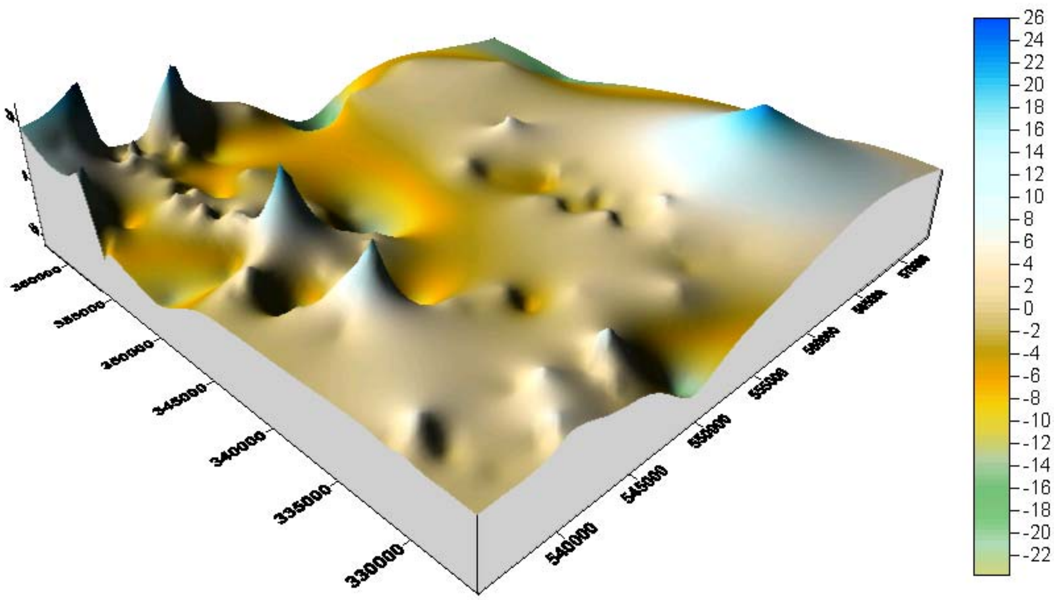
Three-Dimensional Surface Maps of the Unconfined Groundwater Level Changes for Certain Time Periods

Special Notes: (1) All surface maps of the groundwater level changes are generated by using the available static water level data for certain time periods. Thus, these maps only reflect some average features during the indicated time periods and they do not represent the real water level changes and their spatial distributions at any specific times. Additionally, uneven distributions of the available wells in both space and time may result in disparate shapes in the maps for different time periods. (2) The unit for all maps is meter.

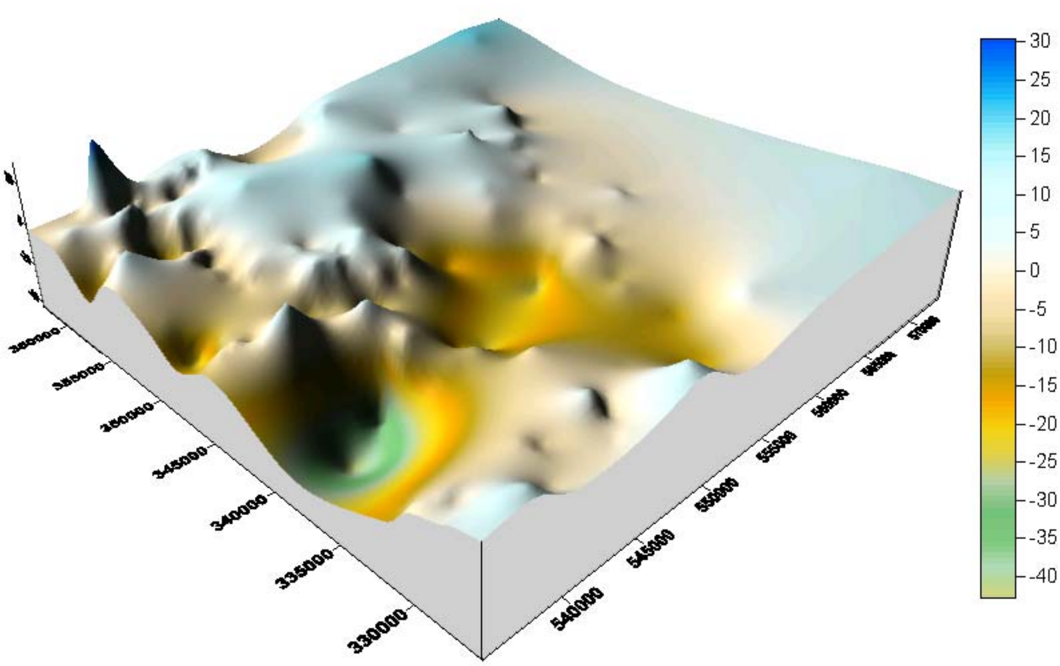
1966-1999 Three-Dimensional Surface Map of Groundwater Level Changes (difference between 1990-1999 and 1966-1975 groundwater levels, DE = E90-99 – E66-75)



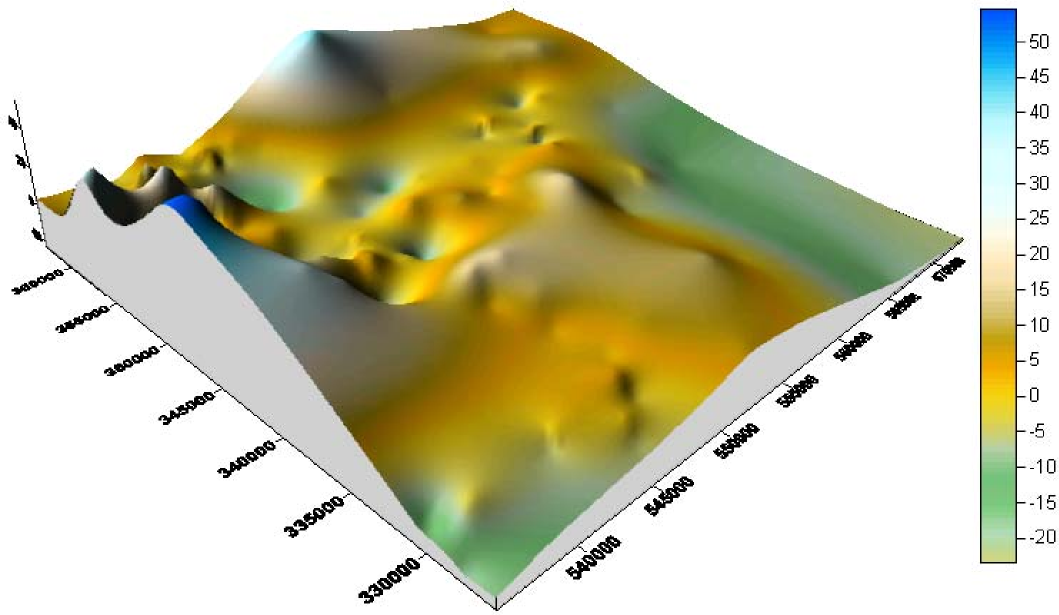
1986-1999 Three-Dimensional Surface Map of Groundwater Level Changes (difference between 1990-1999 and 1986-1995 groundwater levels, DE = E90-99 – E86-95)



1976-1995 Three-Dimensional Surface Map of Groundwater Level Changes (difference between 1986-1995 and 1976-1985 groundwater levels, DE = E86-95 – E76-85)



1966-1985 Three-Dimensional Surface Map of Groundwater Level Changes (difference between 1976-1985 and 1966-1975 groundwater levels, DE = E76-85 – E66-75)



1976-1999 Three-Dimensional Surface Map of Groundwater Level Changes (difference between 1990-1999 and 1976-1985 groundwater levels, DE = E90-99 – E76-85)