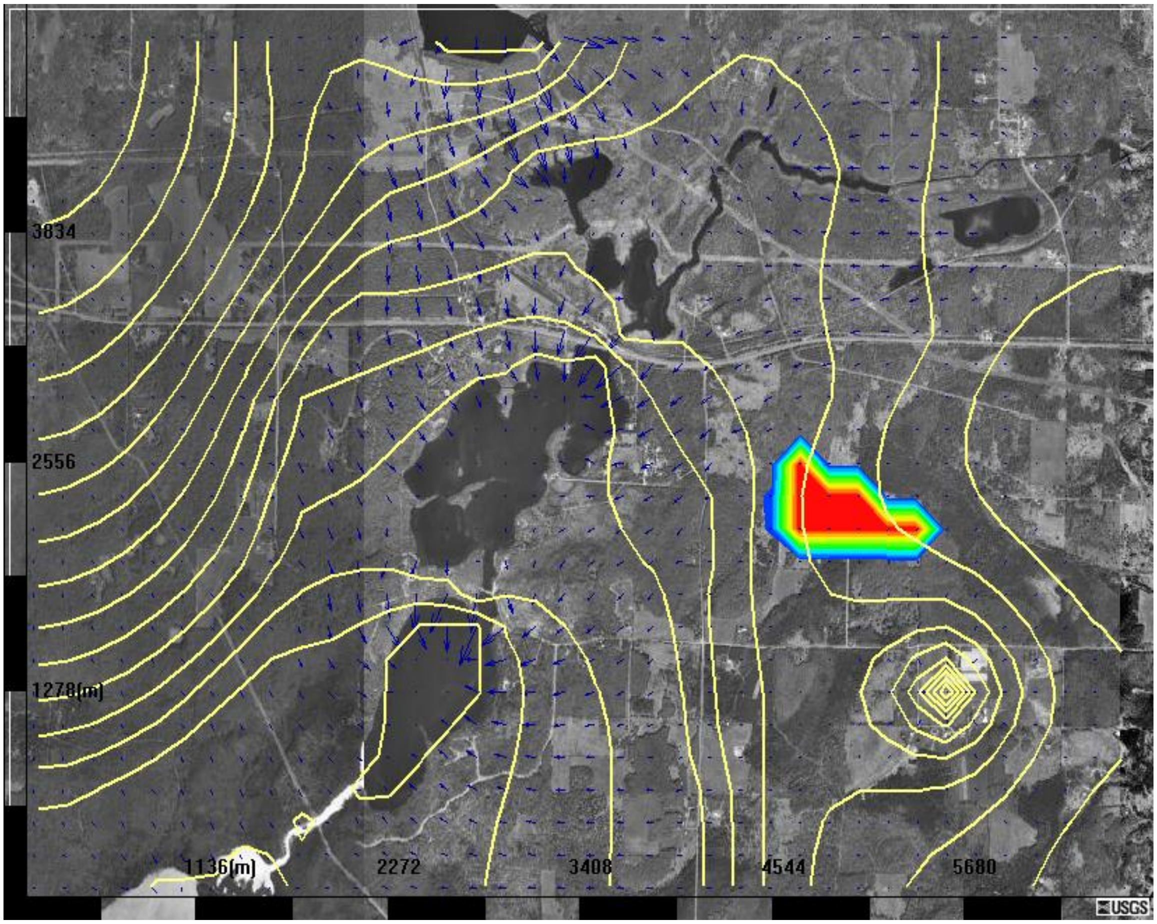
DR. SHUGUANG LI AND ASSOCIATES

INTERACTIVE GROUNDWATER MODELING (IGW)



TUTORIALS: GIS-Enabled Modeling

IGW Version 5.2.1P

Dr. Shuguang Li and Associates at Michigan State University

IGW Tutorials for *Version 5.2.1P*

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DOCUMENT VERSION: **2011-01**

http://www.egr.msu.edu/~lishug

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Chapter 1 INTRODUCTION

This tutorial is designed to step you through some of the basic features of GIS-enabled groundwater modeling using the IGW software (*Version 5.2.1P*).

You will get the most out of this tutorial if you work the sections in order, and complete all of the sections within a chapter at the same sitting. It is recommended that you use the suggested values for each step in the tutorial. Using the suggested values will walk you through an example, providing you with results that are intuitive, graphical and instructional. The example is very similar to a real world problem, however, bear in mind that this example is only for illustrative purposes.

You should consult the IGW User's Manual for more in-depth information concerning program implementation and functions.

For detailed information concerning technical content of the model (i.e., mathematics and theory), please consult the *IGW Version 5.0P* Reference Manual.

1.1. LEARNING OBJECTIVES

Through a hypothetical problem narrative (Section 1.4), you will learn to:

- become familiarized with IGW GIS-interface (GI);
- visualize and analyze GIS data within GI;
- develop a conceptual groundwater models using GIS data;
- use GIS data as mapping features in the model domain;
- setup aquifer boundaries and boundary conditions;
- add sources and sinks;
- descritize and run the numerical model;
- calibrate the model using GIS data;
- add GIS layers in an existing model; and,
- perform routine modeling tasks (water balance; particle tracking; surface water-groundwater interactions etc.).

1.2. STRUCTURE OF THE TUTORIAL

This tutorial is designed to help you setup a groundwater model based on GIS data for a hypothetical problem. The next section briefly explains the GIS datasets used in this tutorial. This is followed by a *problem narrative* which requires groundwater modeling. The tutorial will guide you through the development of groundwater models built around the problem using the GIS datasets.

Chapter 2 will introduce you to the GIS-interface of IGW. You will learn how to import and display data, read data attributes, select data for mapping and modeling, and export selected data to IGW modeling interface. In Chapter 3 you will learn data analysis and visualization capabilities within the GIS interface. Up to this chapter you will only get familiarization with GIS-interface. The real modeling tasks start in Chapter 4. Here you will conceptualize and develop a groundwater model based on the narrative using GIS data. In Chapter 5 you will calibrate this model using addition GIS data. In Chapter 6 you will use the calibrated groundwater model and perform some routine modeling tasks, such as water balance and particle tracking, and groundwater-surface water interactions using more GIS data.

1.3. GIS DATA SETS

GIS enabled modeling in *IGW Version 5.2.1P* allows use of both raster and vector datasets. Vector data sets supported by IGW include GIS shape files for point, polyline and polygon features. IGW has its own GIS Interface, explained in Chapter 2, to handle vector data. Raster data is not handled in GIS Interface. IGW Modeling Environment can directly read from the raster files in a specified directory. Raster data in IGW can be used for DEM, bedrock top, hydraulic conductivity, recharge and rivers.

The data used in this tutorial is taken from Michigan's GIS data bases including GWIM, NHD and Wellogic. GIS interface in IGW is specifically designed and fully integrated with GWIM, NHD and Wellogic databases.

Figure 1.1 shows the dense coverage of Michigan's drinking water wells data in the backdrop of some other data layers. Water wells data contain hydrologic attributes for every well record such as static water level at the time the well was drilled, the bore logs describing sequence and thicknesses of lithology, and types of aquifers i.e., drift/bedrock etc. The dense coverage of this data is illustrated in the figure.

Besides water wells data, there are many other data layers in Michigan's databases with hydrological information. For example NHD data has information on surface water features and the stage of water in those features. The data also contains estimates of baseflow in the streams. Estimates of groundwater recharge rates are also available as a separate GIS layer across the state.

IGW's ability to directly upload modeling data from these huge databases virtually precludes the need to collect site data for the first cut models almost anywhere in the state. High data density in most parts of the Lower Peninsula even allows groundwater modeling to fine details. IGW has predefined filters to exclude bad data, plus a user controlled data analysis and visualization interface for customized processing of GIS data before importing into the model.

IGW GIS-interface allows a modeler to zoom anywhere within the state and clip desired GIS data from a selected region into the IGW modeling-interface. Besides modeling data, IGW can also use GIS data as mapping layers to make groundwater models more illustrative and to put modeling results in perspective.

For the sake of this tutorial a small subset of data layers was taken from the statewide databases for an area approximately 36 x 39 km as shown in Figure 1.3. The tutorial allows the user to pan across this selected area just as one can do across the entire state with full data layers available.

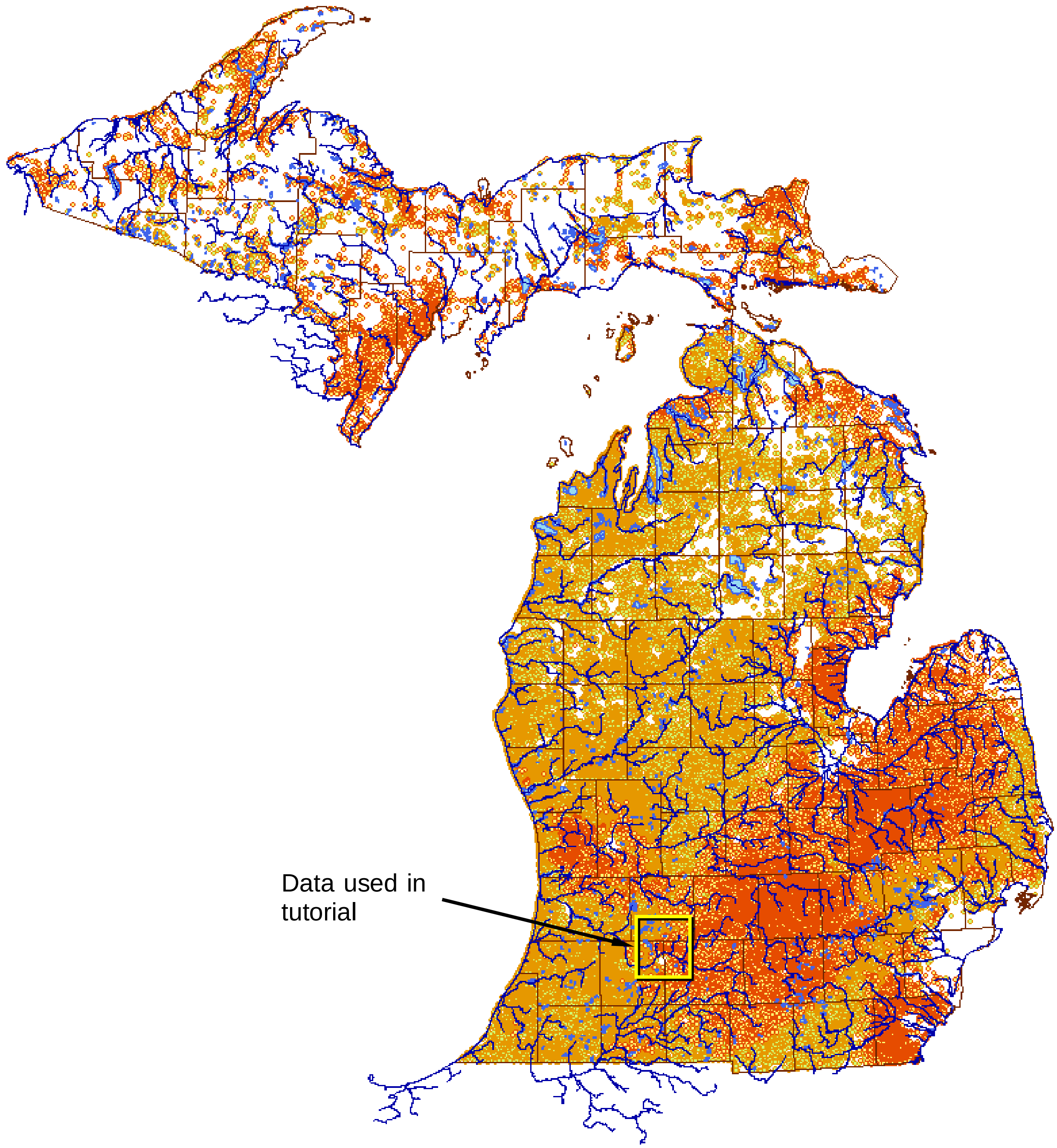


Figure 1.1 Michigan GIS Data showing big streams, large lakes and the dense coverage of drinking water wells in drift and bedrock.

i	The current version of IGW is specifically designed to directly read hydrological attributes from the Michigan's statewide data bases such as GWIM, NHD and Wellogic. The interface is programmed to use exact *field names* and assigned *units* for the hydrologic

parameters in the data.

GIS data files from other databases can be used in IGW when *field names* and *units* for the hydrologic parameters are the same as those in Michigan's databases.

The GIS data layers most commonly used in groundwater modeling are summarized as follows:

1.3.1. Data for Developing a Model

Following data layers were used to develop the model for the study site:

- Static water level (Wellogic);
- Hydraulic conductivity (Wellogic);
- Size, locations and elevations of surface water features such as lakes and wetlands (GWIM);
- Stream geometries and elevations (NHD);
- Subsurface information such as elevations of geological layers, their lithology and specific capacity etc.(GWIM);
- Surface elevations and topography (DEM);
- Surface water divides (GWIM);
- Recharge rates (GWIM and Surface Hydrology Modeling team);
- Mapping features, such roads, county boundaries etc. (GWIM); and,
- pre-processed raster data sets including:-
    - 10m, 30m and 90m surface elevations or DEM,
    - 500m bedrock elevations,
    - 500m hydraulic conductivity,
    - 500m recharge estimates, and
    - 90m river.

1.3.2. Data for Calibrating a Model

Following data layers were used to calibrate the model for the study site:

- Estimates of base flow in stream arcs and lakes (NHD); and,
- Information on static water levels (recorded at the time of construction) in the existing water wells (Wellogic).

1.3.3. Data for Mapping Layers and Additional Modeling Tasks

- Sites of environmental concern or SEC (GWIM);
- Roads and highways (GWIM);
- Cities and villages (GWIM);
- Glacial landforms (GWIM);
- Gauging stations (GWIM);
- Airports (GWIM); and,
- Schools (GWIM); etc. etc.

1.4. THE PROBLEM NARRATIVE

A high capacity pumping well at 2500 gal/min is required to support a proposed project located between Wabascon Creek and one of its smaller tributary (hereinafter called Wabascon Tributary) as shown in Figure 1.2. The creek is a 3rd order stream while the tributary a 1st order stream. Wabascon Tributary is considered important for its ecological value. The permitting agency would only approve the project if the flow reduction in Wabascon Tributary does not exceed a specified limit. The developer also wants to consider an alternate location for the well, farther from the tributary but closer to some lakes.

Before submitting the proposal the developer wants to evaluate the impact from the proposed location and alternate location of the well:

- What is groundwater contribution area for Wabascon Tributary?;
- what will be the net impact of pumping on the tributary flow for the proposed location of the well?;
- would pumping deeper from bedrock aquifer have lesser impact?; and,
- what would be the impact on the nearby lake levels if the well is moved to the alternate location?;

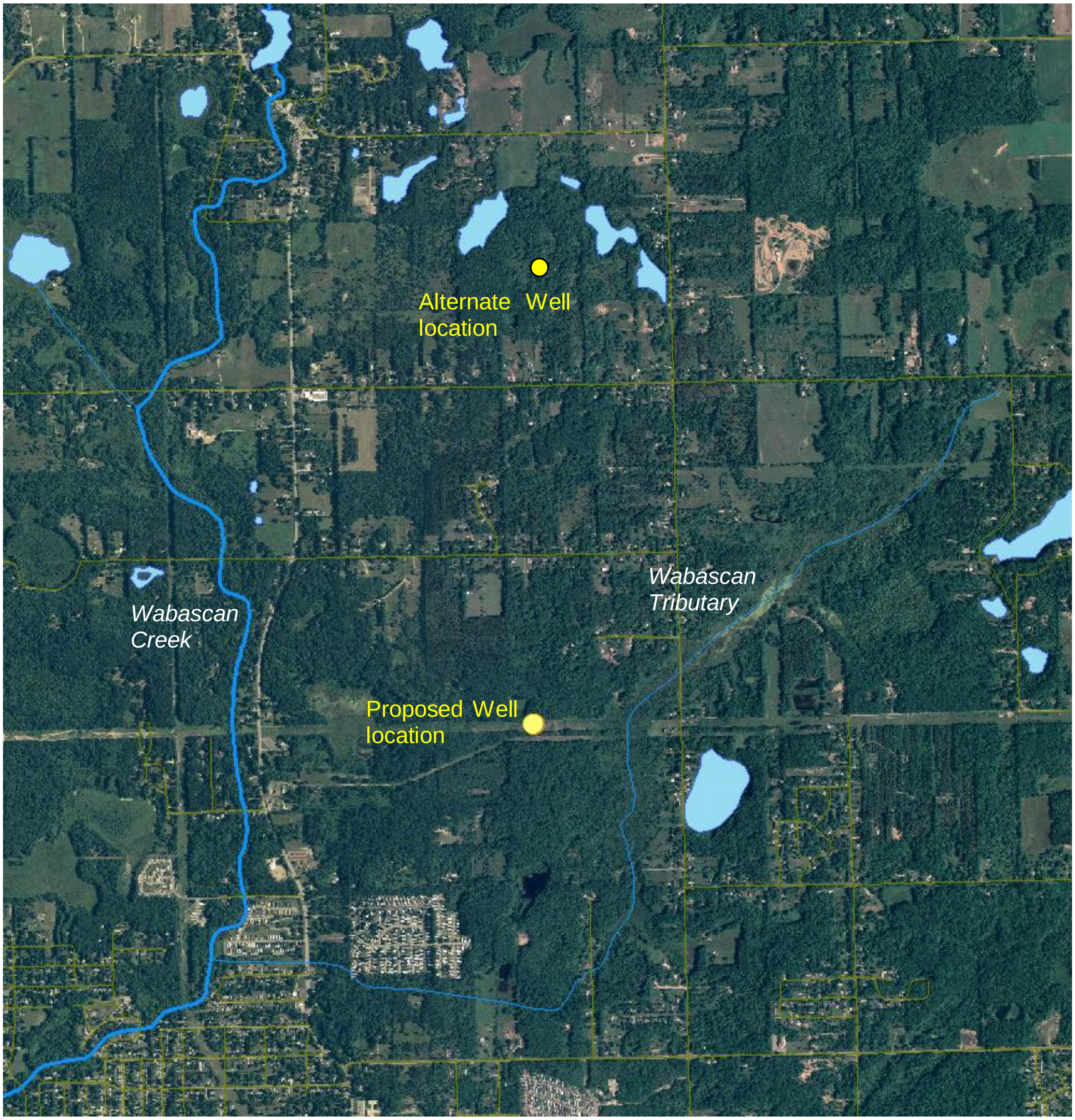


Figure 1.2 Narrative problem area and proposed well location

The above questions may be evaluated using a groundwater model for area. Dense coverage of state-wide GIS databases, including data on hydrological paramenters, is available for this area as shown in Figure 1.3.

This tutorial will help you systematically build a groundwater model using the existing GIS data to answer above questions. Data on aquifer properties, aquifer dimensions, sources and sinks, and mapping layers will be acquired from the available GIS data. See Chapter 4 for groundwater model of the watershed.

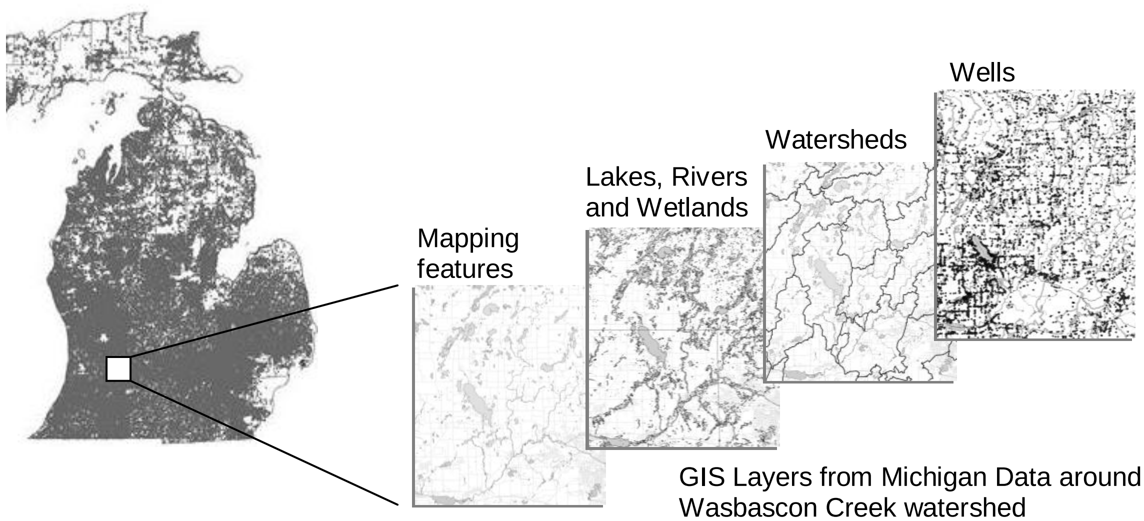


Figure 1.3 Some GIS Data layers in southern Michigan

i A folder containing GIS data files from Michigan's databases for this tutorial is created for the narrative problem. The folder can be downloaded at:

http://www.egr.msu.edu/hydrology/Research/software_igw_trial_version.htm

! This narrative is hypothetical only. The model parameters, data and site characteristics used here are for illustrative purposes only and should not be taken to present reality.

1.5. COMMENTS

Now you have a list of questions to be answered from the problem narrative, and have the GIS data for building and calibrating the model, you may start building the model in GIS-enabled environment of *IGW Version 5.2.1P*. However, before starting the actual modeling tasks, it would be helpful to become familiar with the IGW's GIS-interface and handling of GIS files in IGW.

The next two chapters will familiarize you with features and functionalities of IGW GIS-Interface. The actual modeling tasks will begin in Chapter 4.

Chapter 2 IGW GIS-INTERFACE

This chapter will give you an overview of the software's GIS-interface or GI. You will get yourself familiarized with GI and learn how to import GIS files for modeling and/or mapping purposes.

2.1. STARTING GIS-INTERFACE

The third item in the Menu Bar of IGW Main Window reads 'GIS'. To open GI:

Step 1: In the Menu Bar of IGW Main Window click on 'GIS'

Step 2: Click on 'GIS Interface' from the dropdown menu. This will open a separate window for GI on your desktop as shown in Figure 2.2

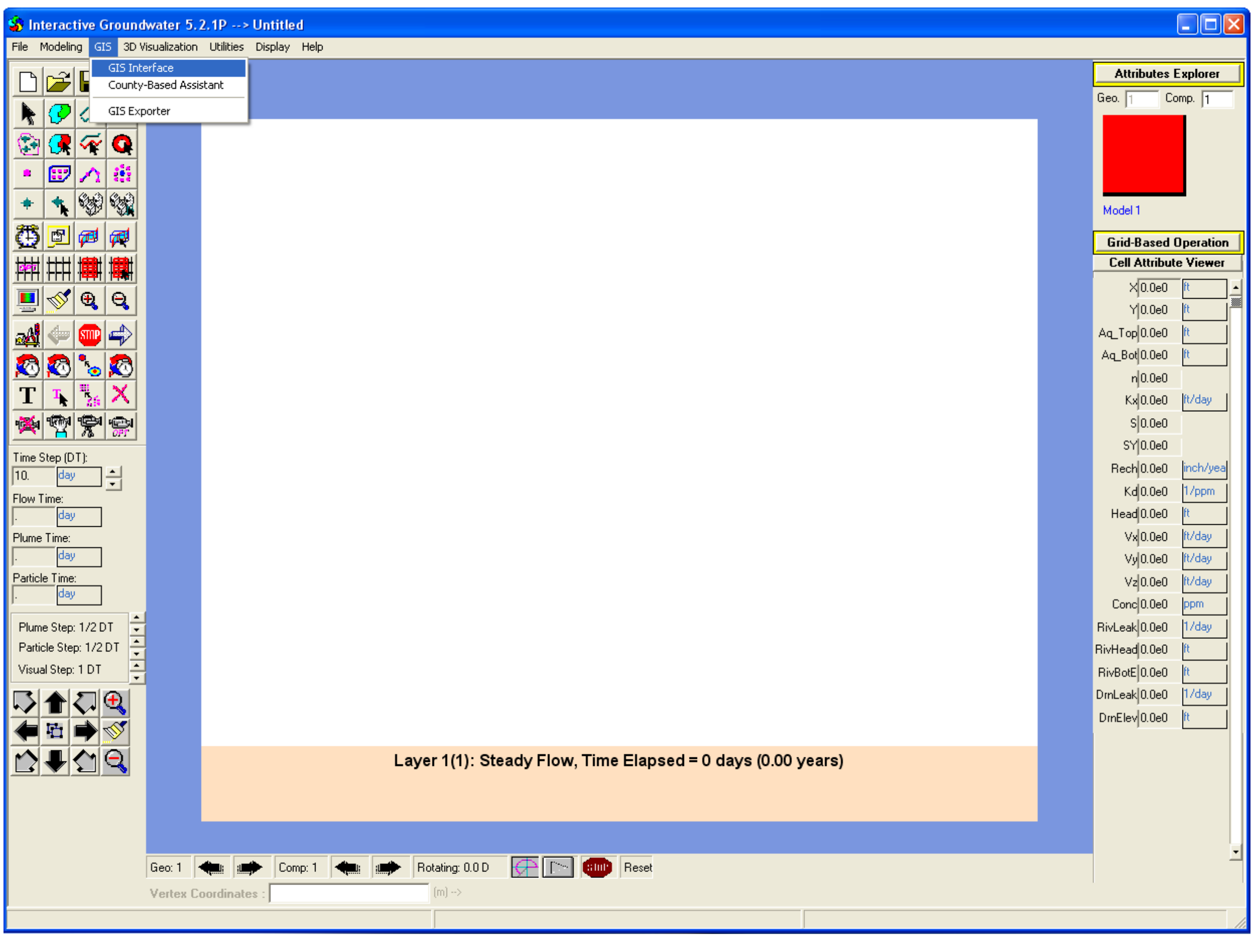


Figure 2.1 IGW Main Window

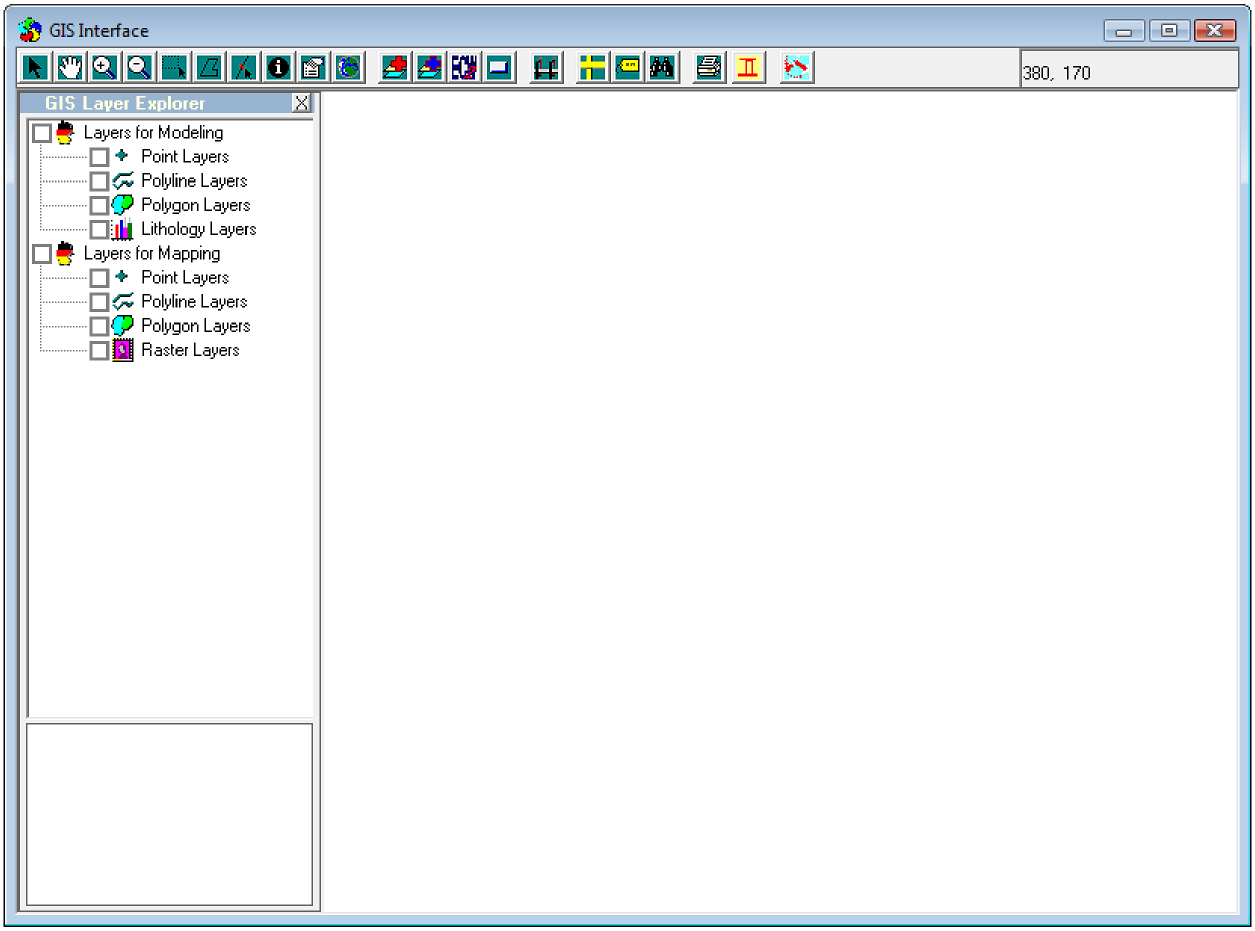


Figure 2.2 IGW GIS-interface or GI

Basic functions of GI allow you to open GIS files for modeling or mapping purposes, view GIS files, view attribute tables from the GIS files, view attributes of individual data features, select data in different ways, and export selected data to IGW modeling environment. Advanced functions of GI allow statistical analysis of GIS data, geostatistical interpolation and creating GIS files.

The next section explains all the buttons and features of GI and following sections would explain the basic functions.

2.2. IGW GIS-INTERFACE

Fully integrated with Michigan's GIS databases, IGW GIS-Interface is shown in Figure 2.3 with statewide data loaded. After loading the GIS data in the interface, one can zoom anywhere in the state and pickup GIS data for groundwater modeling.

GIS Interface can be divided into five regions as shown in Figure 2.3. Each of these regions is briefly discussed below.

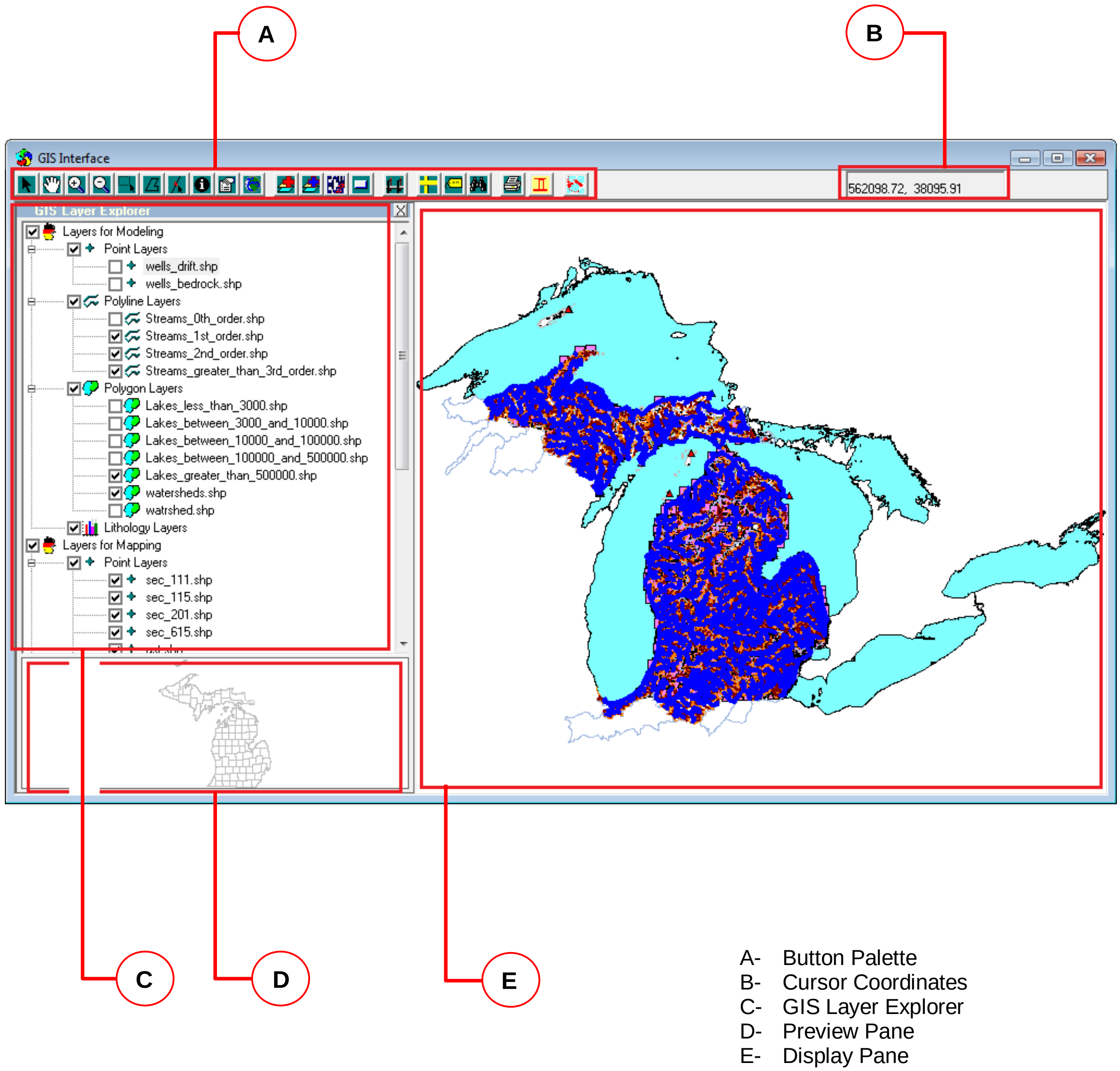
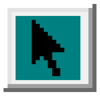
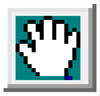


Figure 2.3 Regions of IGW GIS-Interface

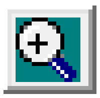
2.2.1. Button Palette



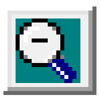
Reset cursor button. Pressing the button will reset cursor shape to



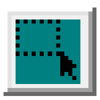
Pan button. Pressing the button changes the cursor to . Press left mouse button to pan GIS files display in the 'Display Pane'.



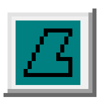
Zoom in Map button. Pressing the button changes the cursor to . Drag a box in 'Layer Display Pane' to zoom in.



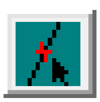
Zoom out Map button. Pressing the button changes the cursor to . Drag a box in 'Display Pane' to zoom out or click to zoom out in steps.



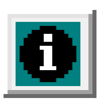
Draw a Selection Box button. Pressing the button changes the cursor to +. Drag cursor to select data in 'Display Pane'. Alternately, by clicking once in a predefined GIS polygon will select all the data within that polygon. Also see Section 3.1.1



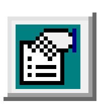
Draw a Selection Polygon button. Not active in *IGW version 5.2.1P*



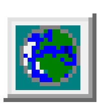
Draw a Selection Polyline button. Pressing the button changes the cursor to +. Draw a polyline in 'Display Pane' to select data. Also see Section 3.1.2



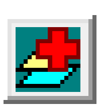
Identify button. Pressing the button changes the cursor to . First click on GIS layer in the 'GIS Layer Explorer' pane and then click on a feature from that layer in 'Display Pane' to display a table of attributes associated with that feature in a separate window. Also see Section 2.4



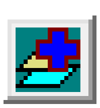
Show Data Table button. Click on a GIS layer in the 'GIS Layer Explorer' pane and then hit this button. A table showing all the data and attributes for that layer will show in a separate window. Also see Section 2.4



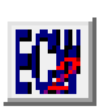
Full Extent button. Hit this button to show full extent of GIS maps in the 'Display Pane'.



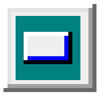
Add New Modeling Layer button. Clicking this button will open a window to browse, select add a GIS *.shp file GI for modeling purposes. Also see Section 2.3



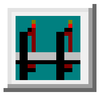
Add New Mapping Layer button. Clicking this button will open 'Open' window to browse, select add a GIS *.shp file or a graphic file in GI for mapping purposes. Also see Section 2.3



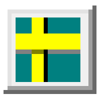
Add ECW Air Photo button. Clicking this button will open 'Open' window to browse, select add a *.ecw air photo in GI for mapping purposes. Also see Section 2.3



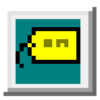
Open/Close GIS Layer Explorer button. Clicking the button will show/hide 'Explorer Pane' and 'Preview' pane.



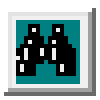
Extract Model Features to IGW button. Clicking this button with open 'Extraction Criteria' window for the selected data for further exporting data to IGW. Also see Section 4.2



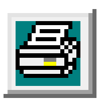
Measure button. Clicking the button once, then successively click at two points within the 'Display Pane'. As soon as second point is clicked, a pop window shows up displaying the distance between the two points.



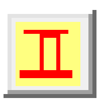
Label button. Not active in *IGW version 5.2.1P*



Search button. Not active in *IGW version 5.2.1P*

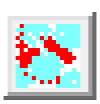


Print button. Not active in *IGW version 5.2.1P*



Add All Shape Files button. Clicking the button will open 'Browse for Folder' window. Select the folder to add all shape files from that folder to GI.

!	This button is specifically designed to read Michigan's GIS databases from large file folders. It will load only those GIS files form a folder which have the exact names and structure as in Michigan's databases.



Data Explore button. Clicking the button will open 'Scatter Point Data Exploratory Options' window for data analysis of selected scatter points. Also see Section 3.2

2.2.2. Cursor Coordinates

Top right corner of GI shows xy-coordinates at the cursor location in 'Display Pane'.

2.2.3. GIS Layer Explorer

'GIS Layer Explorer' displays GIS layers loaded in GI. The layers are displayed in two groups - Modeling Layers and Mapping Layers.

Types of Modeling Layers that can be added in GI include Point Layers, Polyline Layers, Polygon Layers and Lithology Layers. Lithology Layers option is active in *IGW Version 5.2.1P*.

Types of Modeling Layers that can be added in GI include Point Layers, Polyline Layers, Polygon Layers and Raster Layers. Raster Layers option is not active in *IGW Version 5.2.1P*.

2.2.4. Display Pane

All modeling and mapping layers loaded in the GI are displayed in the 'Display Pane'. Using the buttons explained in Section 2.2.1, regions can be defined for selecting data in the display pane. Layers' display can be switched on/off using the check boxes in the 'GIS Layer Explorer' pane. Also see Figure 2.4

2.2.5. Preview Pane

'Preview Pane' displays the full extent of first layer added in GI. Whenever an area is selected (Section 3.1) in GI, its preview also appears in the 'Preview Pane' showing the relative location of selection compared to the full extent of data in GI. See Figure 3.1.

i	Display in the 'Preview Pane' is automatic. There are no user defined options for it in *IGW Version 5.2.1P*

R	The first data layer imported in the model displays in the Preview Pane. For a better preview, you may select the first layer which is a more representative *map* of the entire area, for example, watershed boundaries, roads network, etc.

2.3. Importing and Viewing Files in GIS-Interface

For the sake of this tutorial, a set of GIS data files is created for a selected region in south west Michigan. You may download the folder containing these file from:

www.egr.msu.eu/igw/tutorials/gis_files

After you have downloaded and saved these files on your hard disk, you are all set to use them in this tutorial. Table 2.1 briefly describes the files that are included in the tutorial:

Table 2.1 GIS data layers used in tutorial

File Name	Type	Remarks
tutorial_boundary.shp	Polygon	Boundary for GIS data in south west Michigan covering an area approximately 1382 km^2
tutorial_bedrock.shp	Polygon	Bedrock formations
tutorial_cities.shp	Polygon	City boundaries
tutorial_county_boundaries.shp	Polygon	County boundaries running through the selected area
tutorial_lakes1.shp	Polygon	Lakes less than 3000 m^2
tutorial_lakes2.shp	Polygon	Lakes between 3000 m^2 and 10,000 m^2
tutorial_lakes3.shp	Polygon	Lakes between 10,000 m^2 and 100,000 m^2

File Name	Type	Remarks
tutorial_lakes4.shp	Polygon	Lakes between 100,000 m^2 and 500,000 m^2
tutorial_lakes5.shp	Polygon	Lakes greater than 500,000 m^2
tutorial_landforms_icecontact_outwash.shp	Polygon	Glacial landform – ice-contact outwash
tutorial_landforms_lodge_till.shp	Polygon	Glacial landform – lodge-till
tutorial_landforms_marginal_till.shp	Polygon	Glacial landform – ice-marginal till
tutorial_landforms_proglacial_outwash.shp	Polygon	Glacial landform – pro-glacial outwash
tutorial_roads_highways.shp	Polyline	Highways running through the selected area
tutorial_roads_residential.shp	Polyline	Roads running through the selected area
tutorial_stream_gauges.shp	Point	USGS stream gauging stations
tutorial_streams_1st_Order.shp	Polyline	First-order streams
tutorial_streams_2nd_Order.shp	Polyline	Second-order streams
tutorial_streams_3rd_higher_Order.shp	Polyline	Third and higher-order streams
tutorial_villages.shp	Polygon	Villages in selected area
tutorial_watershed.shp	Polygon	Surface watershed boundaries
tutorial_wells_bedrock.shp	Point	Bedrock wells in the area
tutorial_wells_drift.shp	Point	Drift wells in the area
tutorial_wetlands.shp	Polygon	Wetlands in the area
AUGUSTA_NW.ecw	Air Photo	
BANFIELD_NE.ecw	Air Photo	
BANFIELD_NW.ecw	Air Photo	
BANFIELD_SE.ecw	Air Photo	
BANFIELD_SW.ecw	Air Photo	
DELTON_NE.ecw	Air Photo	
DELTON_SE.ecw	Air Photo	

2.3.1. Importing GIS Files in IGW GIS-Interface

Follow these steps to import modeling layers in GI:

Step 1: Open GIS-Interface as explained in Section 2.1, if not already open.

Step 2: Click 'Add New Model Layer' button. 'Open' window pops up and you can browse to the folder where you have the GIS files.

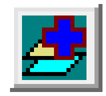
Step 3: In the file folder, you can select a single or multiple files and click 'open'.

The selected file(s) is (are) loaded in the 'Display Pane'. Names of all files loaded also appear under 'Modeling Layers' in the 'GIS Layer Explorer'.

Follow these steps to import mapping layers in GI:

Step 1: Open GIS-Interface as explained in Section 2.1, if not already open.

Step 2: Click 'Add New Mapping Layer' button. 'Open' window pops up and you can browse to the folder where you have the GIS files



Step 3: In the file folder, you can select a single or multiple files and click 'open'.

The selected file(s) is (are) loaded in the 'Display Pane'. Names of all files loaded in GI appear in the 'GIS Layer Explorer'

i	GI does not allow loading the same GIS file both as a mapping layer as well as a modeling layer. However, you may save the same file with different names and then load as separate files in either group

Follow these steps to open an ECW air photo in GI:

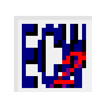
Step 1: Open GIS-Interface as explained in Section 2.1, if not already open.

Step 2: Click 'Add ECW Air Photo' button. 'Open' window pops up and you can browse to the folder where you have the ECW file.

Step 3: In the file folder, select an air photo and click 'open'.

The selected file is loaded in the 'Display Pane'. ECW file name does not show in the 'GIS Layer Explorer'.

To clear air photo form Display Pane, click the button again and click 'Yes' on the pop-up message.



!	'Add ECW Air Photo' button  becomes active only after at least one GIS file has been loaded in GI. Only one *.ecw image can be loaded at a time. ECW image and GIS file(s) in the 'Display Pane' must have overlapping spatial coverage. If the image is completely outside the spatial limits of the GIS file(s) in the Display Pane, the image will not show.

2.3.2. Viewing GIS Files

Figure 2.4 shows how GIS files are displayed in the 'Display Pane'. In the 'GIS Layer Explorer' the layers are automatically arranged under the specific file types (point, polyline or polygon). You can use the check boxes in 'GIS Layer Explorer' besides a layers name to switch on/off its display in the 'Display Pane' or globally switch on/off a group using the check box for the group.

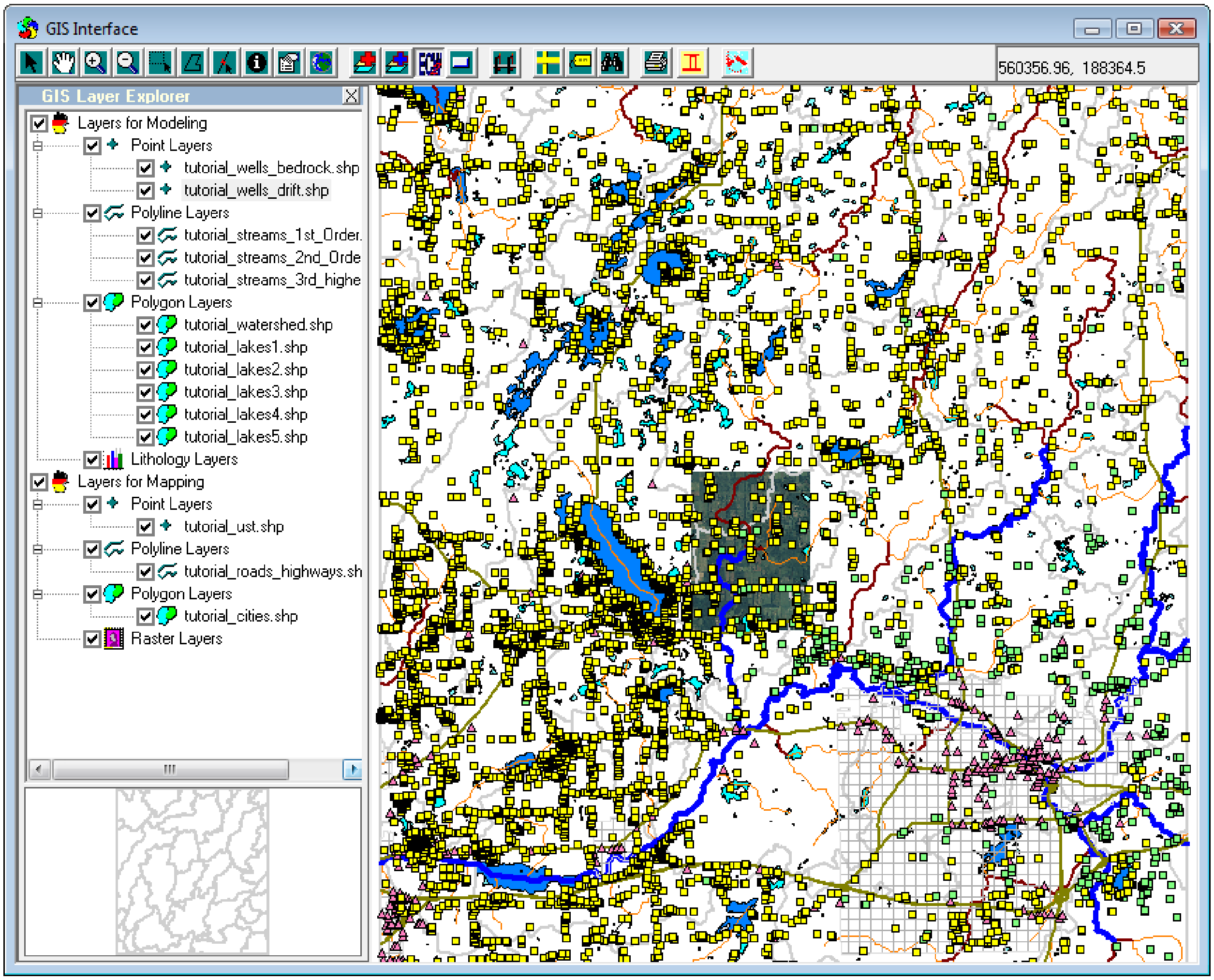


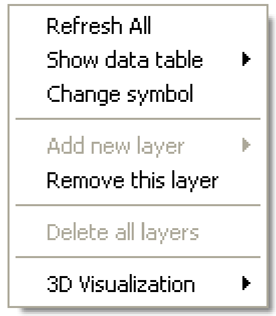
Figure 2.4 GIS-Interface with GIS data layers and air photo

After loading data files in GI, you may also experiment with Zoom-in, Zoom-out and Pan buttons. To fit data extents in the 'Display Pane' you may click 'Full Extent' button at any time.

2.3.3. GI's Right Click Menu

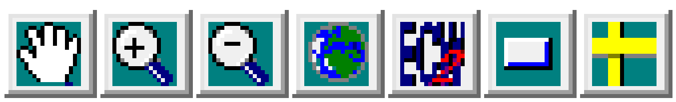
Right clicking on a layer's name or group in the 'GIS Layer Explorer' (or anywhere inside the 'Display Pane') opens a pop-up menu with the following options.

- Refresh All
- Show data table
    - Show entire layer's dataset
    - Show selected dataset
- Change symbol
- Add new data layer
    - Add modeling layer
    - Add mapping layer
- Remove this layer
- Delete all layers
- 3D visualization
    - Visualize entire layer
    - Visualize selected



Depending on where you click, available options on the menu are clear while others are grayed out. You may experiment with these options after loading GIS data in the GI.

R To get better familiarization with GI's display options, you may load a few GIS files in GI and experiment with the following buttons:



You may also experiment with different option from the Right-Click menu. Most recommended option to explore at this point is 'Change symbol' option.

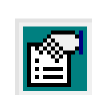
2.4. Exploring Data in GIS-Interface

IGW GIS-interface has many features to help you explore data files and individual data items loaded in the interface. Some of these are listed below.

To see data table associated with a GIS layer:

Step 1: Select the GIS layer by clicking once on its name in the 'GIS Layer Explorer'.

Step 2: click the 'Show Data Table' button.



Step 3: Data table associated with the selected file will pop up as shown in Figure 2.5. Explore the data table using the slide bars.

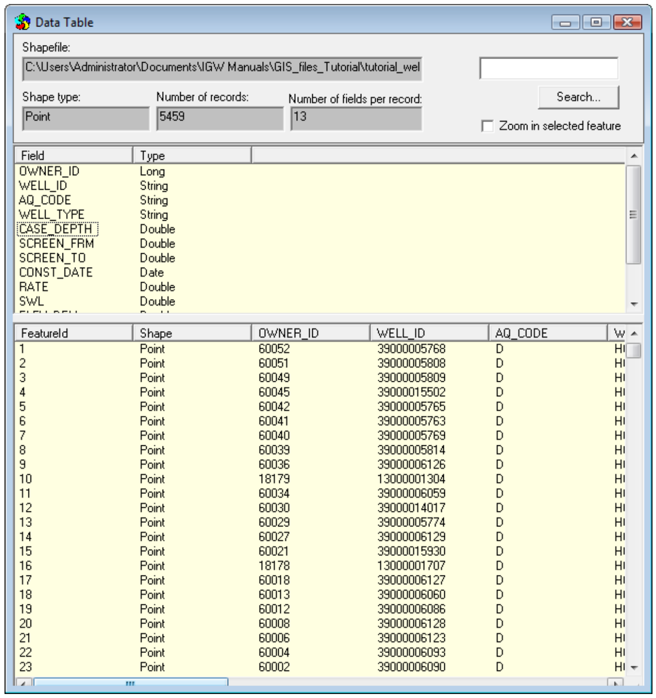


Figure 2.5 Data table for a GIS file

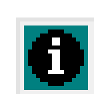
The data table provides information about the file location, number or records and number of fields in the record table. A list of all field names and their types appears in the top half of the table while the bottom half contains the list of all data items in the file.

! Search and zoom features shown in the top right of the Data Table window are not available in *IGW Version 5.2.1P*.

To see the attributes related to an individual item in a particular GIS file:

Step 1: Select the GIS layer by clicking once on its name in the 'GIS Layer Explorer'. (e.g. layer for the drift wells)

Step 2: Click the 'Identify' button. The cursor shape will change to  as soon as you bring it inside the 'Display Pane'.



Step 3: Now click on a feature in 'Display Pane' belonging to the selected layer (for example, a drift well). A window will pop up with all the information available for that feature as shown in Figure 2.6.

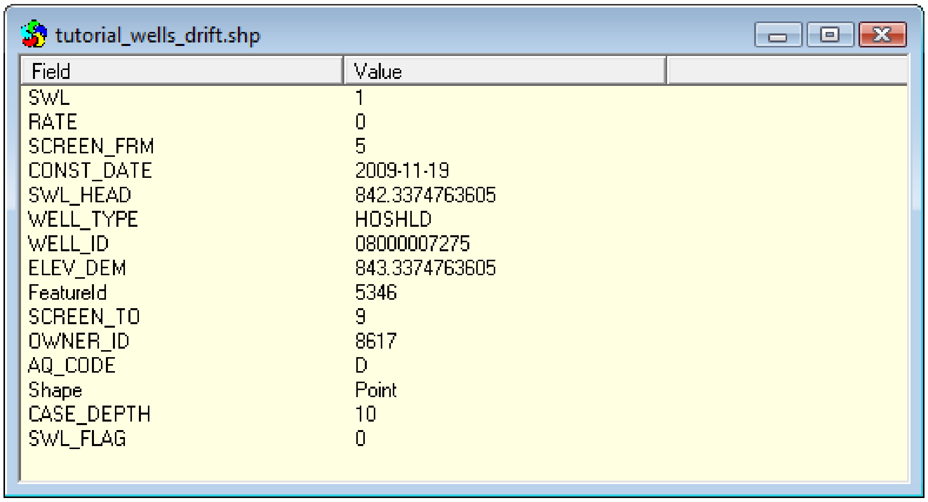


Figure 2.6 Feature information table

2.5. Raster Data Layers

Raster data layers used in this tutorial are listed in Table 2.2. However, unlike vector data, raster data are not handled in GI. These can be directly read by the IGW modeling environment after specifying their directory path in the ‘Default Attribute – Layer *n*’, within the ‘Attributes Explorer’ window and/or within the ‘Extraction Criteria’ window. Detailed account on importing raster data to IGW groundwater models is given in Section 4.3.

Table 2.2 Raster Data Layers used in the tutorial

File Name	Type	Remarks
90M_RiverRaster_1.lhs	Raster	90m raster for 1st order streams
90M_RiverRaster_1_2.lhs	Raster	90m raster for 2nd order streams
90M_RiverRaster_1_3.lhs	Raster	90m raster for 3rd and higher order streams
90M_DEM_MICHIGAN_1.txt	Raster	90m DEM
rastert_bedrockTop.txt	Raster	500m bedrock elevation
raster_recharge.txt	Raster	1600m (1 mile) recharge estimate
500m_conductivity_h1_1.txt	Raster	500m specific capacity based conductivity
540M_CONDUCTIVITY_H2_1.txt	Raster	540m lithology based conductivity
BedRock_Tran (folder)	Raster	Variable resolution bedrock transmissivity

Chapter 3 DATA SELECTION AND ANALYSIS

Once data files are imported in GI, the interface allows you to select data anywhere within the spatial limits of the GIS files. Although GI has in-built filters to reject bad data, the user can choose his/her own selection criteria for the data. The data can be selected within the 'Display Pane' in one of the following ways:

- by drawing a rectangular region;
- by drawing a polygonal region;
- by drawing a polyline intersecting with desired features; and,
- by choosing a region in bounded by an existing GIS polygon.

The selected data can either be extracted to IGW or it can be further analyzed using GI data analysis tools. This chapter will guide you through step by step procedures for selecting and analyzing data in GI.

Before selecting and analyzing data, you will create an IGW model file and import specified GIS files in the GI. Follow these steps to setup data selection and analysis exercises:

Step 1: Start a new IGW model

Step 2: From the Menu Bar select File → Save As → Conceptual Model and save the model on your hard disk as 'GIS_tutorial_01.igw'

(or give it a name you like but this tutorial will use the recommended name for referring back to this model)

Step 3: From the Menu Bar select GIS → GIS Interface to open GI

Step 4: In GI, click 'Add new modeling layer' button and navigate to the folder on your hard disk where you had saved the GIS tutorial files

Step 5: From the Open window, select 'tutorial_watershed.shp' and click 'Open'. This is the first file you have loaded and it will also serve as a reference map in the 'Preview Pane'

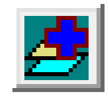
Step 6: Click again on the 'Add new modeling layer' button and select the following files in the Open window:

tutorial_wells_bedrock.shp
tutorial_wells_drift.shp
tutorial_lakes1.shp
tutorial_lakes2.shp
tutorial_lakes3.shp
tutorial_lakes4.shp
tutorial_lakes5.shp
tutorial_streams_1st_Order.shp
tutorial_streams_2nd_Order.shp

tutorial_streams_3rd_higher_Order.shp

Click 'Open' to import all selected files into GI (you may also import these files one by one)

Step 7: For mapping reference of the area, you may import the following files using 'Add new mapping layer' button:

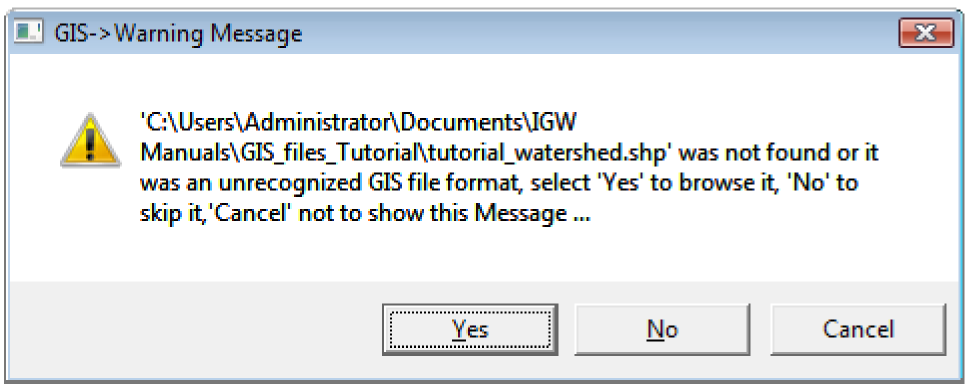


tutorial_roads_highways.shp

tutorial_roads_residential.shp

Step 8: Go back to IGW Main Window and save the model again. The saved model will retain the information of GIS file locations in your computer and whenever next time you will open this model, GI will automatically import all files from the specified directories.

i IGW model only stores information on GIS file locations on your hard disk. If you move the GIS files or change directory path/names or GIS filenames, the files will not be reloaded when you start the next session. However, IGW will open the model with the following warning message.



You may reload GIS files from new location after the model is open

With GIS data files in GI, we are now ready to explore data selection and analysis tools/features in the interface.

3.1. Selecting Data in GI

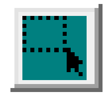
The three different methods of selecting data mentioned earlier are elaborated as follows:

3.1.1. Drawing a Rectangular Region

Step 1: Go to GIS interface with data files loaded

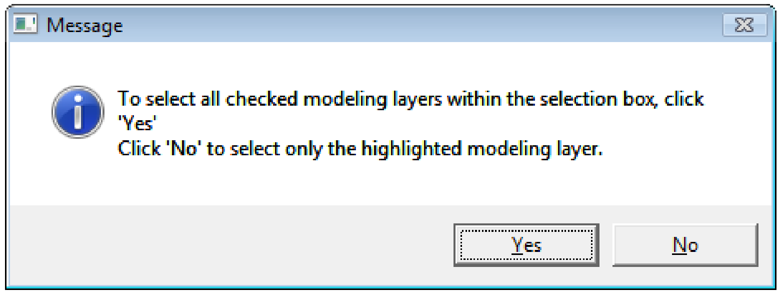
Step 2: In the 'GIS Layer Explorer' select any modeling layer by clicking once on the layer's name

Step 3: Click ‘Draw a selection box’ button. The cursor turns to + when you move it inside ‘Display Pane’.



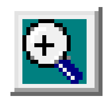
Step 4: Drag a box in the ‘Display Pane’ by holding down the left mouse button.

Step 5: As soon as you release the left mouse button, a message pops up:



Step 6: Click ‘Yes’ to select all data in the rectangular selection box. You will notice that the selected features turn red. See Figure 3.1. Notice that selection box also appears in the ‘Preview Pane’.

Step 7: (optional) You may like to zoom in to see more clearly the selected features inside the box. See Figure 3.2.



Step 8: Clicking + anywhere in the ‘Display Pane’ outside the selection box will undo the selection.

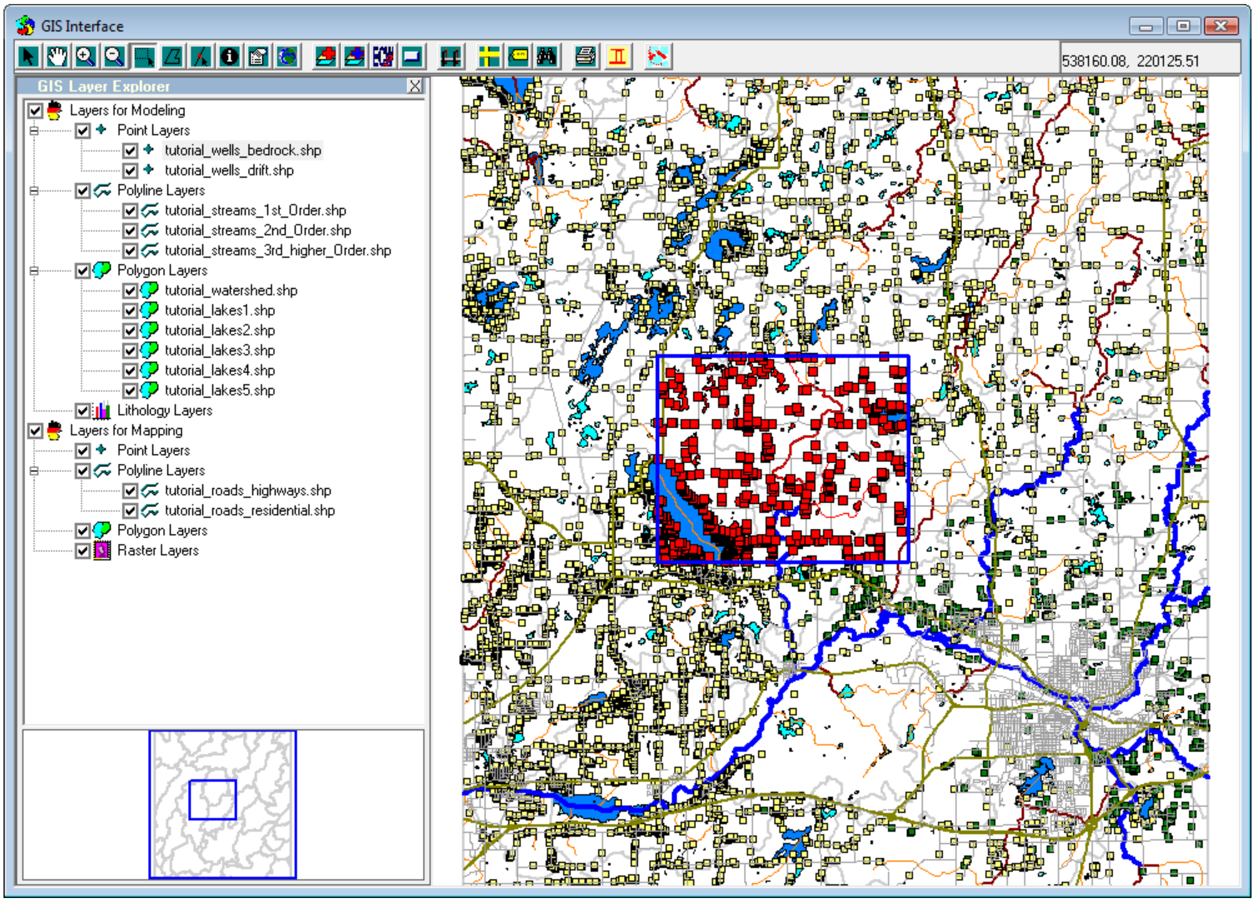


Figure 3.1 Data selected in a rectangular zone

!	Only those GIS features in 'Display Pane' will be selected which are completely inside the box. Polygon or polyline features being intersected by the boundary of the box will not be selected. Notice some lakes and stream arcs in Figure 3.2 which do not turn red – means they are excluded from the selection.

i	If a modeling layer is not selected in 'GIS Layer Explorer' prior to clicking 'Draw a selection box' button, the software will prompt you to do so as soon as you try to drag a box anywhere in the 'Display Pane'

R	You may experiment drawing boxes at different locations in the 'Explore Pane' to get a feel how it works

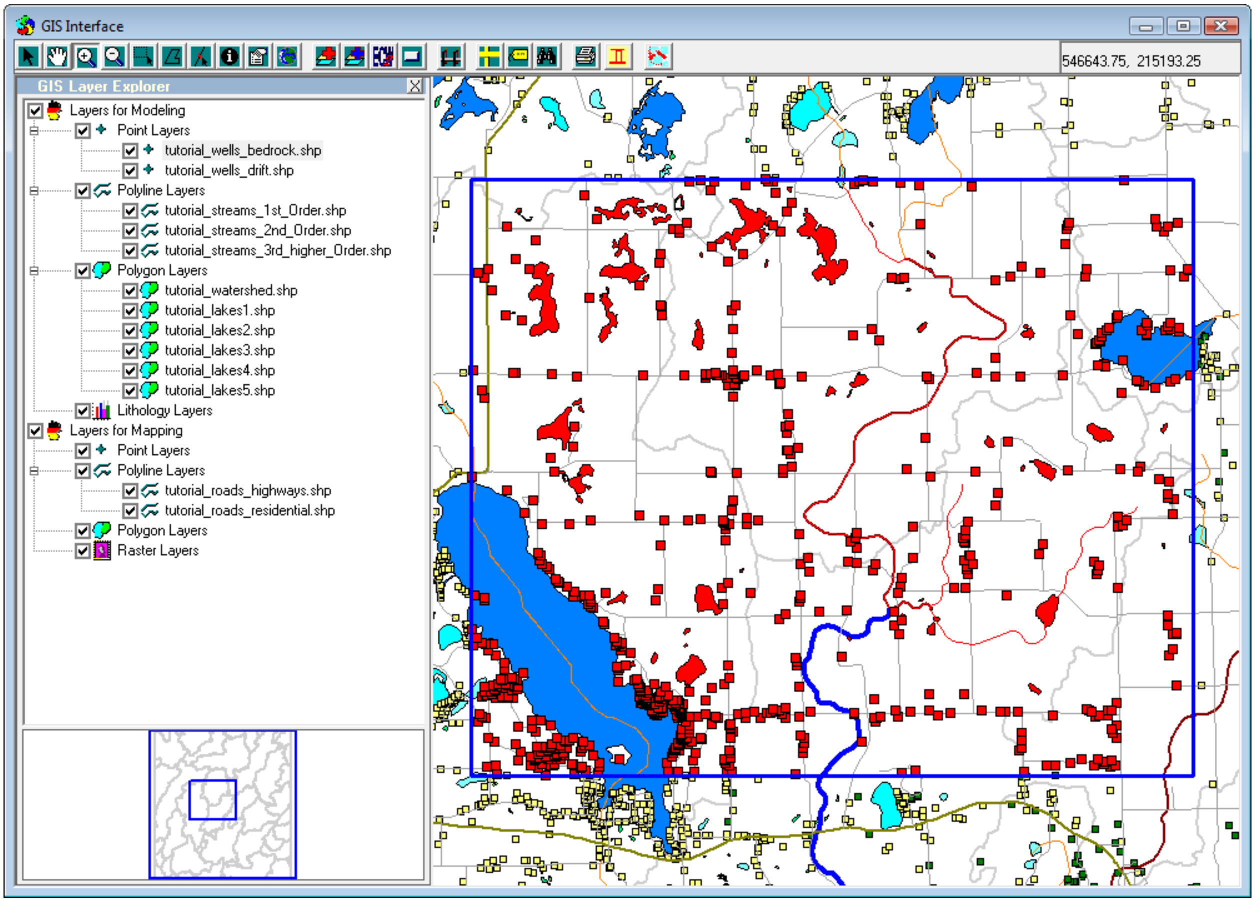


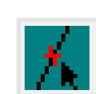
Figure 3.2 Selected data zoomed-in in 'Display Pane'

3.1.2. Drawing a Polyline across Features

Step 1: Go to GIS interface with data files loaded

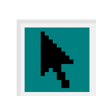
Step 2: In the 'GIS Layer Explorer' select any modeling layer by clicking once on a layer name

Step 3: Click 'Draw a selection polyline' button. The cursor turns to + when you move it inside 'Display Pane'.



Step 4: Draw a line passing through all the features you want to select. Click the mouse once to create vertices of the line. When line is complete, double click the mouse and you will see all features touched by the polyline turn red.

Step 5: To exist polyline selection mode, click 'Reset' button



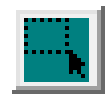
R	Uncheck 'tutorial_watershed.shp' and experiment with polyline selection feature.

3.1.3. Selecting Data within a GIS Polygon

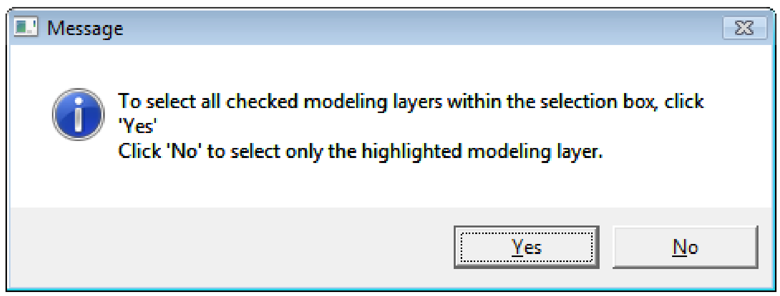
Step 1: Go to GIS interface with data files loaded

Step 2: In the 'GIS Layer Explorer' select 'tutorial_watershed.shp' layer by clicking once on the layer name (this layer contains a number of watershed polygons and you will use one these watersheds to select all data inside it)

Step 3: Click 'Draw a selection box' button. The cursor turns to + when you move it inside 'Display Pane'.



Step 4: In the 'Display Pane' click once inside a watershed polygon. Following message pops up:



Step 5: Clicking 'Yes' will select data within the polygon from all modeling layers. Clicking 'No' will only select the polygon with no data inside.

Step 6: Clicking + anywhere in the 'Display Pane' outside the selection polygon will undo the selection.

i	To exclude data from a GIS file in the selection-area, turn its display off using the check box in the 'GIS Layer Explorer'. The file should be turned off BEFORE the selection of selection-area.

3.2. Analyzing and Viewing Selected Data

IGW GIS-Interface allows statistical/geostatistical analyses and visualization of data attributes in the scatter-point shape files. The analysis handles both numeric and text fields. In this section, you first explore numeric fields and then text fields.

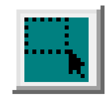
3.2.1. Exploring Numeric Data

For the sake of this tutorial, you will analyze static water level data from water wells in drift aquifer for the watershed of northern half of Augusta Creek. This section will guide you through the basic steps involved in data analysis and let you explore a number of options for data analysis and visualization.

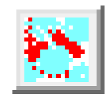
Step 0: All GIS files imported at the beginning of this chapter are assumed to be in GI before going to the following steps.

Step 1: Select 'tutorial_watershed.shp' in 'GIS Layer Explorer' by clicking once on the layer name.

Step 2: Click 'Draw a selection box' button and click inside the watershed polygon for the northern half of Augusta Creek (as shown in Figure 3.3). This will select all data from all modeling layers within the polygon.



Step 3: To start analyzing data from scatter points selected within the watershed polygon click the 'Data Explore' button. This will open 'Scatter Point Data Exploratory Options' window as shown in Figure 3.4. Figure 3.4 (a) is the standard window without custom data filtering options. Notice that 'Exploratory Level' box within the window has options to choose from 'Raw Data', 'Excluded Invalid Data' [default option], and 'Customized'.



Step 4: Check the 'Customized' option in Exploratory Level and it will expand 'Scatter Point Data Exploratory Options' window with all customized filtering options as shown in Figure 3.4 (b).

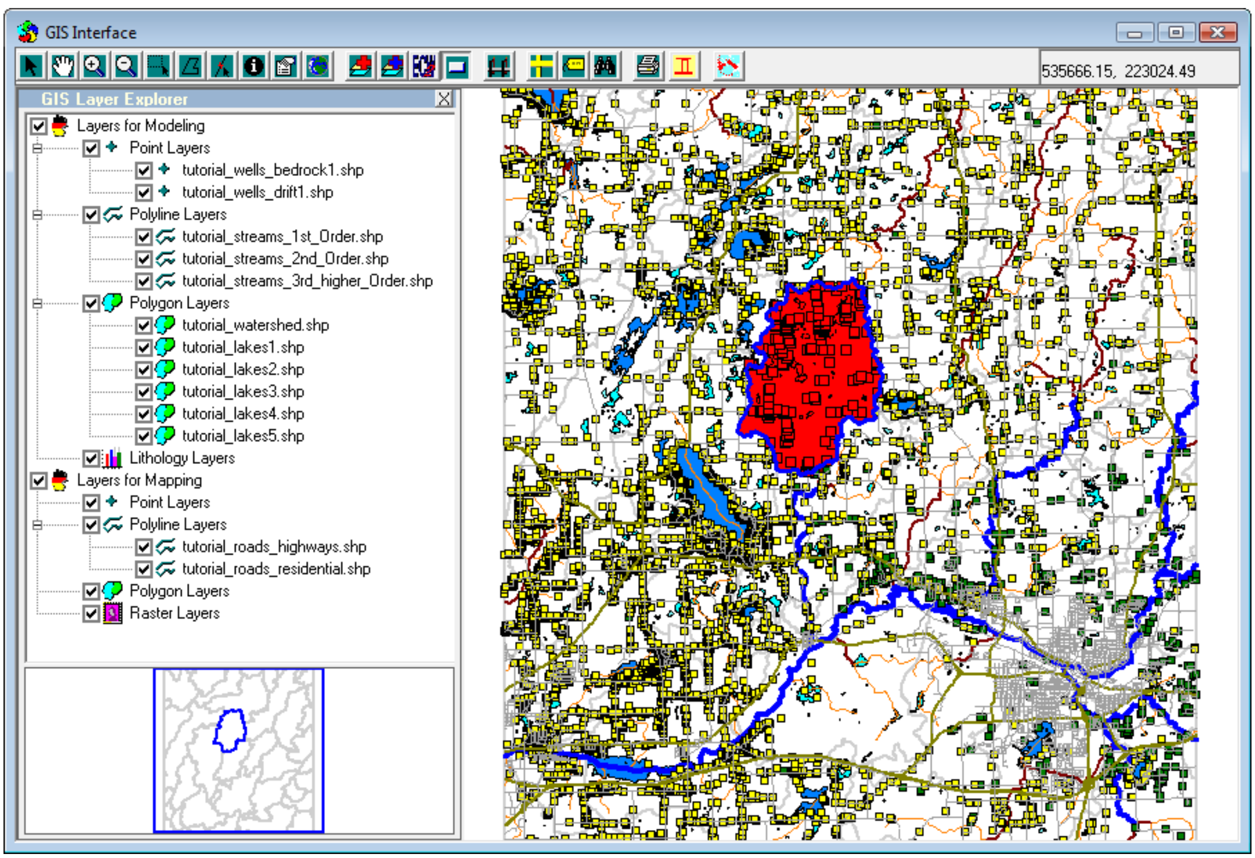
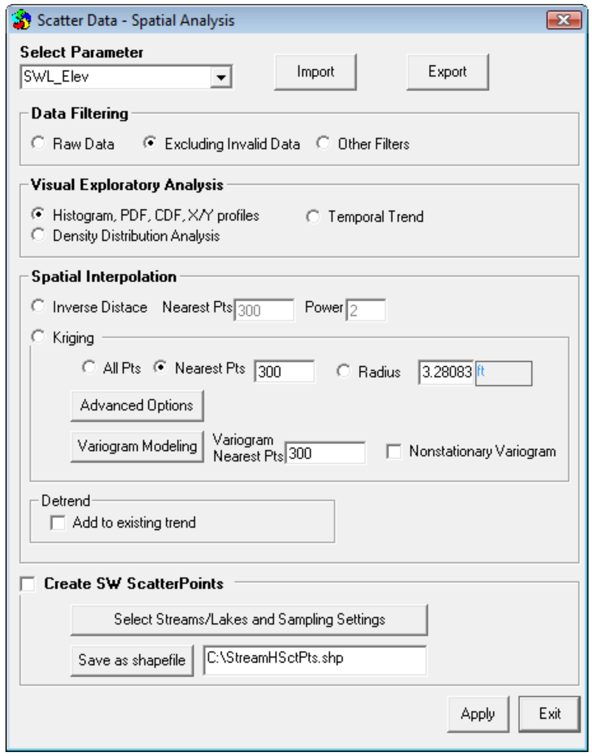


Figure 3.3 Data selected in northern watershed of Augusta Creek

(a)



(b)

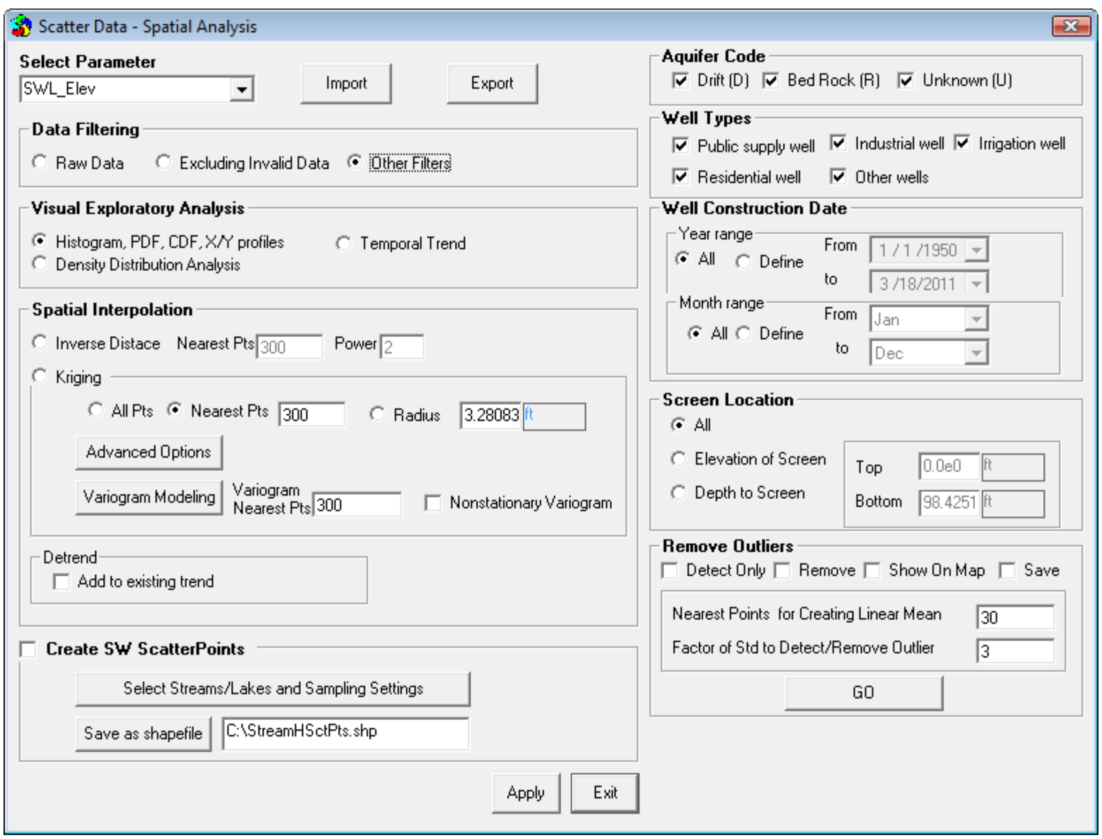


Figure 3.4 'Scatter Data - Spatial Analysis' window without custom filter options (a) and with custom filter options (b)

Notice in Figure 3.3 that layers for both bedrock and drift wells are checked in 'GIS Layer Explorer'. This means that wells from both bedrock and drift aquifers have been selected within the watershed.

Step 5: To exclude bedrock wells from the selection un-check 'Bedrock (R)' option under 'Aquifer Code'.

You may also like to have a look at other customized filter options. These options are primarily based on filtering data from Michigan's water wells database – Wellogic.

After selecting the filtering options in steps 4 and 5, now you are ready to extract a desired parameter from the selected scatter points. First you will select a parameter to be explored. Parameters associated with the selected points can be viewed and selected from the dropdown list under 'Parameter to be explored' in 'Scatter Point Data Exploratory Options' window.

Step 6: Select 'SWL_Elev' from the drop down list under 'Parameter to be explored'. This is a numeric field giving the elevation of static water level at a well location at the time the well was constructed.

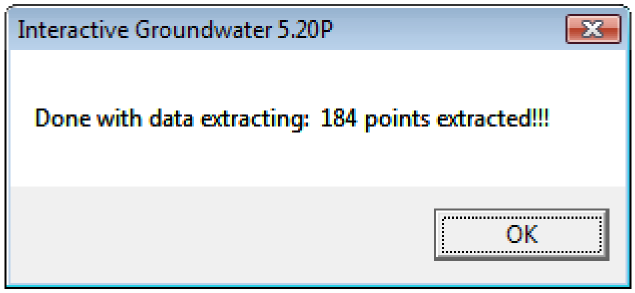
By now you have selected data filtering options and a parameter for data exploration (i.e SWL_Elev). Following 'Data Exploratory Options' are available 'Scatter Point Data Exploratory Options' window:

- Visual Exploratory Analysis
    - Histogram, PDF, CDF and X/Y Profiles
    - Temporal Trend
    - Density Distribution
- Spatial Interpolation
    - Inverse Distance
    - Kriging
    - Detrend
- Create Surface Water Scatter Points

You will explore the 'Visual Exploratory Analysis' options in this chapter, while the next three options will be explored as you build the groundwater models using the GIS data in Chapter 4.

Step 7: Select 'Histogram, PDF, CDF and X/Y Profiles' by checking the radio button next to it.

Step 8: Click 'Import' button. A message prompting the number of data points extracted will pop-up. Click 'OK'



Step 9: Now click 'Apply' button at the bottom

This will open 'Exploratory Data Analysis Window' as shown in Figure 3.5 (a). Notice that this window is following tabs active tabs on its left: Histogram, PDF, CDF, h-Scatterplot, X-Spatial and Y-Spatial (last tab, Temporal, is inactive). The first four tabs are standard statistical representations of data. X-Spatial (and Y-Spatial) tab is the projection of data in a vertical plane in the east-west direction (north-south in case of Y-Spatial) as shown in Figure 3.5 (b).

(a)

(b)

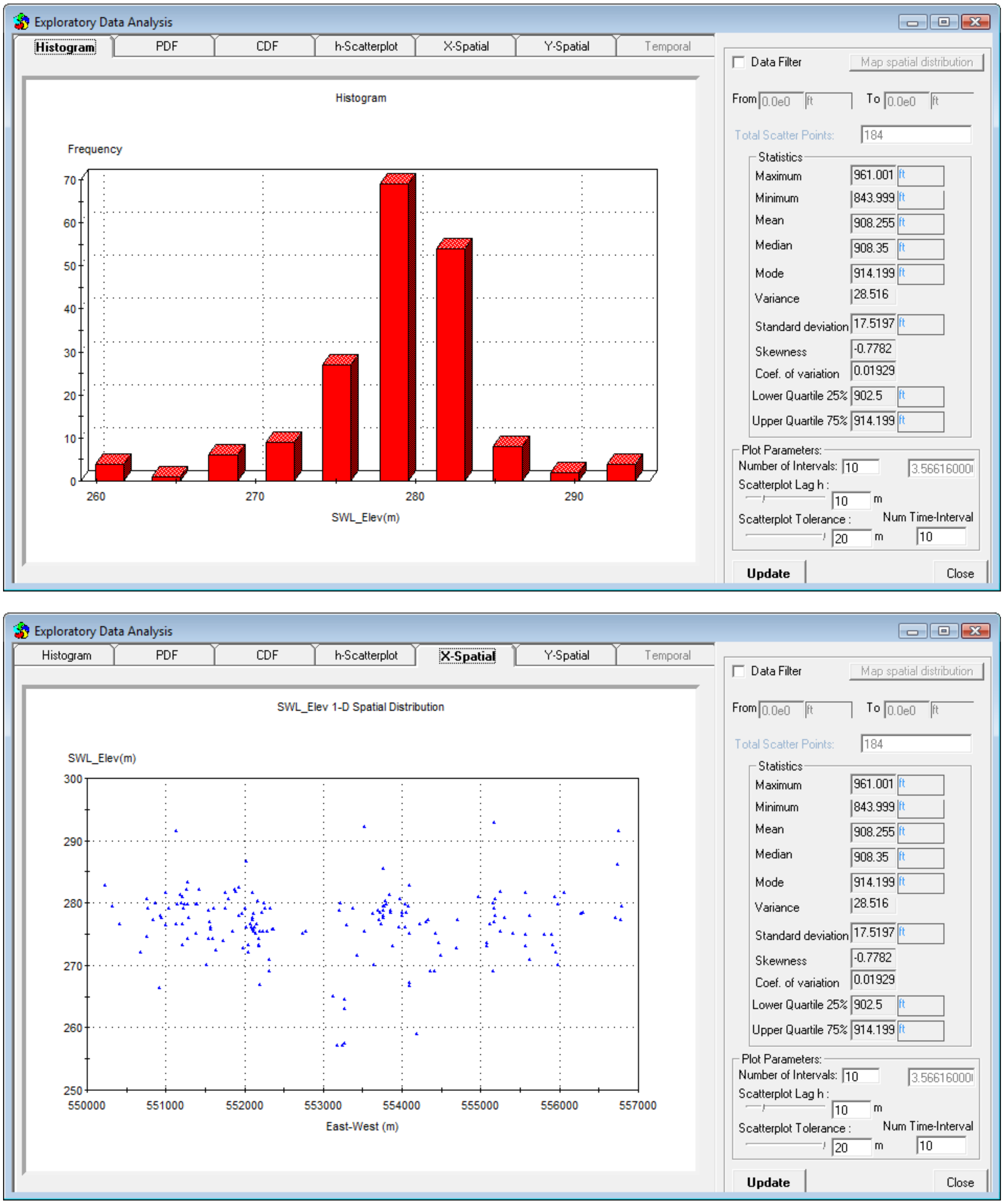


Figure 3.5 Exploratory Data Analysis window

R	Click all tabs in 'Exploratory Data Analysis' window to explore statistical representation of data under each tab.

Right hand side of 'Exploratory Data Analysis Window' has three sub sections as illustrated in Figure 3.6. Top part gives data filtering options within the max and minimum limits of data range. The middle portion enumerates descriptive statistics of selected data and the bottom portion provides options for histogram, pdf, cdf and scatter plot draw/display options. These options are explained the following subsections.

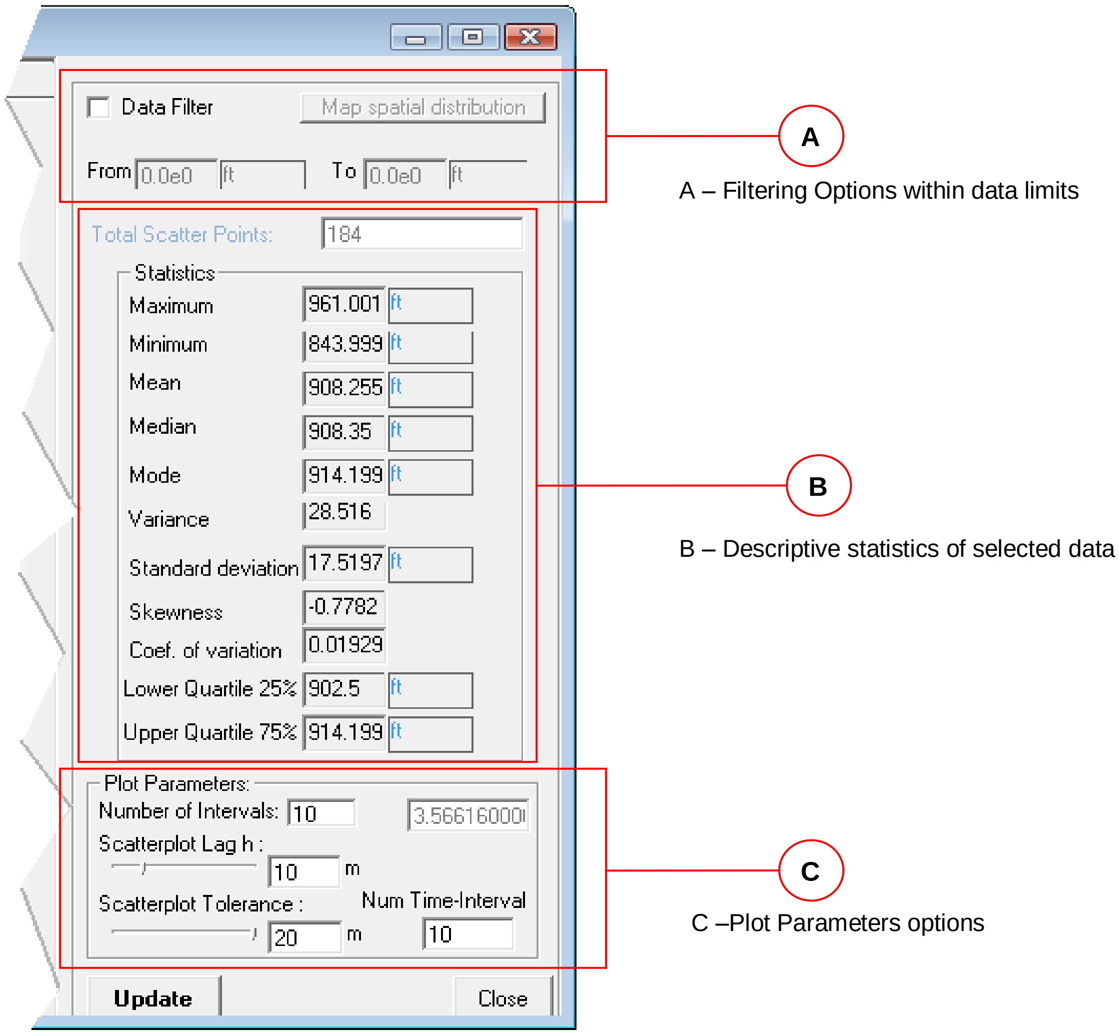


Figure 3.6 Data filtering and display options in Exploratory Data Analysis window

To illustrate data filter options, let's consider the data range of SWL between 844 ft and 961 ft as seen in Figure 3.6. For example, you want to know:

- how the data looks like for SWL higher than 920 ft; and
- where do these points occur in the map.

Follow these steps:

Step 10: Check the box before 'Data Filter' and all options in the box become active.

Step 11: In the From/To boxes enter 920 and 970 respectively

Step 12: Click the 'Update' button at the bottom. This will update all plots in left side of the window and update all the descriptive statistics in the right side of the window as shown in Figure 3.7. Notice that before there were 184 scatter points, but now there are only 33.

Step 13: In order to see these 33 points in the GI, click 'Map spatial distribution' button. These points in show within the selection polygon with light green circles as shown in Figure 3.8.

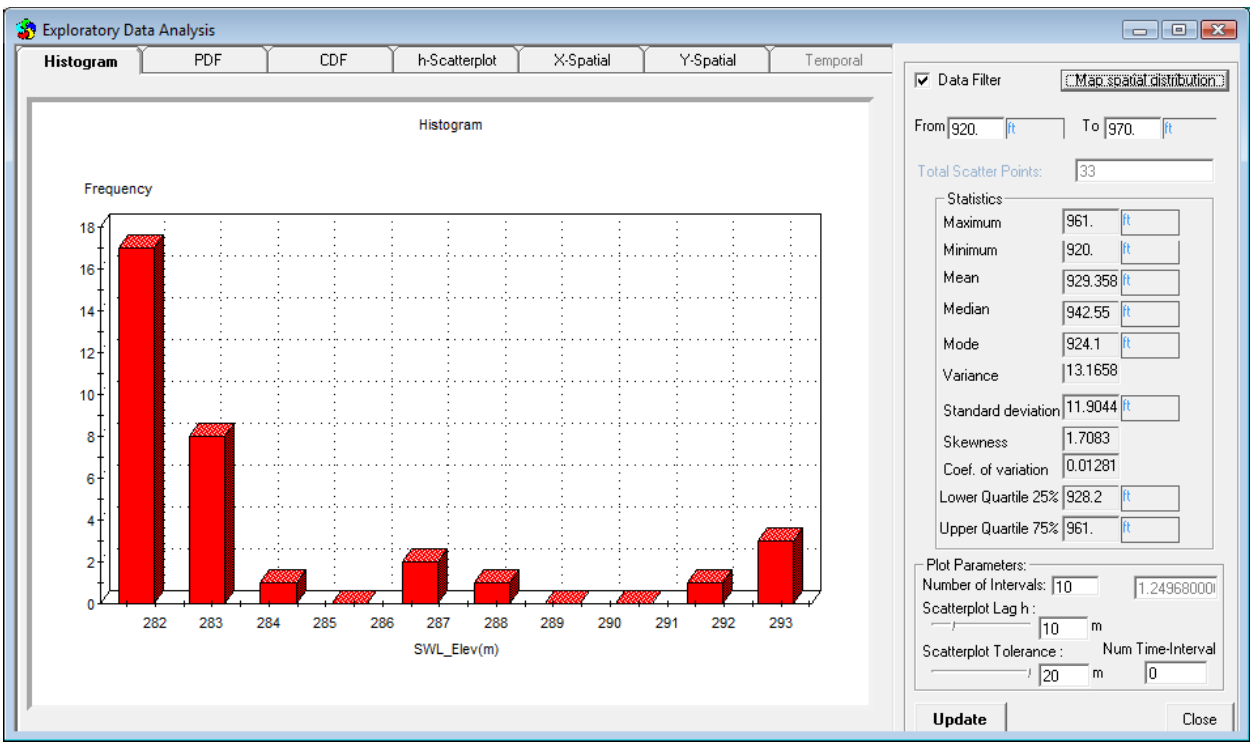


Figure 3.7 Updated data

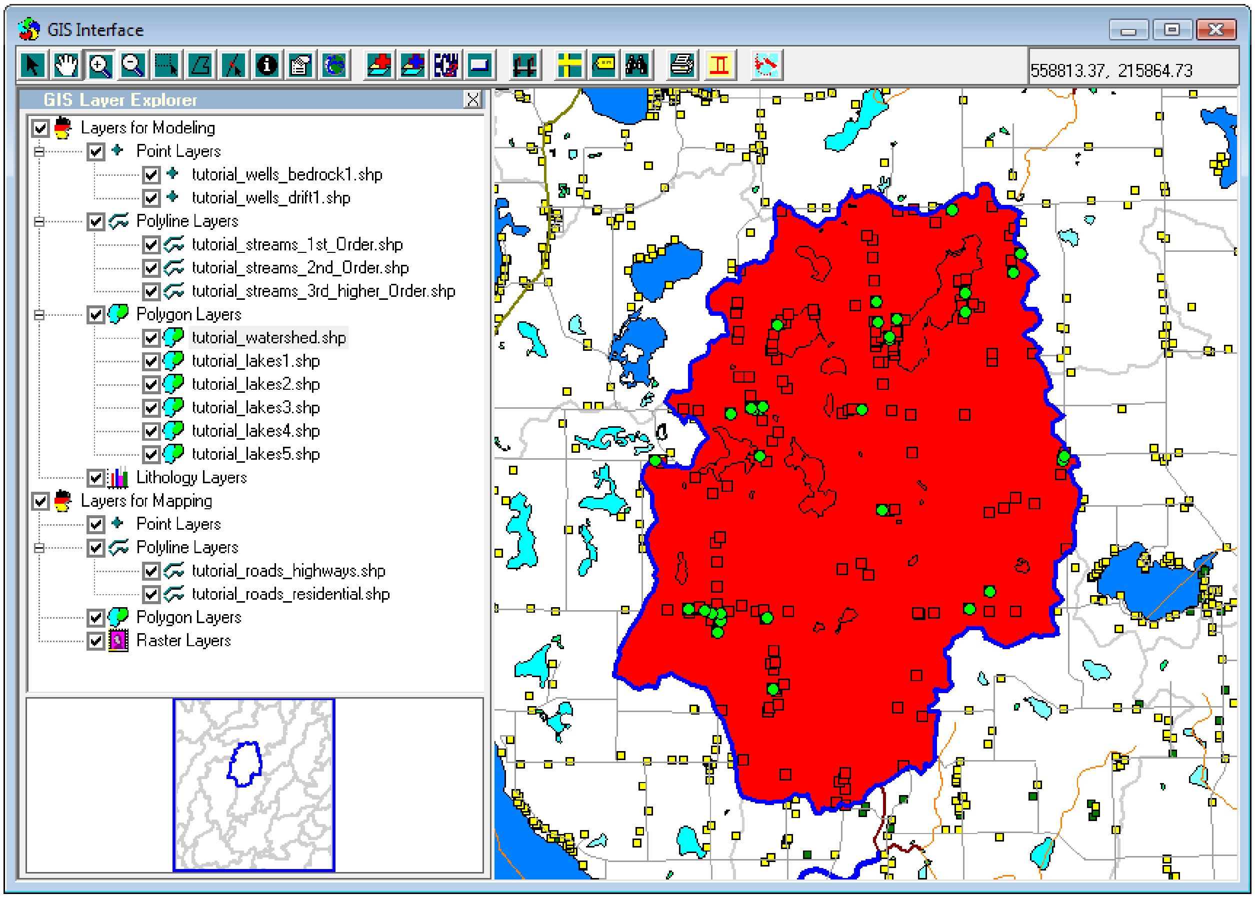


Figure 3.8 Well locations in GI with filtered data

R	Click all tabs in 'Exploratory Data Analysis' window to explore statistical representation of updated data. You may like to experiment with different data filtering values and see how it works.

Descriptive statistics include the number of points in data, maximum, minimum, mean, median, mode, variance, standard deviation, skewness, coefficient of variation, lower quartile and upper quartile. The units of statistical parameters also appear next to their values, which can be changed by clicking on the units. You may explore the available units by successively clicking on any unit. The numerical values automatically change corresponding to the selected unit.

You have the option of changing the number of intervals for histogram, PDF and CDF. Lag distance and tolerance for h-scatter plot can also be changed. To make changes:

Step 14: Make desired changes in numeric fields provided in the 'Plot Parameter' options area.

Step 15: Click the 'Update' button at the bottom. This will update all plots in left side of the window. Descriptive statistics are not affected by changing plot options.

Up to this point you have explored "Histogram, PDF, CDF and X/Y Profiles" option. Before moving on to "Temporal Trend" option, you must uncheck 'Data Filter' option and close 'Exploratory Data Analysis' window.

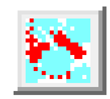
Step 16: Uncheck 'Data Filter' option in the 'Exploratory Data Analysis' window

Step 17: Click 'Close' button at the bottom right of the window

Now you are ready to explore Temporal Trend option. Follow these steps:

Step 0: Assume that data is already selected in GI in the same watershed as for the previous example.

Step 1: click the 'Data Explore' button to open 'Scatter Point Data Exploratory Options' window

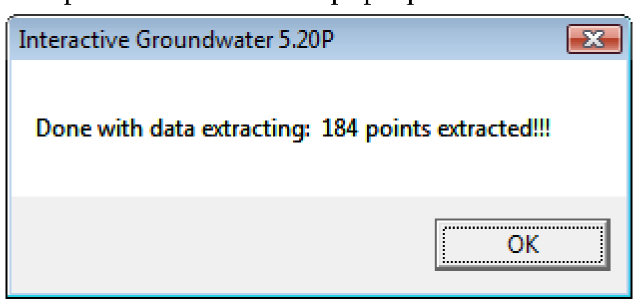


Step 2: Choose 'Customized' from the 'Exploratory Level' and uncheck 'Bedrock' under 'Aquifer Code'

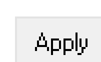
Step 3: Select 'Temporal' under the 'Data Exploratory Options'

Step 4: Select 'SWL_Elev' from the dropdown list under 'Parameter to be explored' option.

Step 5: Click 'Import' button. A message prompting the number of data points extracted will pop-up. Click 'OK'



Step 9: Now click 'Apply' button at the bottom. Exploratory Data Analysis window will pop-up.



Step 9a: If the window does not show any display, click on the 'Temporal' tab.

Figure 3.9 shows SWL elevation at data points on vertical scale plotted against time of well construction date. Descriptive statistics are not displayed in 'Temporal' option. Also note that all tabs on the right, except Temporal, are in-active.

From the plot you will notice that few data points show a construction date close to 1900. In order to find these points on map you can follow the following steps:

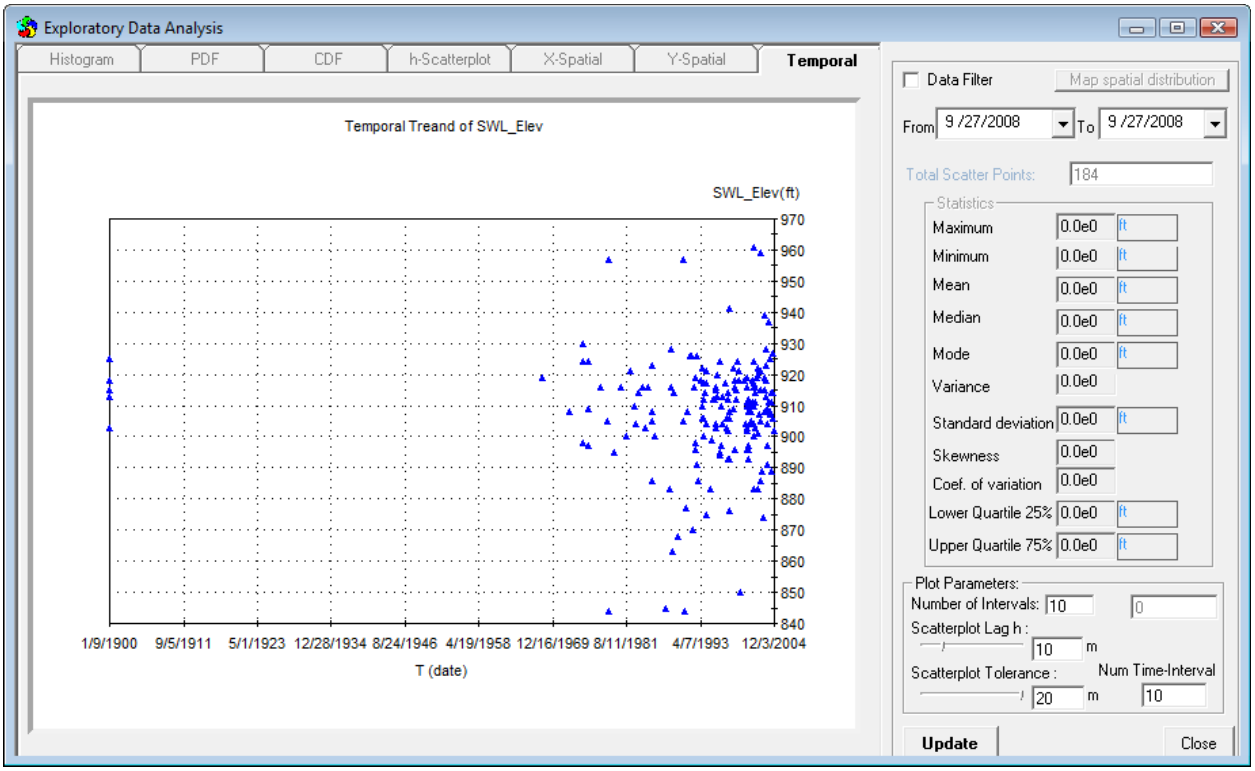


Figure 3.9 Temporal trend

Step 10: Check the box before 'Data Filter'.

Step 11: In the From/To fields enter the following dates: 1/1/1900 and 1/1/1910.

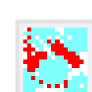
You can increase or reduce the number of vertical intervals in 'Num Time-Interval' field in the 'Plot Parameters' options.

Finally we you will explore 'Density Distribution' option.

To visualize and explore data distribution density within the watershed you can follow these steps:

Step 0: Assume that data is already selected in GI in the same watershed as for the previous example.

Step 1: Click the 'Data Explore' button to open 'Scatter Point Data Exploratory Options' window

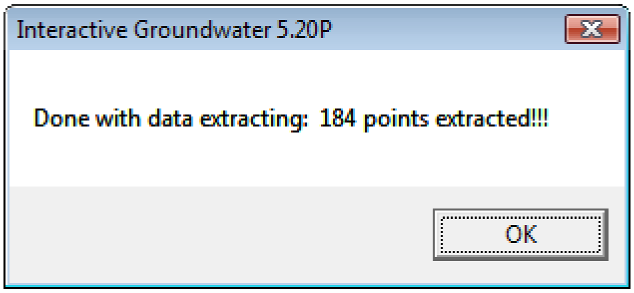


Step 2: Choose 'Customized' from the 'Exploratory Level' and uncheck 'Bedrock' under 'Aquifer Code'

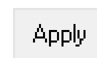
Step 3: Select ‘Density Distribution’ under the ‘Data Exploratory Options’

Step 4: Select ‘SWL_Elev’ from the dropdown list under ‘Parameter to be explored’ option.

Step 5: Click ‘Import’ button. A message prompting the number of data points extracted will pop-up. Click ‘OK’



Step 9: Now click ‘Apply’ button at the bottom. ‘Well Density Distribution’ window shows with a 3D Bar Chart representation of water wells density in the area as shown in Figure 3.10.



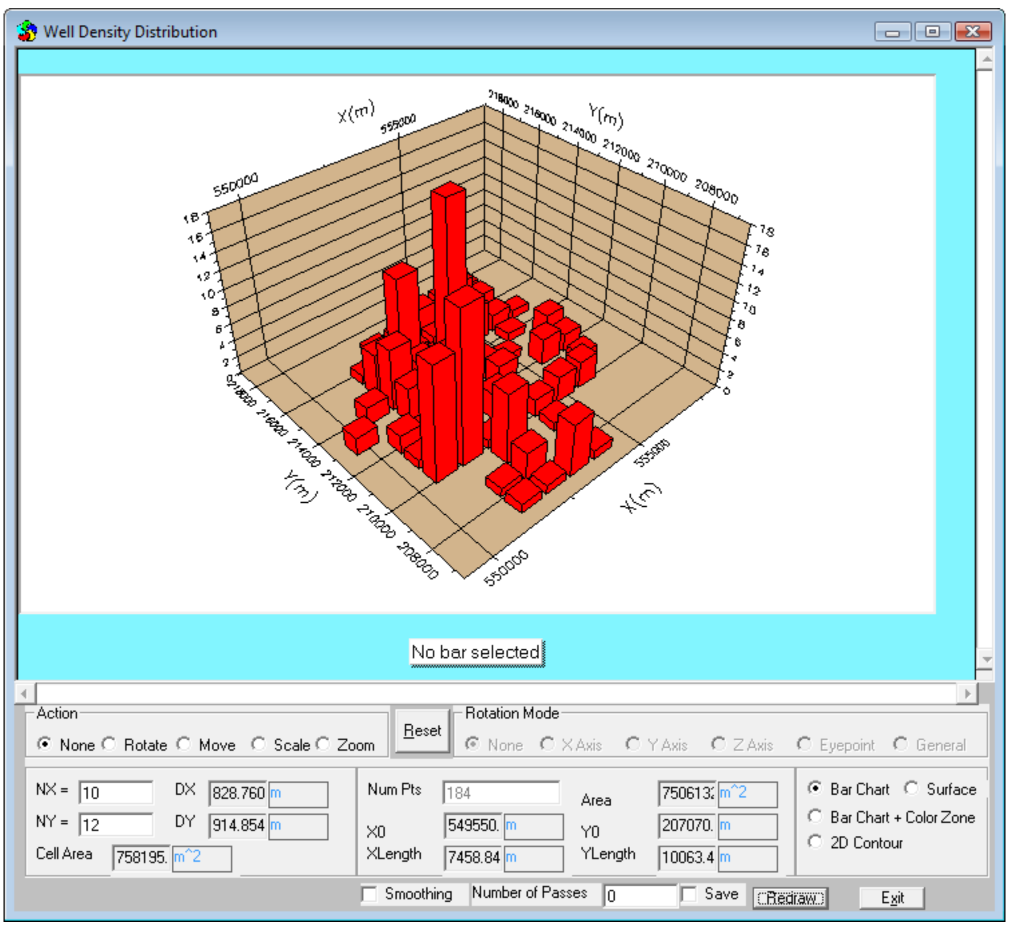


Figure 3.10 Well density distribution in selected area

Step 10: Hover mouse cursor over the bars. The bar under the cursor changes color, displaying its corresponding cell address (NX, NY), and the number of data points in that cell as shown in Figure 3.11.

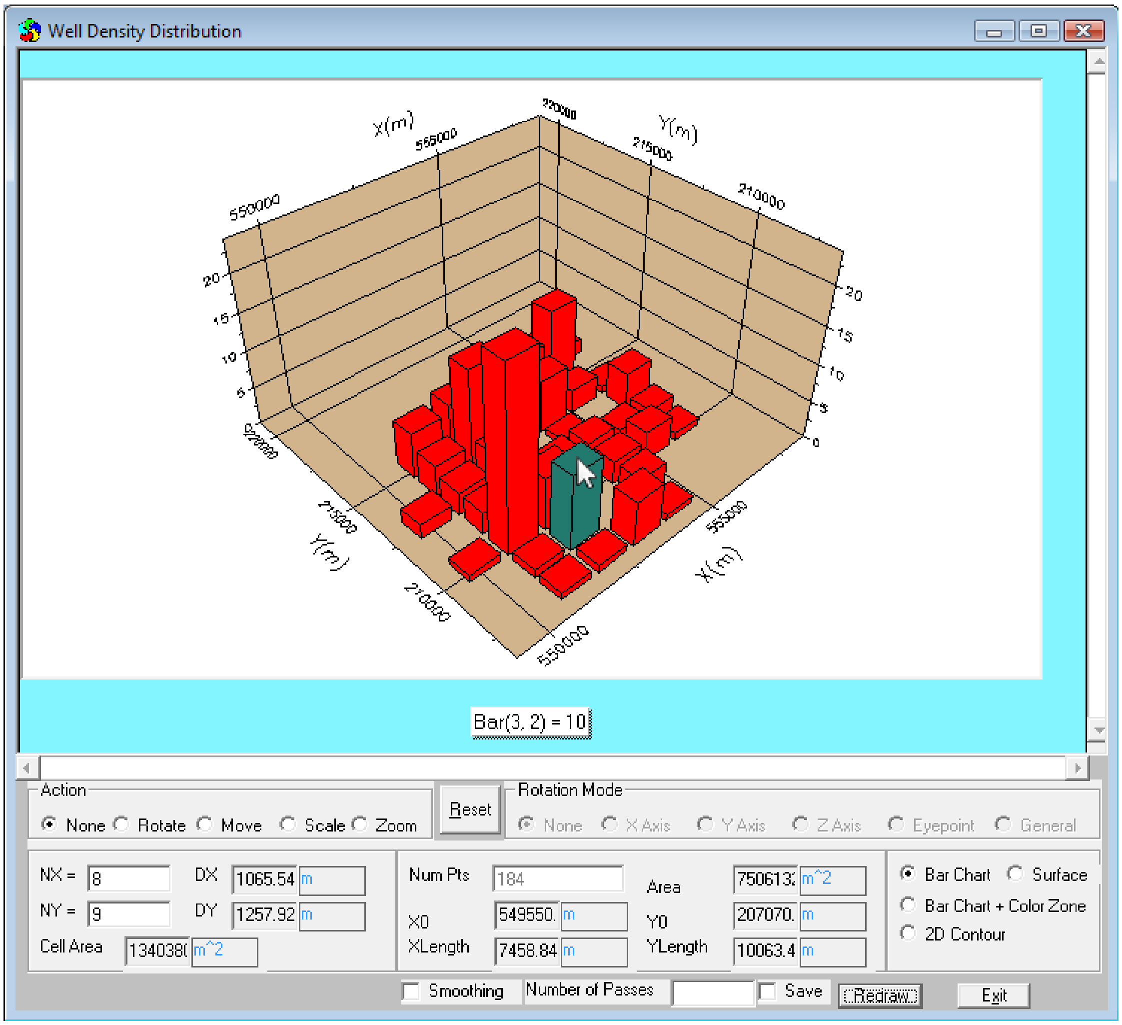


Figure 3.11 Hovering mouse over 3D bars

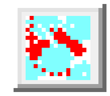
R	There are number of display options under the 3D chart. You can explore these options and visualize density distribution in a number of different ways

3.2.2. Exploring Non-Numeric Data

By now you should have sufficient practice on selection and handling of data in GIS interface. Just as you select a numerical attribute in the dropdown list under 'Parameter to be explored', you can select an non-numerical attribute such as "well type" or "test method" etc. The display options discussed above for the three 'Data Exploratory' options for numeric data are as well applicable to non-numeric data. The following steps will let you explore non-numeric data.

Step 0: Select data within a watershed polygon as explained in the previous sections.

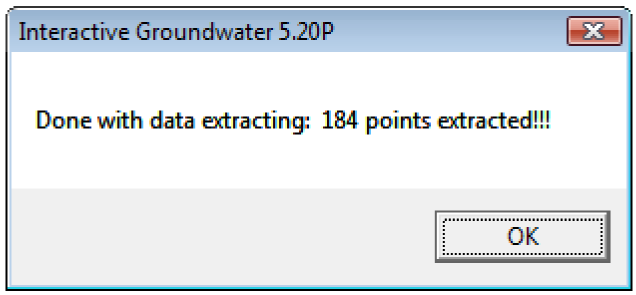
Step 1: Click the 'Data Explore' button to open 'Scatter Point Data Exploratory Options' window



Step 2: Select 'Histogram, PDF, CDF and X/Y Profile' under the 'Data Exploratory Options'

Step 3: Select 'Test_Methd' from the dropdown list under 'Parameter to be explored' option.

Step 4: Click 'Import' button. A message prompting the number of data points extracted will pop-up. Click 'OK'



Step 5: Now click 'Apply' button at the bottom. 'Exploratory Data Analysis' window, as shown in Figure 3.12, pops up with number of wells under each test method shown as bars.

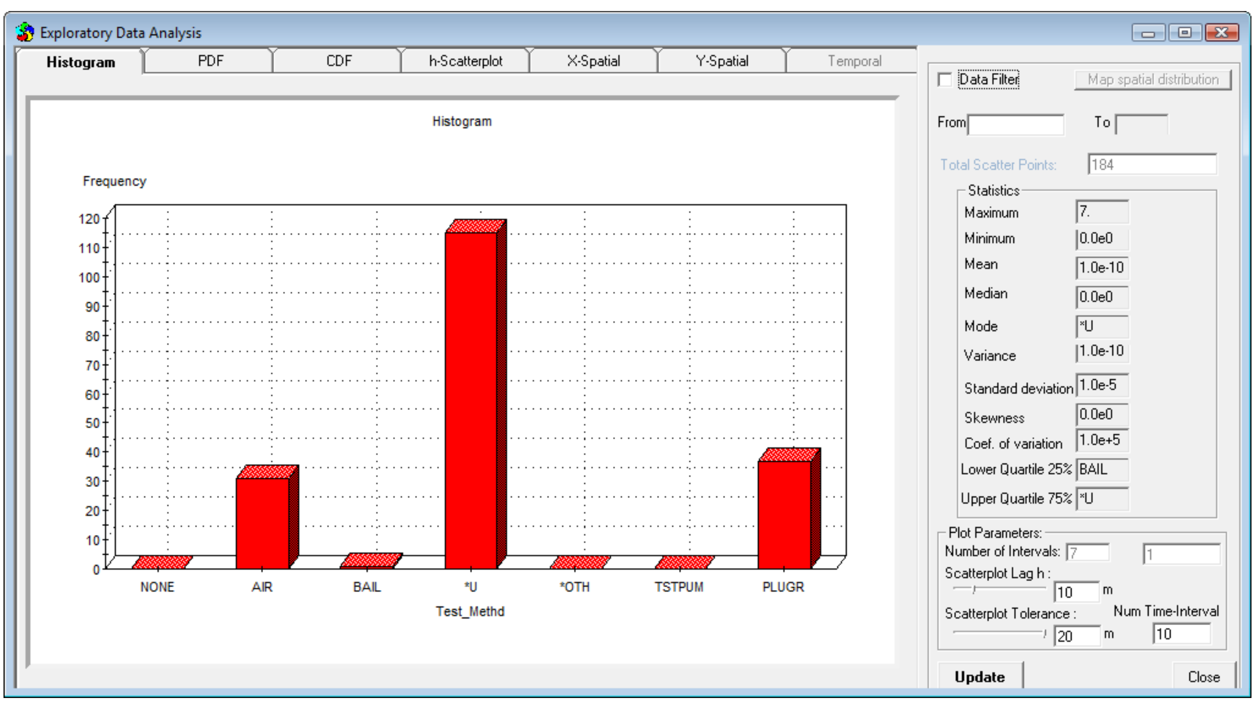


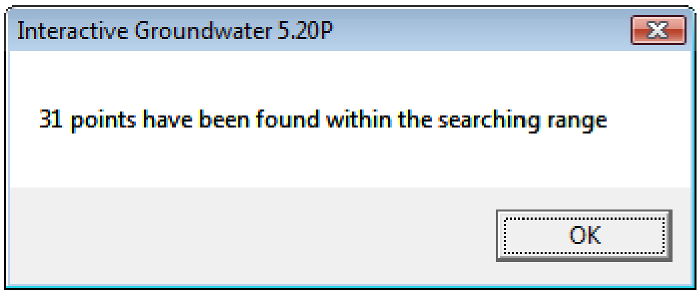
Figure 3.12 Non-numeric data histogram

For example, form Figure 3.12, you can see there are 30+ wells under method 'AIR'. You can locate these wells in the GI 'Display Pane' as follows:

Step 6: Check the box before 'Data Filter'. Notice that only 'From' field is active.

Step 7: Type 'AIR' in 'From' filed.

Step 8: Click 'Map spatial distribution' button. Following message pops up.



Step 9: Click OK.

Step 10: Well locations with test method as 'AIR' will show as light green circles in the selected area in GI as shown in Figure 3.13

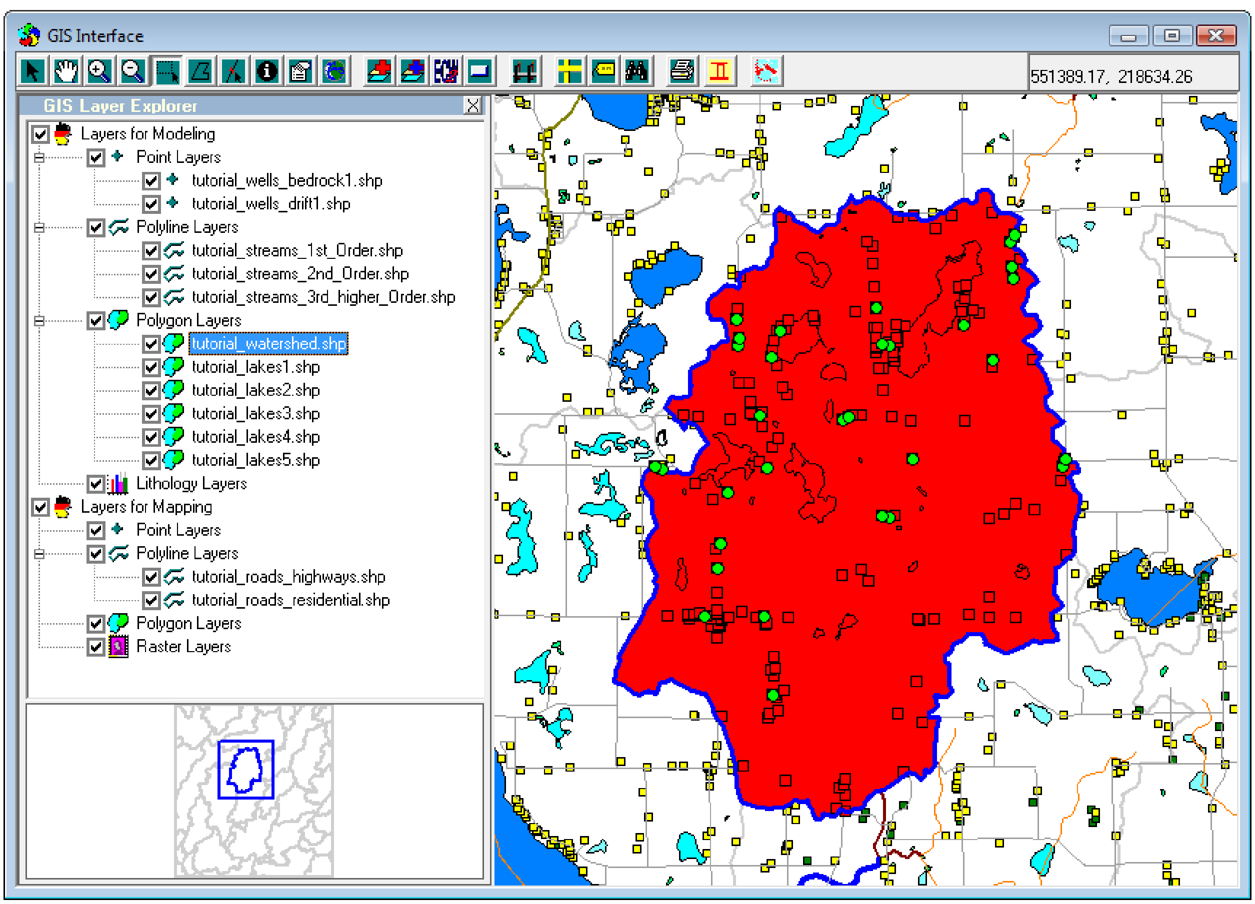


Figure 3.13 Wells with 'AIR' as test method

If in Step 2 above, you choose ‘Temporal’, Step 5 will result in ‘Exploratory Data Analysis’ window, as shown in Figure 3.14.

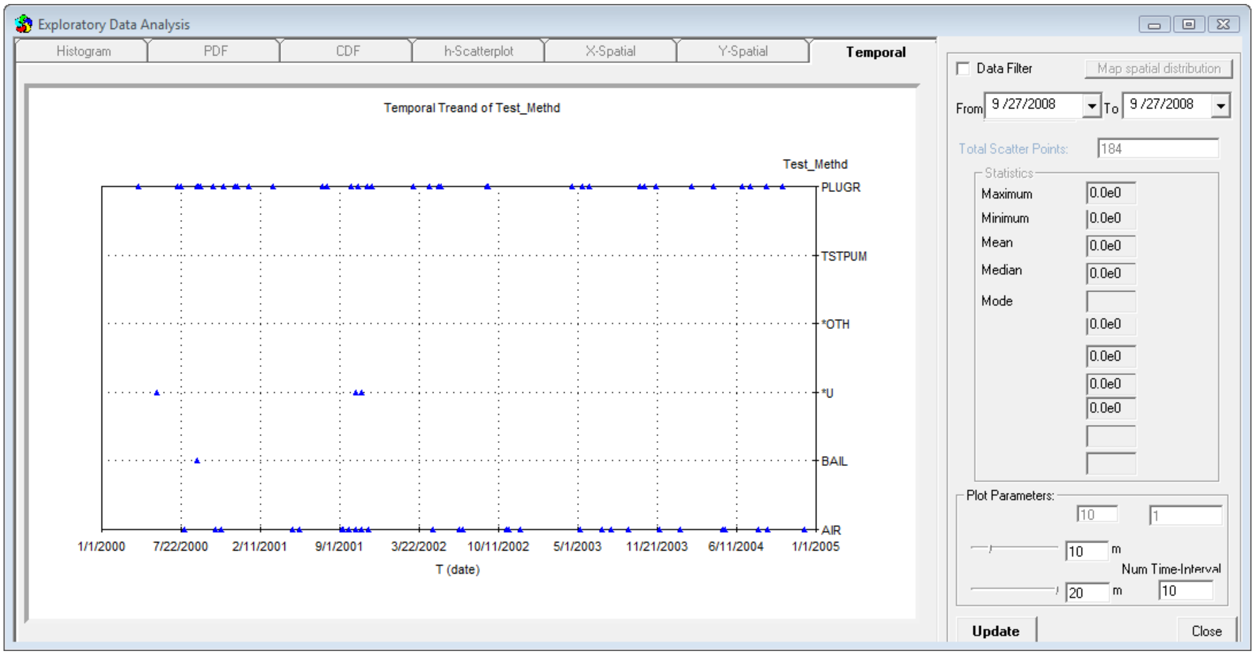


Figure 3.14 Temporal distribution of Test Methods

If in Step 2 above, you choose ‘Density Distribution’, Step 5 will result in exactly the same output as you have seen in Figure 3.10 and Figure 3.11.

R	You may experiment more with the data exploration options with non-numerical data choosing other parameters such as ‘well types’, ‘aquifer code’ etc.

This concludes the basic functionality and features of data selection, visualization and analyses options in IGW GIS-Interface. There are more advanced options which will be discussed as we build an actual groundwater model in the next chapter.

Chapter 4 BUILDING GROUNDWATER MODEL WITH GIS DATA

This chapter will walk you through the basic steps of building a relatively simple groundwater model with GIS data for the narrative problem described in Section 1.4. The aim of this chapter is to learn the use of GIS data in IGW groundwater models by employing a simple illustrative example.

i	For the sake of simplicity, intricate modeling issues such as validity of modeling assumptions and boundary conditions will not be scrutinized as part of the tutorial exercises.

4.1. Develop a Conceptual Groundwater Models Using GIS Data

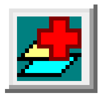
In this section you will develop a conceptual groundwater model around narrative problem area shown in Figure 1.2. The conceptual model will be built based on the hydrogeological information available in the GIS files for this area.

You may begin conceptualizing the model as follows (these steps assume that you have already downloaded the folder containing GIS files for this tutorial, have unzipped the files and have stored them on your hard disk) :

Step 1: Open IGW *Version 5.2.1P*.

Step 2: Open GIS-Interface

Step 3: Click 'Add new modeling layer' button, browse to the GIS files folder and select the following files:



tutorial_wells_bedrock.shp
tutorial_wells_drift.shp
tutorial_lakes1.shp
tutorial_lakes2.shp
tutorial_lakes3.shp
tutorial_lakes4.shp
tutorial_lakes5.shp
tutorial_proposed_well.shp
tutorial_streams_1st_Order.shp
tutorial_streams_2nd_Order.shp
tutorial_streams_3rd_higher_Order.shp
tutorial_watershed.shp

Step 4: In 'GIS Layer Explorer' right click on any file name. A menu pops up. Click 'Refresh All' in the menu. This will make all polygons transparent. You will notice that watershed polygons showing with thick light gray lines as shown in Figure 4.1.

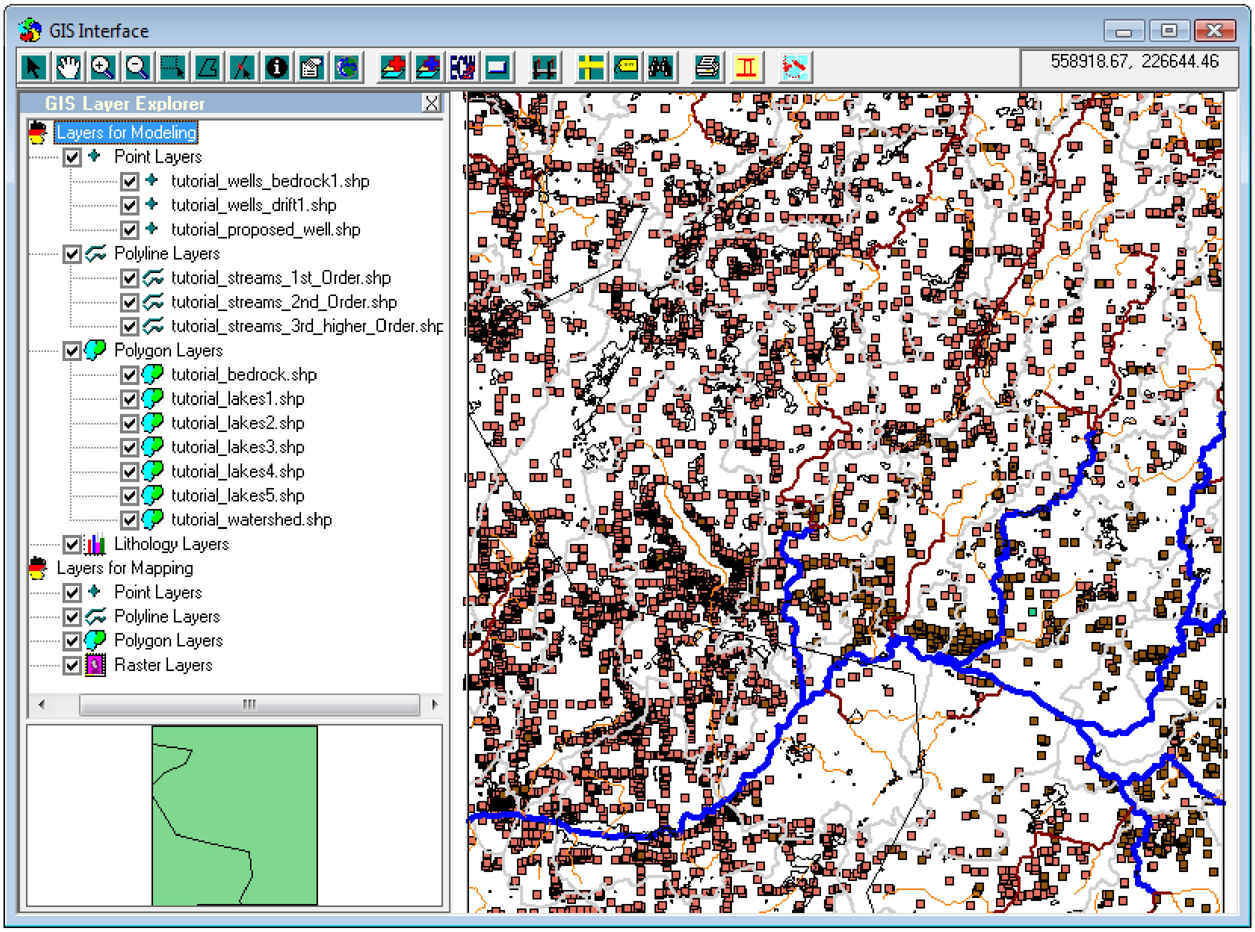
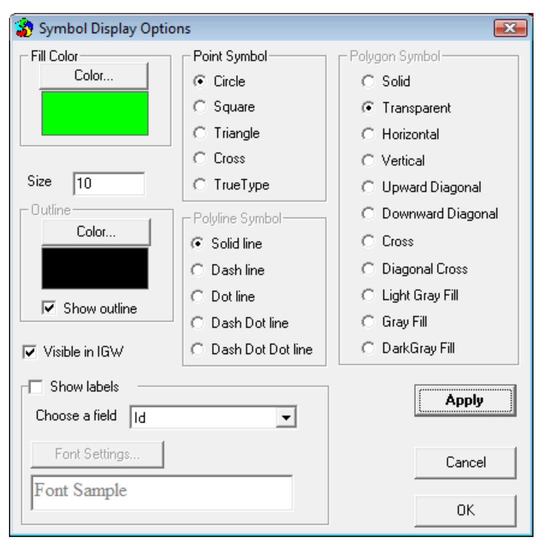


Figure 4.1 GIS data

Notice that a proposed location of the pumping well is also provided as a geo-referenced file. For better visualization of well location, you may like to make it look more prominent by changing its symbol

Step 5: In ‘GIS Layer Explorer’ right click on ‘tutorial_proposed_well.shp’. In the popup menu, click change symbol. In ‘Symbol Display Options’ window, select a prominent color, size and shape for the proposed well and then click ‘OK’.

Now you can see the proposed well location more prominently in relation to other GIS data as shown in Figure 4.2.



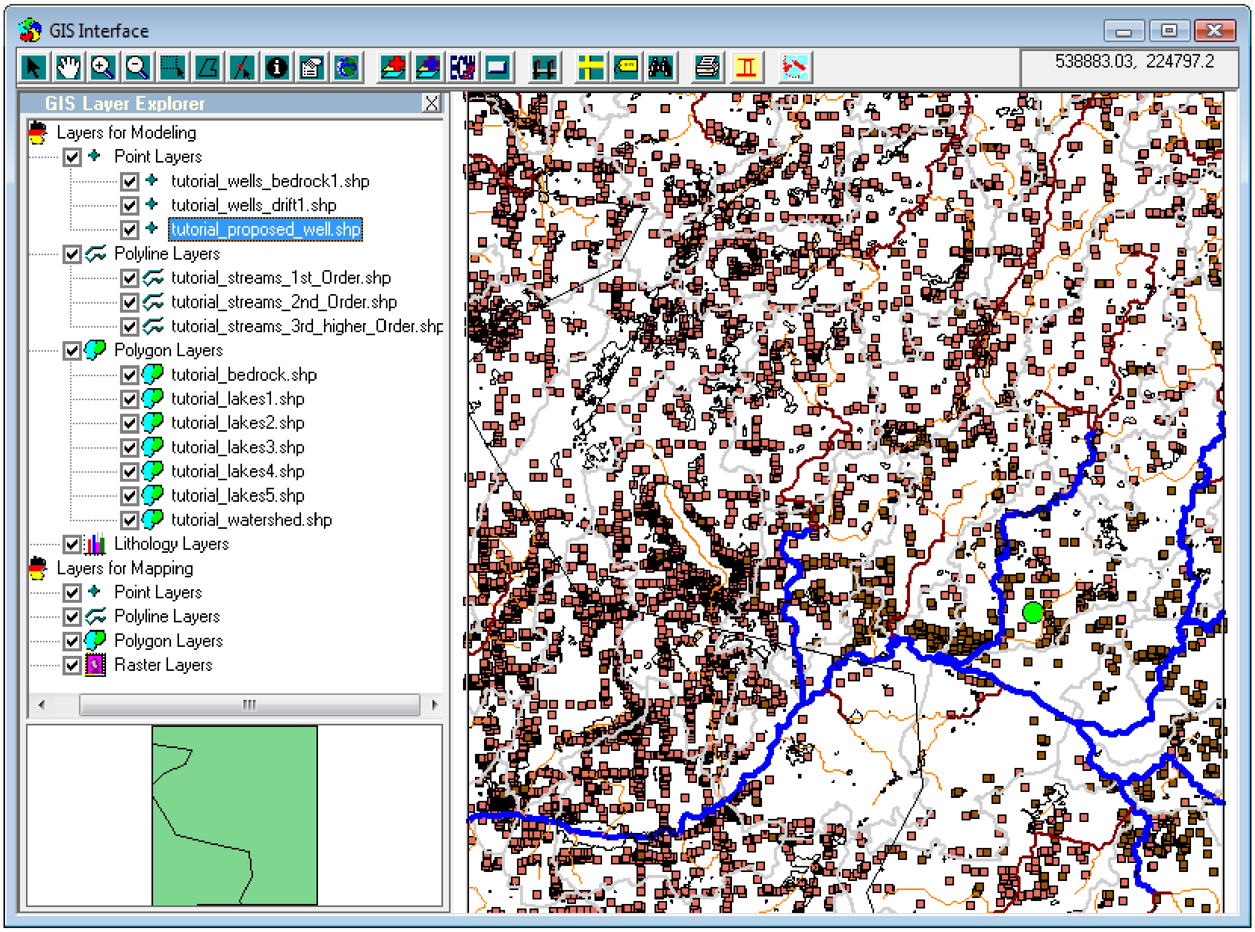


Figure 4.2 GIS Data with proposed well prominently marked

4.1.1. Model Boundaries

Looking at the well location within the available GIS data gives a fair idea on deciding the preliminary model boundaries. Watershed boundaries make a good starting guess (although groundwater-shed may not necessarily conform to surface watersheds). From Figure 4.2, you can pick out the watershed in which the proposed well is located

Step 6: Zoom-in around the watershed in which the proposed well is located as shown in Figure 4.3.

It appears from Figure 4.3 that the watershed around the well may be a good boundary to being the groundwater model. The boundary fully contains Wabascon Tributary. It also contains southern half of Wabascon Creek. With an assumption that groundwater-shed and surface watersheds are closer to each other, it may be taken as the preliminary boundary for groundwater model with a no-flow assumption across the boundary.

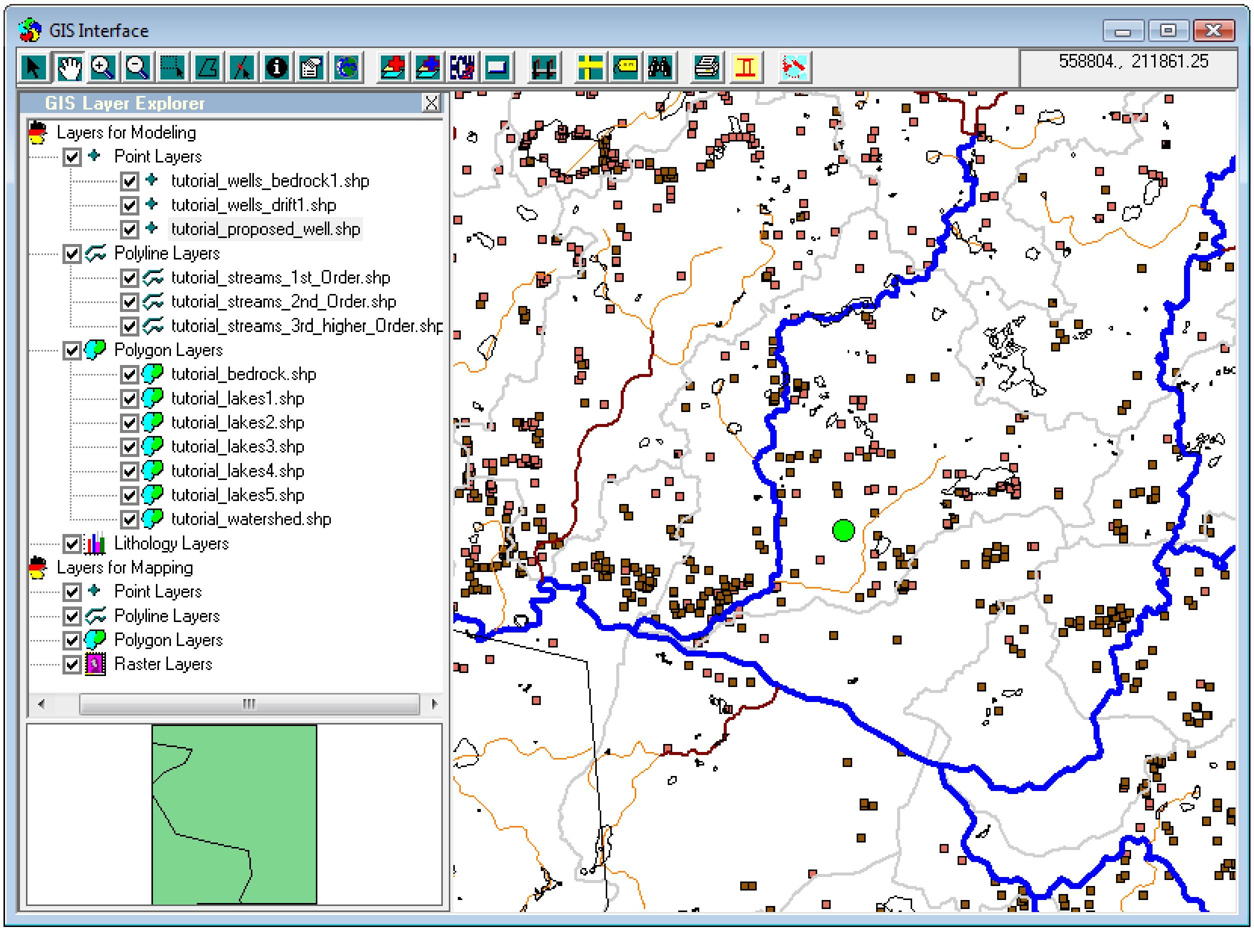


Figure 4.3 Zoomed-in watershed

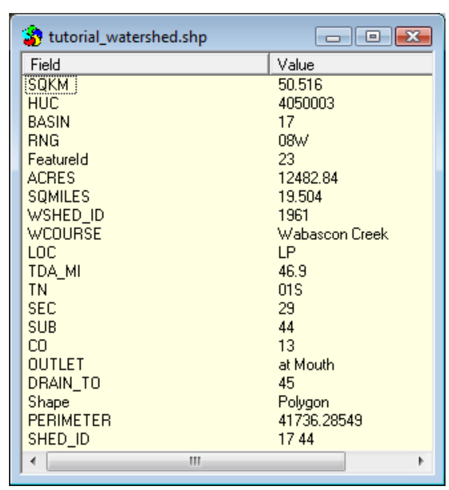
More information about this watershed can be obtained as follows:

Step 7: In 'GIS Layer Explorer', select 'tutorial_watershed.shp' by clicking once on the file name.

Step 8: Click the 'Identify' button and then click the cursor inside the watershed. Information about the watershed is displayed in a popup window.

The watershed is approximately 50 km^2 (19.5 mile^2). The watershed also has an identification code – WSHED_ID equal to 1961.

Henceforth, this watershed will be referred in the tutorial as 'Wshed-1961'

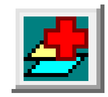


Field	Value
SQKM	50.516
HUC	4050003
BASIN	17
RNG	08W
FeatureId	23
ACRES	12482.84
SQMILES	19.504
WSHED_ID	1961
WCOURSE	Wabascon Creek
LOC	LP
TDA_MI	46.9
TN	01S
SEC	29
SUB	44
CO	13
OUTLET	at Mouth
DRAIN_TO	45
Shape	Polygon
PERIMETER	41736.28549
SHED_ID	17 44

4.1.2. Conceptual Layers

GIS data can also help decide whether the model a single or multiple layers model will be required for this area. From Figure 4.3, you may notice that there are both drift wells and bedrock wells present in Wshed-1961. This suggests that both drift and bedrock aquifers are present in the area.

Using the GIS data, you can find out the extent and types of different glacial landforms within Wshed-1961.



Step 9: Import the following GIS layers for glacial landforms in GI :

tutorial_landforms_icecontact_outwash.shp
tutorial_landforms_proglacial_outwash.shp
tutorial_landforms_lodge_till.shp
tutorial_landforms_marginal_till.shp

The all landform layers appear in the 'Display Pane' as shown in Figure 4.4. You may notice that two types of landforms cover the entire watershed – proglacial outwash in southwest and ice-contact outwash in northeast. Outwash materials, mostly permeable, generally make unconfined aquifer systems within glacial landforms. Model top-layer, therefore may be considered as unconfined glacial outwash.

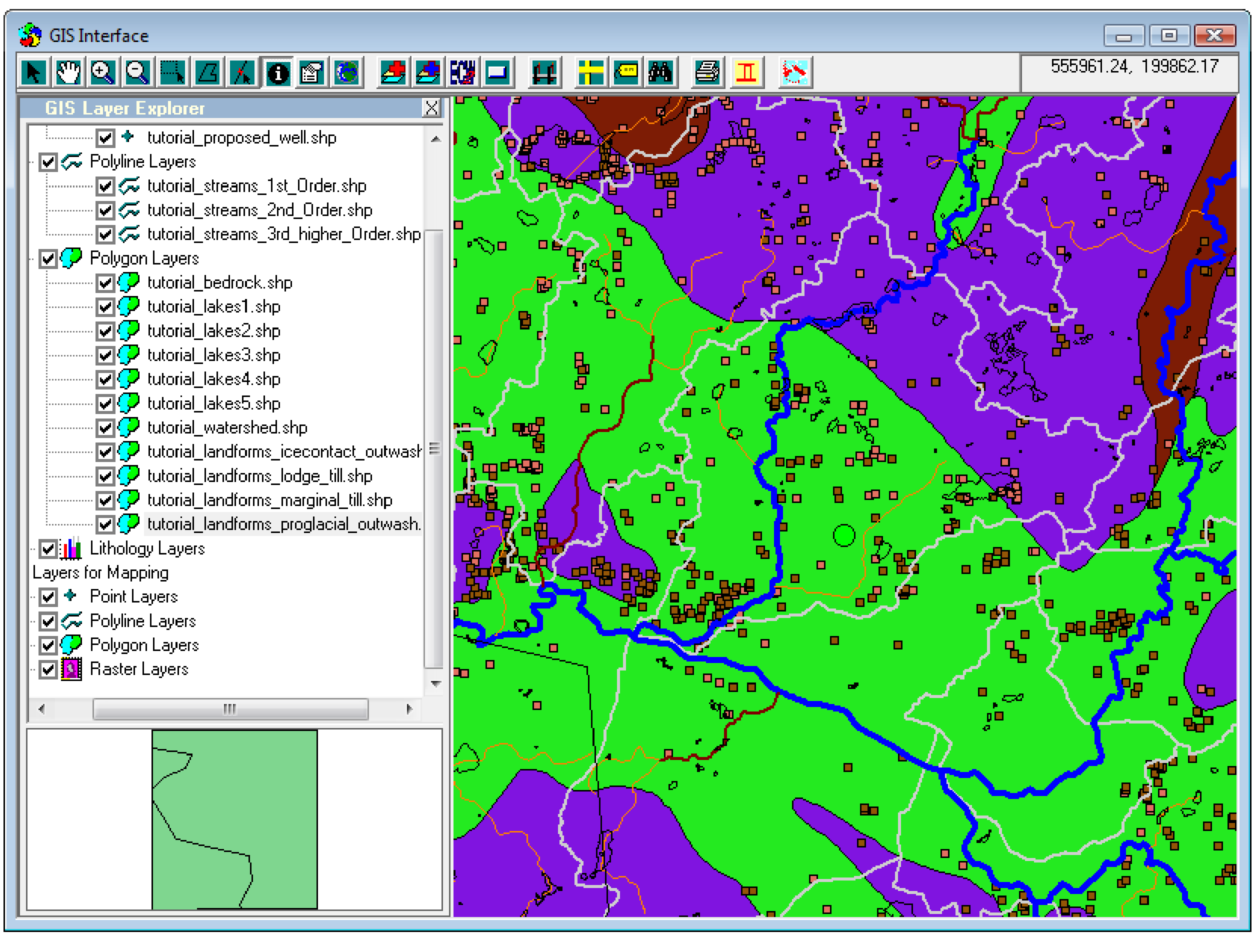


Figure 4.4 Glacial landforms

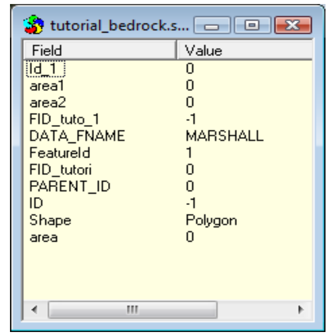
Using the GIS data, you can also find out the extent of transmissive bedrock within the selected model boundary.

Step 10: In 'GIS Layer Explorer', uncheck all glacial landform layers.

Step 11: In 'GIS Layer Explorer', select 'tutorial_bedrock.shp' by clicking once on the file name.

Step 12: Click the 'Identify'  button and then click the cursor  inside the watershed. The extent of bedrock formation under the watershed will flash as you click. The information about the bedrock also pops ups simultaneously.

You will notice that only one formation exists under the watershed and that is Marshall Formation.



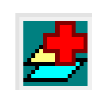
Marshall Formation, therefore, may be considered as models second transmissive layer.

4.1.3. Sources and Sinks

Recharge is one of the major sources for groundwater. You may upload the GIS layer for recharge to see how it is distributed in Wshed-1961.

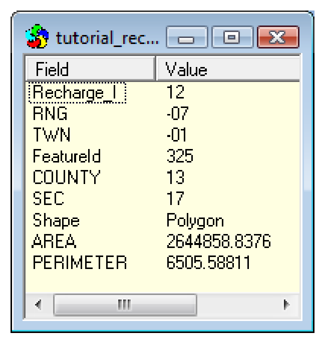
Step 13: Import the following GIS layers for recharge :

tutorial_recharge.shp



Step 14: In 'GIS Layer Explorer', select 'tutorial_recharge.shp' by clicking once on the file name.

Step 15: Click the 'Identify'  button and then click the cursor  inside the watershed. Clicking in different recharge polygons will show information about that polygon. The first field in the information window, i.e., 'Recharge_I' is the value of recharge for the clicked polygon in inch/yr.



You will notice that recharge values for different polygons within Wshed-1961 vary between 11 and 14 inch/yr. This is a significant amount of recharge and can be considered as a source of prescribed flux in the model domain.

From the other data layers as displayed in Figure 4.3, following sources/sinks can be conceptualized:

- First order streams: may be assigned as head-dependent one-way sink;
- Third order stream: may be assigned as head-dependent two-way source/sink;
- Small lakes: may be assigned as head-dependent one-way sink; and,
- Large lakes: may be assigned as head-dependent two-way source/sink.

For the preliminary model, no boundary fluxes are conceptualized.

High capacity pumping wells may be taken as sinks.

4.1.4. Aquifer Elevations

An unconfined aquifer was conceptualized for the model top layer in Section 4.1.2. This means top elevation of the model is equal to the surface elevation.

Second model layer was conceptualized in Section 4.1.2 as transmissive bedrock. The elevation of bedrock is equal to the bottom elevation of glacial drift.

From the GIS-raster datasets we have the following data which could be used to define aquifer elevations:

- 90M_DEM_MICHIGAN_1.txt (90m DEM)
- rastert_bedrockTop.txt (500m bedrock elevation)

These two datasets can be used to define aquifer top and bottom elevations of first geological layer in the model, as well as top of the second geological layer.

The there is no GIS layer available for bedrock depth. A constant thickness of 50m for the bedrock layer may be used in the preliminary model.

4.1.5. Final Conceptual Model

Final conceptual model based on available GIS data is shown in Figure 4.5.

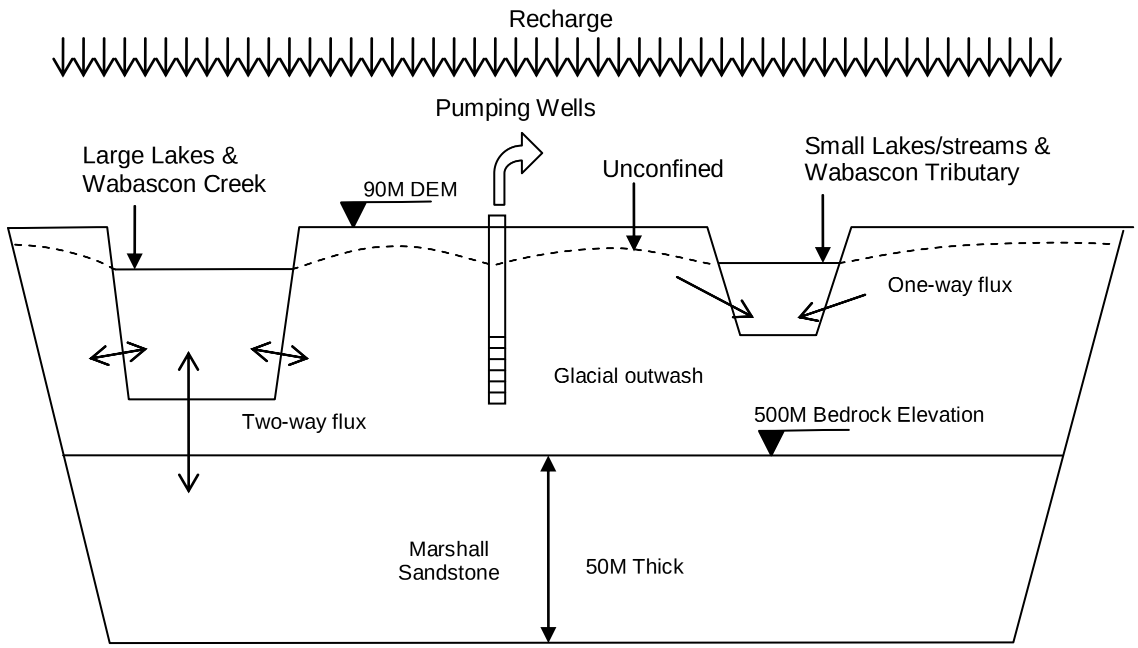


Figure 4.5 Conceptual Model

From the final conceptual model, you can decide the data needs. Following GIS data sets can be used to build the numerical model in IGW:

Table 4.1 GIS Data Layers to be used based on conceptual model

GIS Source Data	Type	Modeling need
tutorial_cities.shp	Vector	Mapping
tutorial_lakes1.shp	Vector	Sink
tutorial_lakes2.shp	Vector	Sink
tutorial_lakes3.shp	Vector	Sink
tutorial_lakes4.shp	Vector	Source, sink
tutorial_lakes5.shp	Vector	Source, sink
tutorial_roads_highways.shp	Vector	Mapping
tutorial_roads_residential.shp	Vector	Mapping
tutorial_streams_1st_Order.shp	Vector	Sink, baseflow calibration
tutorial_streams_2nd_Order.shp	Vector	Sink, baseflow calibration
tutorial_streams_3rd_higher_Order.shp	Vector	Source, Sink, baseflow calibration
tutorial_villages.shp	Vector	Mapping
tutorial_watershed.shp	Vector	Model boundaries delineation
tutorial_wells_bedrock1.shp	Vector	Groundwater head calibration
tutorial_wells_drift1.shp	Vector	Groundwater head calibration
tutorial_proposed_well.shp	Vector	Mapping
BEDFORD_SE.ecw	Air Photo	Mapping
BATTLECREEL_NW.ecw	Air Photo	Mapping
90M_DEM_MICHIGAN_1.txt	Raster	Drift layer top elevation
rastert_bedrockTop.txt	Raster	Bedrock layer top elevation
raster_recharge.txt	Raster	Source
500m_conductivity_h1_1.txt	Raster	Aquifer parameter – drift layer
540M_CONDUCTIVITY_H2_1.txt	Raster	Aquifer parameter – drift layer
BedRock_Tran	Raster	Aquifer parameter – bedrock layer

Note that ‘tutorial_recharge.shp’ layer has not been selected for the modeling needs, instead ‘raster_recharge.txt’ has been added in the list. However, either of the two forms of recharge data (vector or raster) can be used in IGW model. Conversely, river raster layers shown in Table 2.2 are not selected, instead vector layers for the streams are added.

i	Raster data files work faster in IGW modeling environment, especially when model has larger number of grid cells.

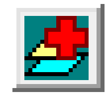
4.2. Importing Data from GIS-Interface to IGW Modeling Environment

Now that you have made a conceptual model and identified the data sources, you may start a fresh IGW session to build the groundwater model using the required GIS data.

Step 1: Open IGW *Version 5.2.1P*.

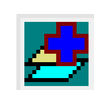
Step 2: Open GIS-Interface

Step 3: Click 'Add new modeling layer' button, browse to the GIS files folder and select the following files:



tutorial_wells_bedrock1.shp
tutorial_wells_drift1.shp
tutorial_lakes1.shp
tutorial_lakes2.shp
tutorial_lakes3.shp
tutorial_lakes4.shp
tutorial_lakes5.shp
tutorial_streams_1st_Order.shp
tutorial_streams_2nd_Order.shp
tutorial_streams_3rd_higher_Order.shp
tutorial_watershed.shp

Step 4: Click 'Add new mapping layer' button, browse to the GIS files folder and select the following files:



tutorial_proposed_well.shp
tutorial_cities.shp
tutorial_roads_highways.shp
tutorial_roads_residential.shp
tutorial_villages.shp

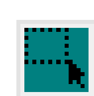
The above steps load all the vectors layers that will be used for modeling and mapping purposes in IGW modeling environment. Now you are ready to import data from GIS-Interface to IGW. The modeling layers that you do not want to import to IGW can be unchecked in the 'GIS Data Explorer' pane.

Step 5: Uncheck the following modeling layers in 'GIS Data Explorer' pane:

tutorial_wells_bedrock1.shp
tutorial_wells_drift1.shp

Step 6: Select 'tutorial_watershed.shp, by clicking once on the file name in 'GIS Data Explorer' pane

Step 7: Click 'Draw a selection box' button and then click once inside 'Wshed-1961' polygon. Then click 'Yes' in the popup message box.



All modeling layers, except the ones unchecked in Step 5, are selected inside the watershed polygon as shown in Figure 4.6.

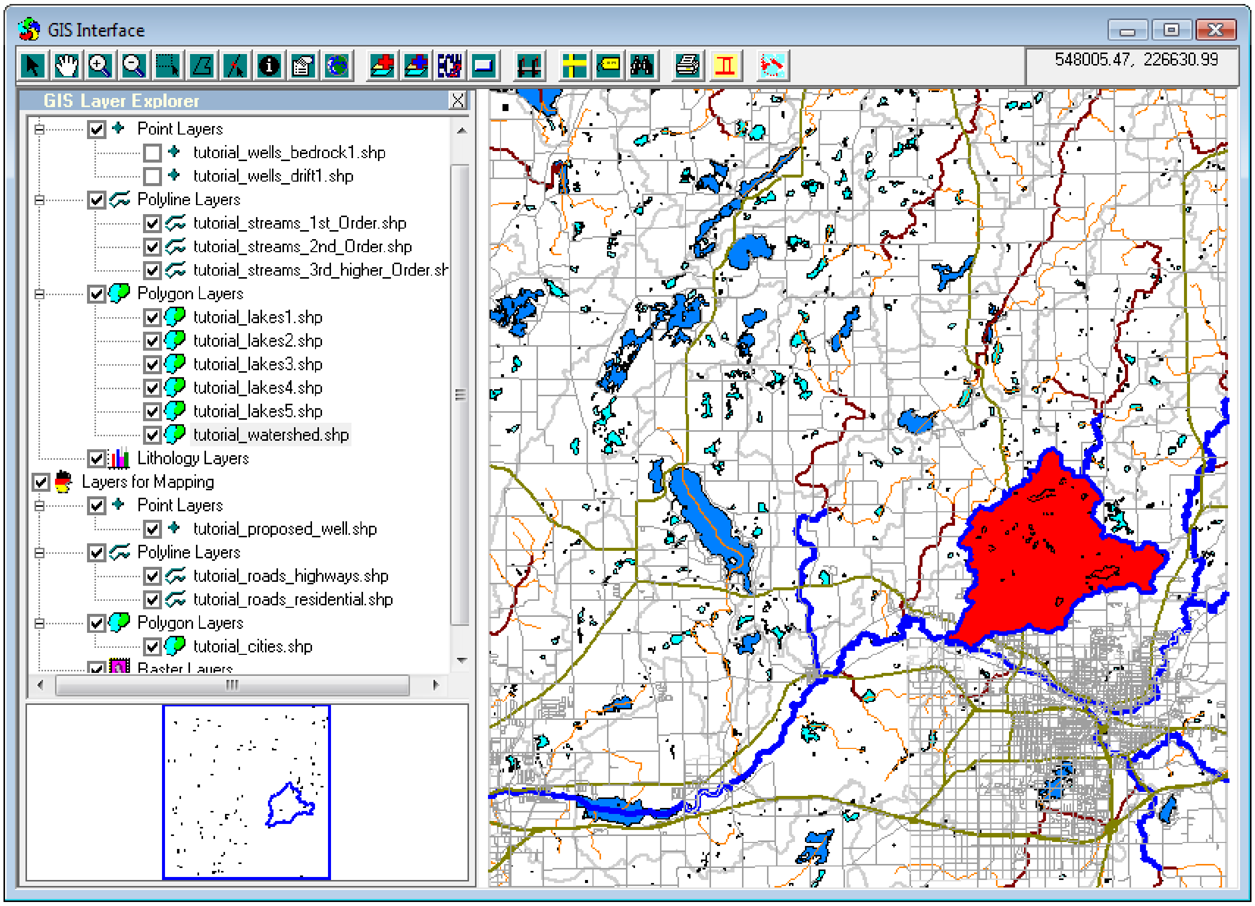
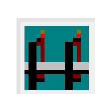


Figure 4.6 Data selected for extraction to IGW

Now you are ready to export these layers to IGW modeling environment.

Step 8: Click ‘Extract/import model feature from GIS to IGW’ button. This opens ‘Extraction Criteria’ window as shown in Figure 4.7.



You may notice in Figure 4.7 that there are three prominent zones in ‘Extraction Criteria’ window, each dealing with a separate type of GIS shape file (i.e., point, polyline and polygon). Our selection in Step 7, however, includes only polyline and polygon files for streams and lakes respectively.

Step 9: In ‘Extraction Criteria’ window, leave the ‘Point Layers’ section as such because there are not point layers in the selection zone. For the polyline and polygon options, make selections for streams and lakes as shown in Figure 4.7.

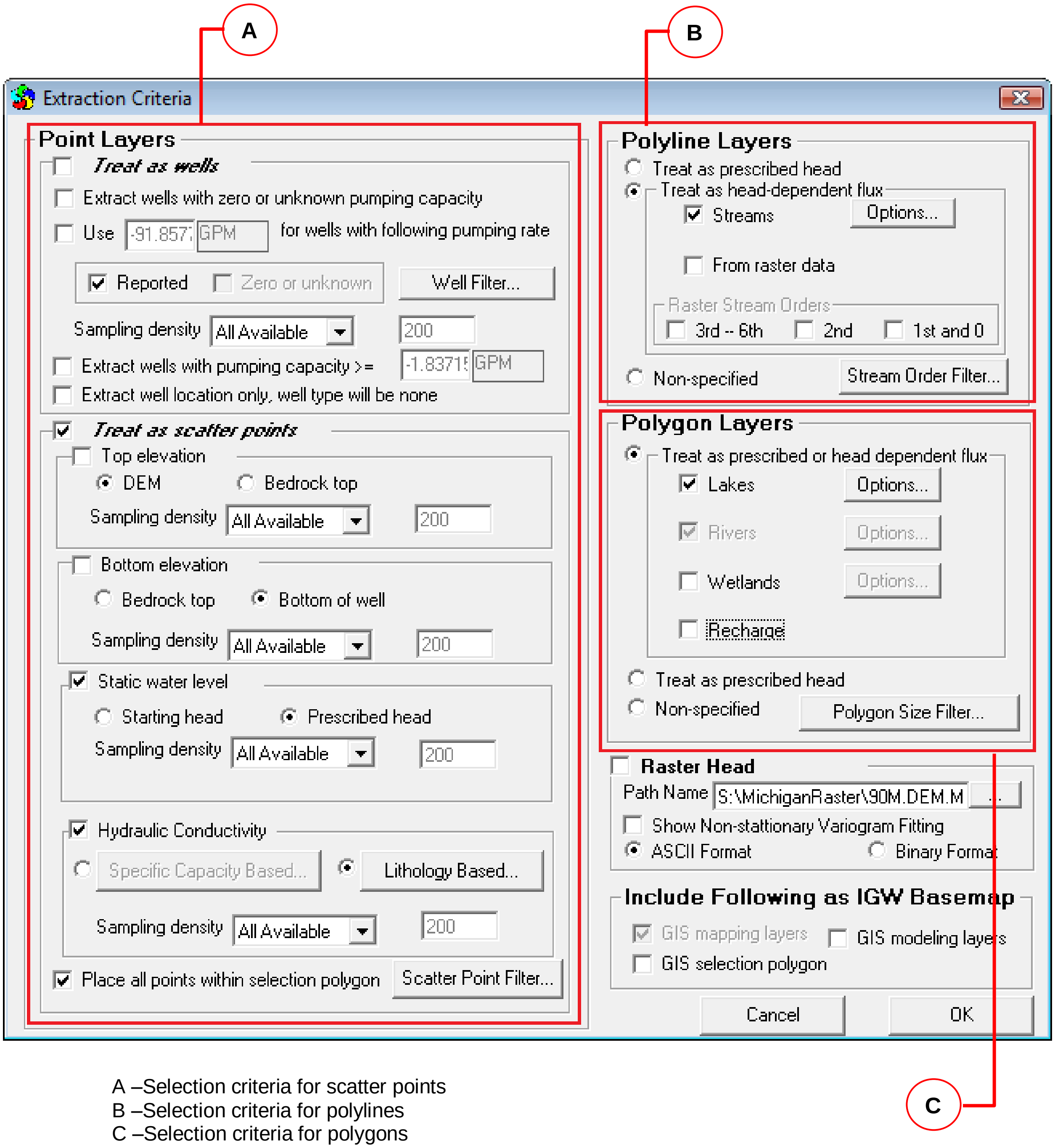


Figure 4.7 GIS data 'Extraction Criteria' window

In the conceptual model, we assumed that smaller lakes and streams will be treated as one-way head-dependent flux. Using the 'Options…' buttons for streams and lakes you can define criteria to segregate larger and smaller streams/lakes.

Step 10: Click 'Options…' button inside the 'Polyline Layers' area opposite to 'Streams'. 'Stream: Assign Leakance and Elevation' window pops up as shown in Figure 4.8.

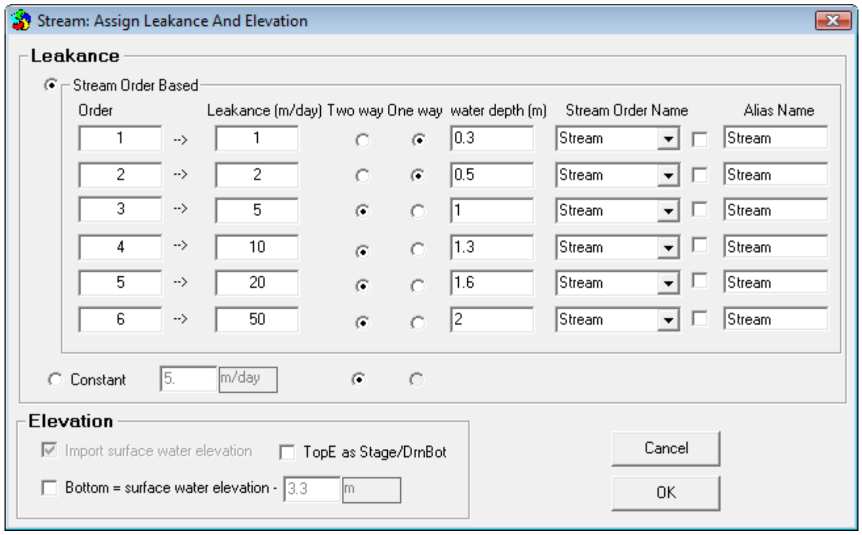


Figure 4.8 Stream leakance and elevation options

Step 11: In 'Stream: Assign Leakance and Elevation' window, select 'One way' for first and second order streams and click OK.

Step 12: Click 'Options…' button inside the 'Polygon Layers' area opposite to 'Lakes'. 'Lakes: Assign Leakance, Elevation And Size Category' window pops up as shown in Figure 4.9.

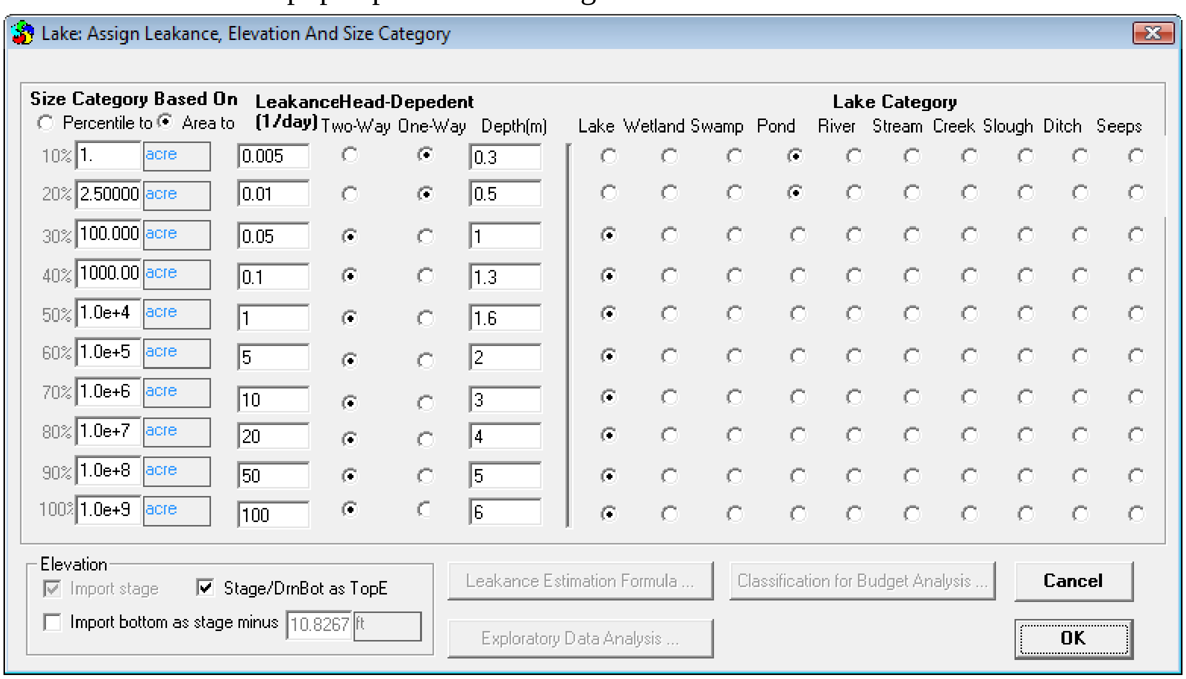


Figure 4.9 Lake area, leakance and category options

Step 13: In ‘Lakes: Assign Leakance, Elevation And Size Category’ window, do the following:

Under ‘Size Category Based on’, select ‘Area to’

In the first column, second box, type 2.50 (keep the unit as acre)

Under ‘LeakanceHead-Dependent’, select ‘One way’ for top two entries

Under ‘Lake Category’, select ‘Pond’ for top two entries

Click OK when done.

Step 14: Click ‘OK’ at the bottom right of ‘Extraction Criteria’ window. IGW modeling window will become active and you will see all selected modeling data and mapping layers in IGW Main Window as shown in Figure 4.10.

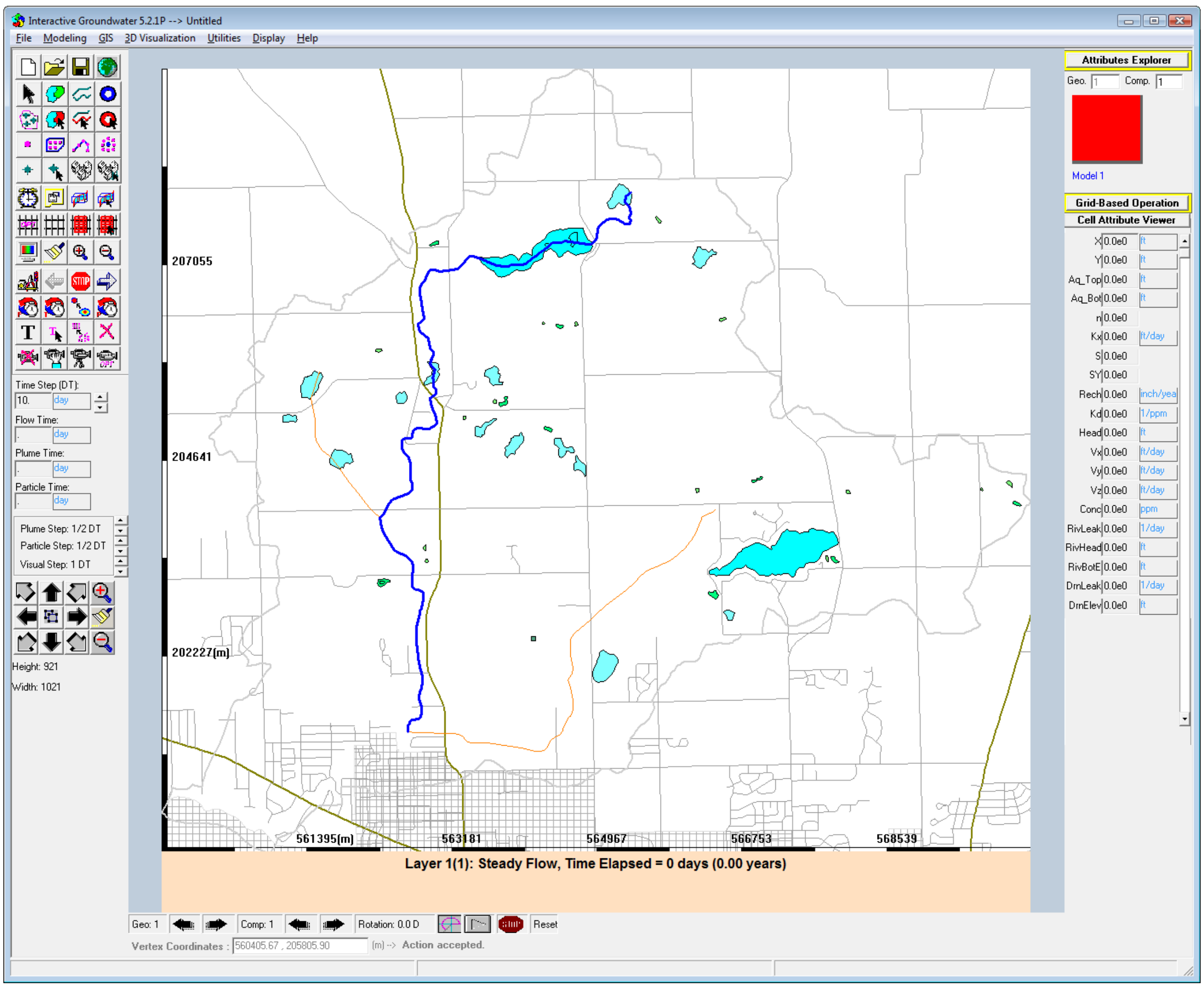


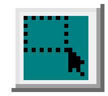
Figure 4.10 GIS data imported in IGW

You may notice that stream arcs at either ends of Wabascon Creek are not imported into the model. It is because these arcs extend beyond the watershed boundary used for selecting data. To import the two stream arcs, go back to GI and repeat the following:

Step 15: In the Menu Bar of IGW Main Window click on 'GIS'

Step 16: Click on 'GIS Interface' from the dropdown menu. This will take you back to GI window.

Step 17: Select 'tutorial_watershed.shp, by clicking once on the file name in 'GIS Data Explorer' pane, and click 'Draw a selection box' button

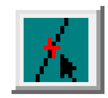


Step 18: Click anywhere in the 'Display Pane' and this will undo the previous selection

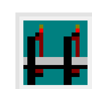
Step 19: Uncheck 'tutoiral_watershed.shp' layer in the 'GIS Layer Explorer' pane (this will avoid reselection of watershed data)

Step 20: Select 'tutorial_streams_3rd_higher_order.shp, by clicking once on the file name in 'GIS Data Explorer' pane

Step 21: Now click on 'Draw a selection polyline' button. In 'Display Pane', click once closer to one side of the stream arc, say the arc at the southern end of the watershed, and then double click on the other side of the arc. Click OK at the popup message. The stream arc intersected by the polyline will be selected.

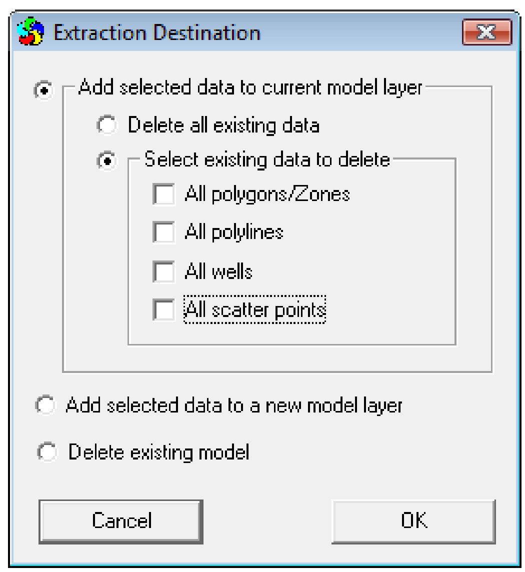


Step 22: Click 'Extract/import model feature from GIS to IGW' button. This opens 'Extraction Criteria' window and you will see previously selected options in the window. Keep these options and just click OK.



Step 23: This open 'Extraction Destination' Window. Select the options as shown to the right and click OK.

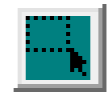
This will bring you back in IGW modeling window and you will see that the stream arc you selected has been added to the model.



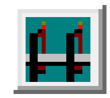
Step 24: Repeat steps 11 and 12, then 16 through 19 to import the stream arc at the nothern end of the watershed.

Now you will import data for the second conceptual layer in the model. We don't have any rivers or lakes in the second conceptual layer. All we need to do is import the model boundary, i.e., Wshed-1961:

Step 25: Go to 'GIS Interface' and uncheck all modeling layers except ‘tutoiral_watershed.shp’

Step 26: Select ‘tutorial_watershed.shp’, by clicking once on the file name in ‘GIS Data Explorer’ pane, and click ‘Draw a selection box’ button 

Step 27: Click in the Wshed-1961 polygon to select data

Step 28: Click ‘Extract/import model feature from GIS to IGW’ button. Keep all settings in ‘Extraction Criteria’ and just click OK. 

Step 29: In the ‘Extraction Destination’ Window, select ‘Add selected data to a new model layer’ option and click OK.

This will bring you back in IGW modeling window with another layer added in the model.

At this point, it is a good idea to save the model.

Step 30: From the Menu Bar select File → Save As → Conceptual Model and save the model on your hard disk as ‘GIS_tutorial_02.igw’

(or give it a name you like but this tutorial will use the recommended name for referring back to this model)

This completes the initial data import from GI to IGW. Figure 4.11 shows IGW Main Window after both ends of stream arc are imported in the modeling environment.

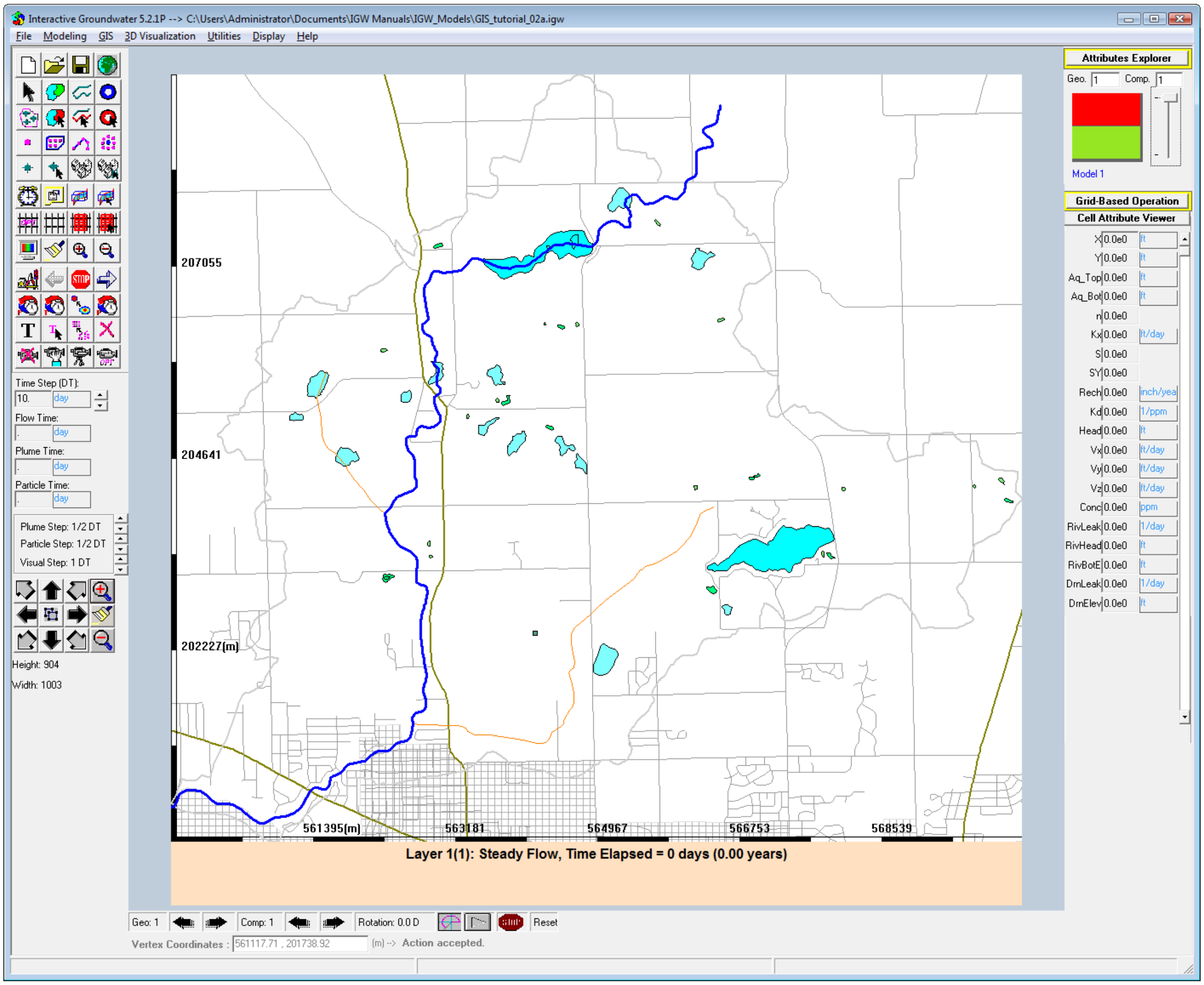


Figure 4.11 GIS data in IGW modeling environment

4.3. Using GIS Raster Data in IGW Modeling Environment

As explained earlier in Section 2.5, raster data for following model parameters can be used in IGW

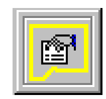
- Aquifer elevations;
- Hydraulic conductivity;
- Prescribed recharge flux; and,
- Streams network.

In this tutorial you will use raster data for the first three categories.IGW can directly read and incorporate raster data in its modeling environment from a specified folder on a directory path or hard disk. The folder named “DemRivRaster” in the GIS data provided for this tutorial contains raster data sets required for the models. The internal structure of the folder should not be changed as IGW is programmed to read from the specified structure of this folder. The following steps assume that you have already saved the folder named “DemRivRaster” at a specified location on your hard disk.

4.3.1. Specifying Raster Data Files and Directory Paths

Step 0: Make sure that Layer 1 is the active model layer before Step 1

Step 1: In the IGW Main Window, click ‘Save/Edit Default Parameters for Active Model’ button. This opens ‘Default Attribute - Layer 1’ window as shown in Figure 4.12.



Step 2: In ‘Select data resolution’ area make the following selections:

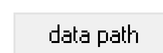
DEM – 90m

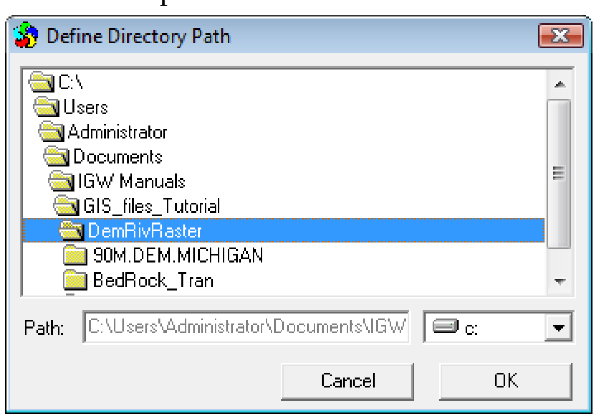
Bedrock elevation – 500m

Drift K – 500m

Bedrock K – 540m

Step 3: Click the ‘data path’ button, browse to ‘DemRivRaster’ folder by and specify this location by double clicking on the folder name. Then press OK





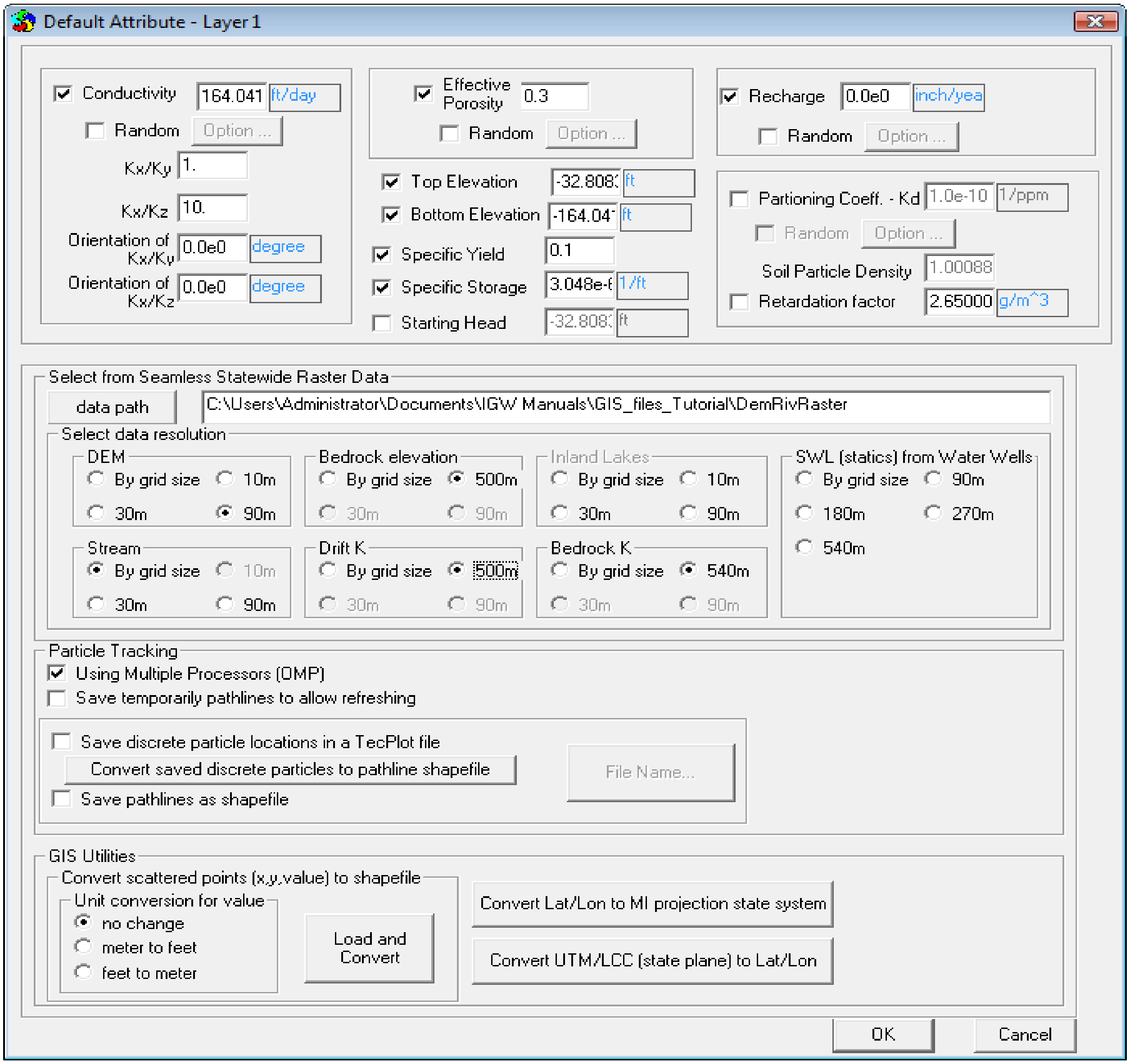


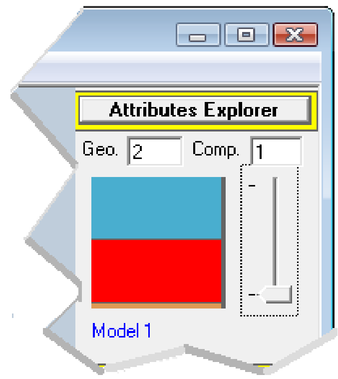
Figure 4.12 'Default Attributes – Layer 1' window.

i Since only limited data is provided with the tutorial exercises, above are the only options available to you.

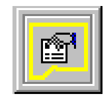
i Recharge raster is based on 1600m resolution (1 mile square). Better resolutions for recharge raster are not available in Michigan.

Step 4: Click OK at the bottom of 'Default Attributes – Layer 1' window.

Step 5: Switch to Layer 2 in IGW Main Window. You may do so by moving the sliding button in the top right corner of Main Window.



Step 6: In the IGW Main Window, click 'Save/Edit Default Parameters for Active Model' button to open 'Default Attribute – Layer 2' window



Step 7: In the 'Default Attribute – Layer 2' make sure that the 'data path' is same as for Layer 1.

Step 8: Only 'Bedrock K' is applicable for Layer 2 in 'Select data resolution' area. Select 540m for bedrock K.

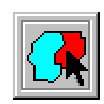
The above steps have specified the raster data files as well as their directory paths for the current model. It is advised to 'Save' the model before proceeding further.

4.3.2. Assigning Raster Data to Modeling Features

To estimate hydraulic conductivity, aquifer elevations, and recharge flux in top modeling layer follows these steps:

Step 1: Switch to Layer 1 in IGW Main Window. You may do so by moving the sliding button in the top right corner of Main Window.

Step 2: From the IGW 'Button Palette' click 'Select/Edit Zone' button



Step 3: Click inside Wshed-1961 polygon in the model area to select the polygon

Step 4: Open 'Attributes Explorer' window [Users' Manual Chapter 4].

Step 5: Under 'Physical Properties' tab, check 'Conductivity' then select 'Using Raster Data', 'Statewide Raster', and 'Drift_H2'.

Step 6: Under 'Aquifer Elevations' tab, check 'Top Elevation' then select 'Using Raster Data' and 'Statewide DEM'.

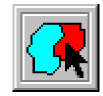
Also select 'Bottom Elevation/Thickness' on the same tab, then select 'Using Raster Data' and 'State-wide Raster'.

Step 7: Under 'Sources and Sinks' tab, select sub tab 'Prescribed Flux'.

Select 'Recharge', 'Raster Data', and 'Statewide Raster'

To estimate hydraulic conductivity, in second modeling layer follows these steps:

Step 8: Switch to Layer 2 in IGW Main Window. You may do so by moving the sliding button in the top right corner of Main Window.

Step 9: From the IGW 'Button Palette' click 'Select/Edit Zone' button 

Step 10: Click inside Wshed-1961 polygon in the model area to select the polygon

Step 11: Open 'Attributes Explorer' window 

Step 12: Under 'Physical Properties' tab, check 'Conductivity' then select 'Using Raster Data', 'Statewide Raster', and 'Bedrock'.

IGW will automatically assign the bottom elevation of top layer as the top elevation of bottom layer. However, you must specify the thickness of the bottom layer as conceptualized in the conceptual model.

Step 13: Under 'Aquifer Elevations' tab, check 'Bottom Elevation/Thickness' then select 'Constant' and 'Thickness'

Step 14: In the 'Thickness' field, keep clicking on the unit until you get 'm'.

Step 15: Type 50 in the value box.

The above steps complete the assignment of raster data to the modeling layers. You are advised to save the model before proceeding to next section.

4.4. Use GIS Data as Mapping Features in the Model Domain

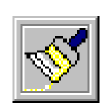
You may have already noted that the mapping layers imported earlier in GI are already showing in the background of model area. Any modeling layer which is checked in the 'GIS Data Explorer' pane in GI automatically shows in the IGW modeling environment as a background map.

In order to show a mapping layer in the background:

Step 1: Go to GIS-Interface

Load the desired mapping layer in GI using 'Add new mapping layer' button (if the layer is not already loaded in GI) 

Step 2: Make sure that the checkbox next to the layer name in 'GIS Data Explorer' pane is checked.

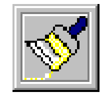
Step 3: Return to IGW modeling environment and click the refresh button if the layer is not showing already. 

In order to remove any mapping layer from the background:

Step 1: Go to GIS-Interface

Step 2: Unchecked the layer in 'GIS Data Explorer' pane

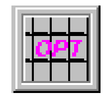
Step 3: Return to IGW modeling environment and click the refresh button

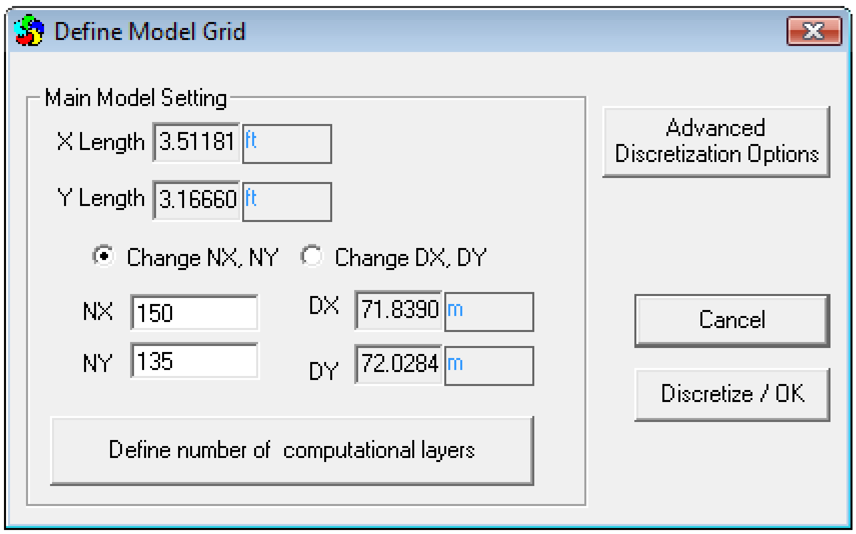


4.5. Descritize and Run the Numerical Model

To descritize the model, follow these steps:

Step 1: In the IGW Main Window, click 'Deep Descritization' button. 'Define Model Grid' window pops up [User's Manual Chapter 12].





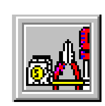
Step 2: Type 150 for NX. NY is automatically adjusted to 135.

Step 3: Click 'Descritize / OK' button.

Depending on the speed of your computer, the mode will be descritized in a few minutes. The progress of descritization process can be observed in the status bar at the bottom of IGW main window.

Before running the model, you will select appropriate solver settings:

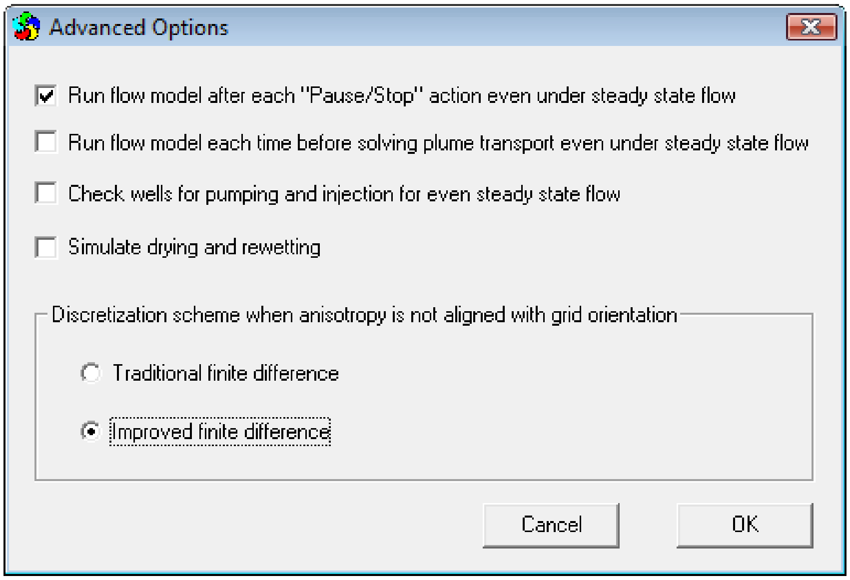
Step 4: Click the 'Numerical Solver Settings' button. This will open 'Solver Settings' window [User's Manual Chapter 13].



Step 5: Click 'Flow' tab on the 'Solver Settings' window.

Step 6: At the bottom left of the 'Flow' tab, click the 'Advanced Options' button.

Step 7: On the advanced options, choose ‘Improved finite difference’ and click OK



Step 8: Click OK again in the ‘Solver Settings’ window

You are now ready to run the model.

Step 9: Click ‘Run Model Forward’ button [User’s Manual Chapter 14]

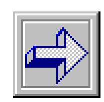
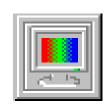


Figure 4.13 shows IGW modeling result. This model is based only on GIS data and default parameters from IGW where data was not available e.g., stream/lake leakance.

You will use GIS data to calibrate this model by adjusting model parameters in the next chapter.

Step 10: [optional] You can change the display settings for model output by clicking ‘Display Options’ button [User’s Manual Section 19.1]



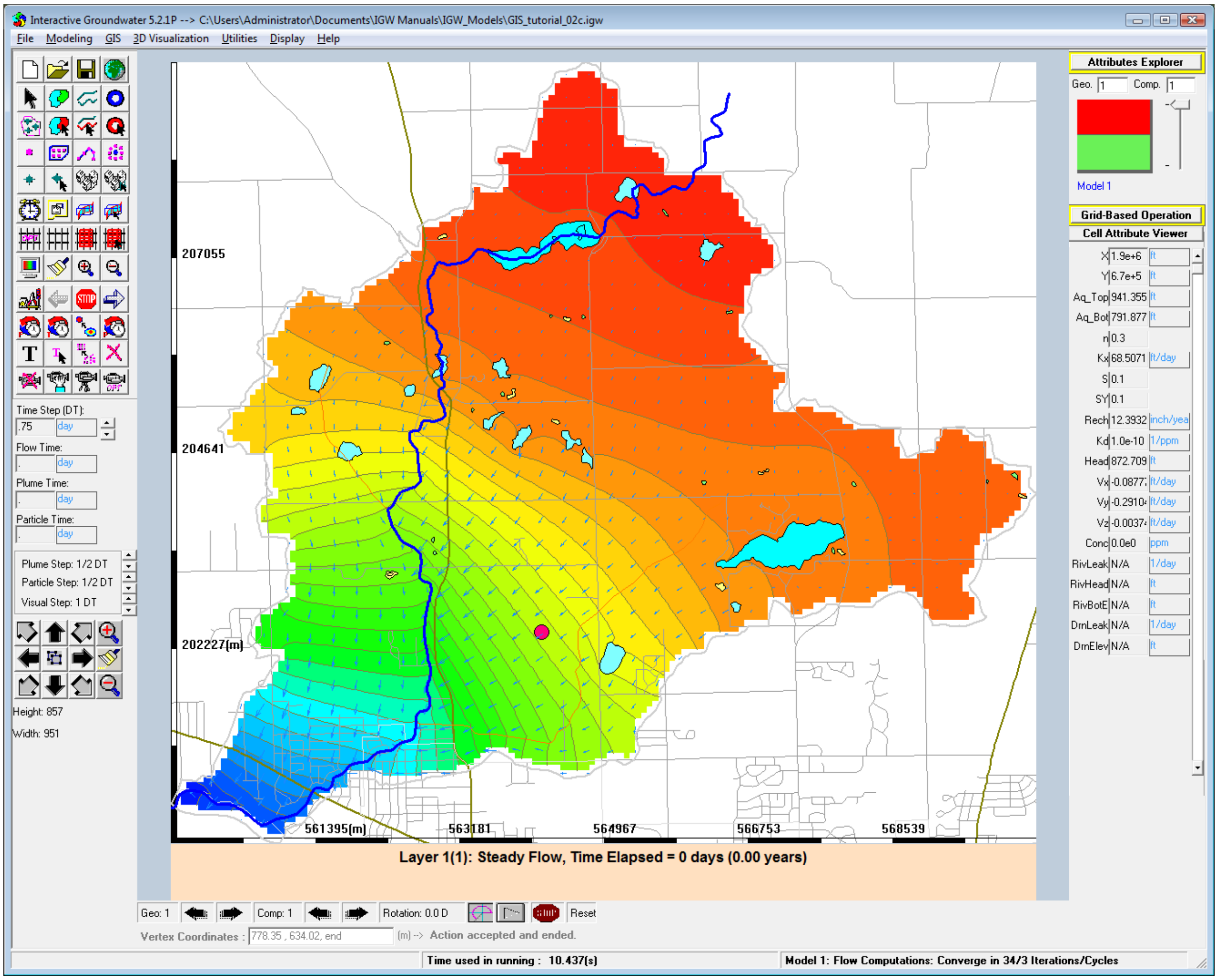


Figure 4.13 IGW Model for Wshed-1961 prior to calibration. Proposed well location is marked with a pink circle.

Chapter 5 CALIBRATING A MODEL WITH GIS DATA

In this chapter you will learn the use of GIS data for model calibration. You will use static water level data from water wells and baseflow estimates from stream data. You will also learn to adjust model parameters and boundaries.

5.1. Comparing Model Heads against Wellogic Data

Wellogic data is noisy due to temporal variations spreading over four decades, measurement noise and lack of QA/QC at the time most data were recorded. However, the data is available in good density over most parts of the state. IGW takes advantage of noisy, but abundant data to calibrate groundwater models. The calibration is achieved along data trends and averages rather than the actual data points. The following steps illustrate this concept as well as guide you through the processes of calibrating using GIS data for static water levels.

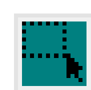
Calibrating heads in the drift layer:

Step 1: Go to GIS-Interface

Step 2: Unchecked the layer ‘tutorial_wells_bedrock1.shp’ in ‘GIS Data Explorer’ pane

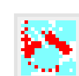
Step 3: Checked the layer ‘tutorial_wells_drift1.shp’ in ‘GIS Data Explorer’ pane

Step 4: Select ‘tutorial_watershed.shp’, by clicking once on the file name in ‘GIS Data Explorer’ pane, and click ‘Draw a selection box’ button

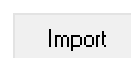


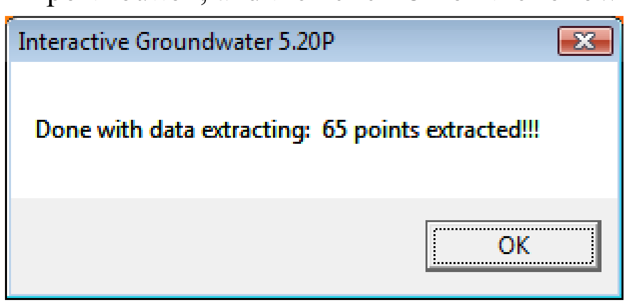
Step 5: Click in the Wshed-1961 polygon, and click ‘Yes’ to select data

Step 6: Click ‘Data Explore’ button to open ‘Scatter Data – Spatial Analysis’ window



Step 7: In ‘Scatter Data – Spatial Analysis’ window, select ‘SWL_Elev’ from the dropdown list under “Select Parameter” and then click ‘Import’ button, and then click Ok on the following message.

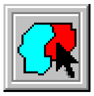




This action will load static water level elevation data from drift wells in IGW to be used for calibration.

Step 8: Switch back to IGW Main Window.

Step 9: Select Wshed-1961 polygon in IGW Main Window using 'Select/Edit Zone' button (you can also select the zone from AE window by clicking once on it name in LHP)



Step 10: From the 'Utilities' menu, select 'Data Sampling' → 'Show Model vs Obs Sampling at Wellogic SWL from GIS Importer'. This will open 'Modeling Samples vs Calibration' window as shown in Figure 5.1.

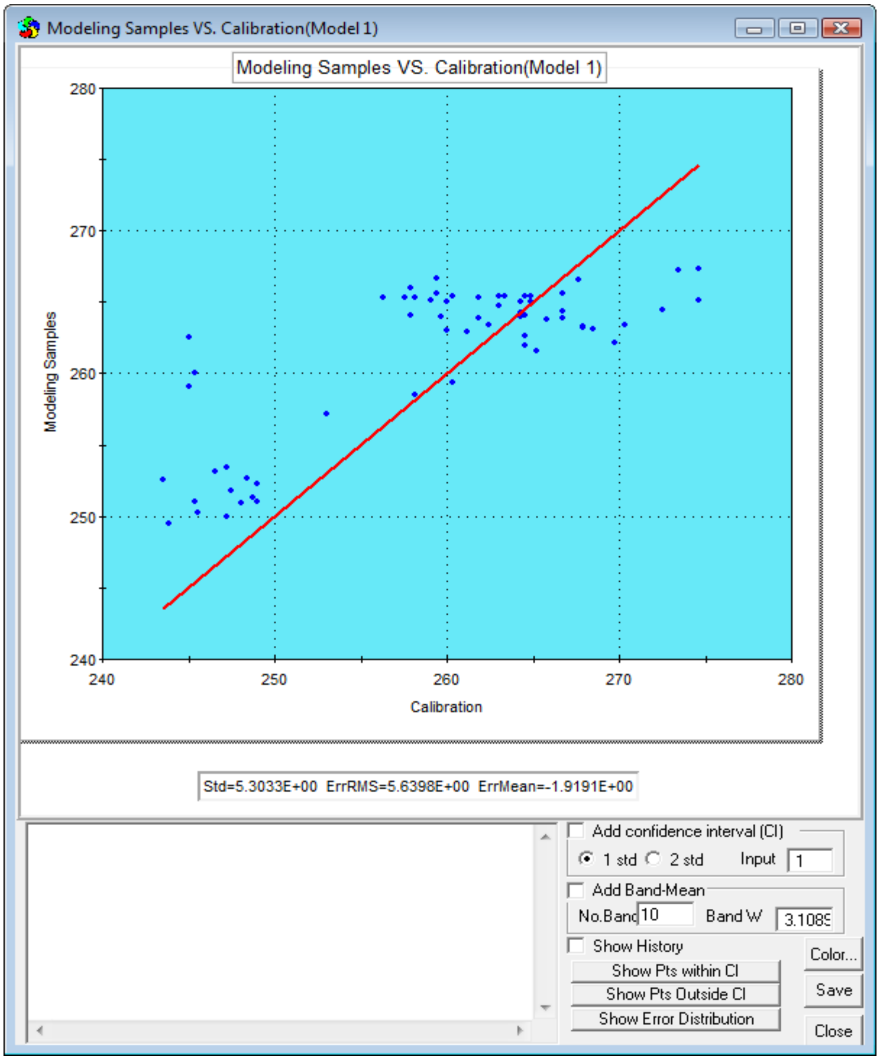


Figure 5.1 Wellogic data vs Model prediction

There are many display options in 'Modeling Samples vs Calibration' window. You can chose confidence intervals within specified standard deviation values, can add mean values of (noisy) data for a specified number of bands, and select single or multiple data points in the plot by simply clicking at the point(s) (check 'Show History' box for selecting multiple points). Selected points in the plot are highlighted within the plot and their information is displayed in the text area in the bottom left, as seen in Figure 5.2. Points shown with yellow triangles are the 'Band Mean'. They give a good feeling of how the model predictions compare with the average values in the data.

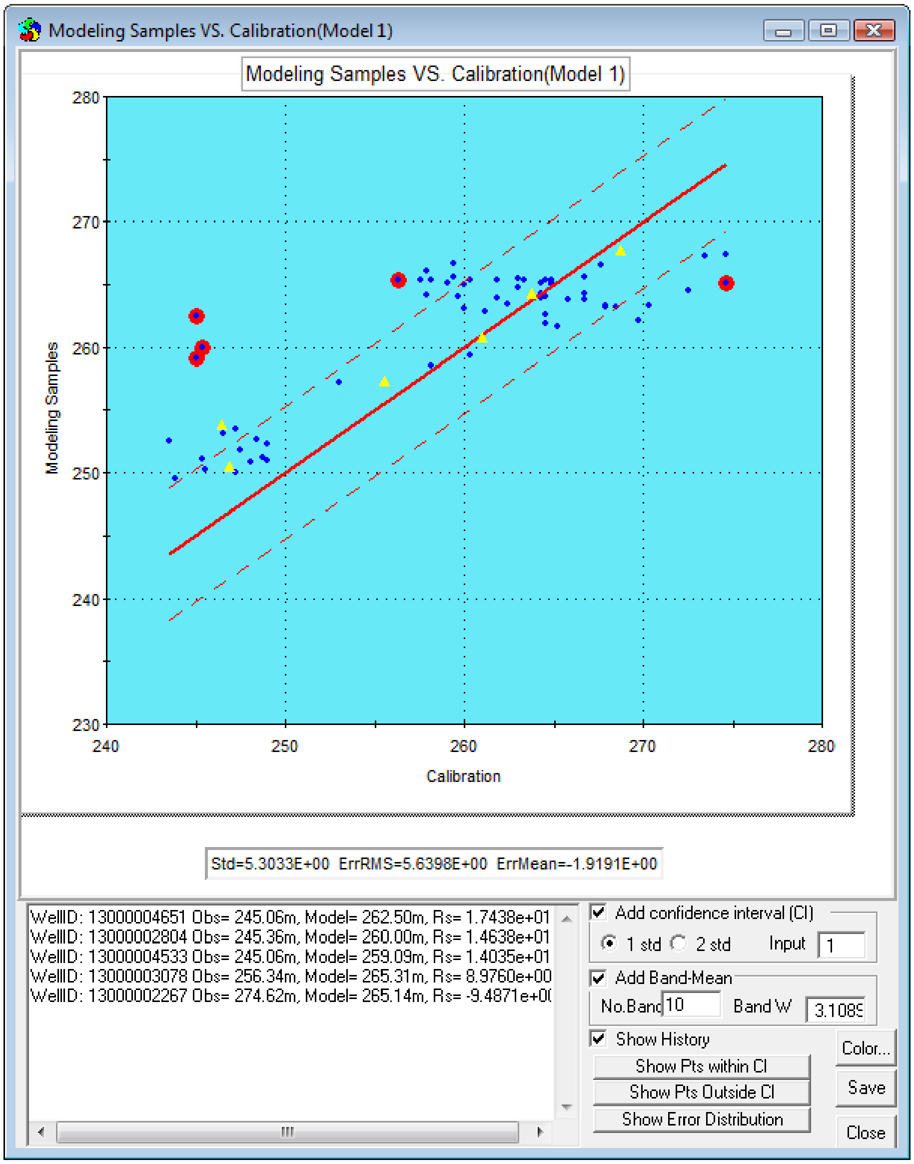
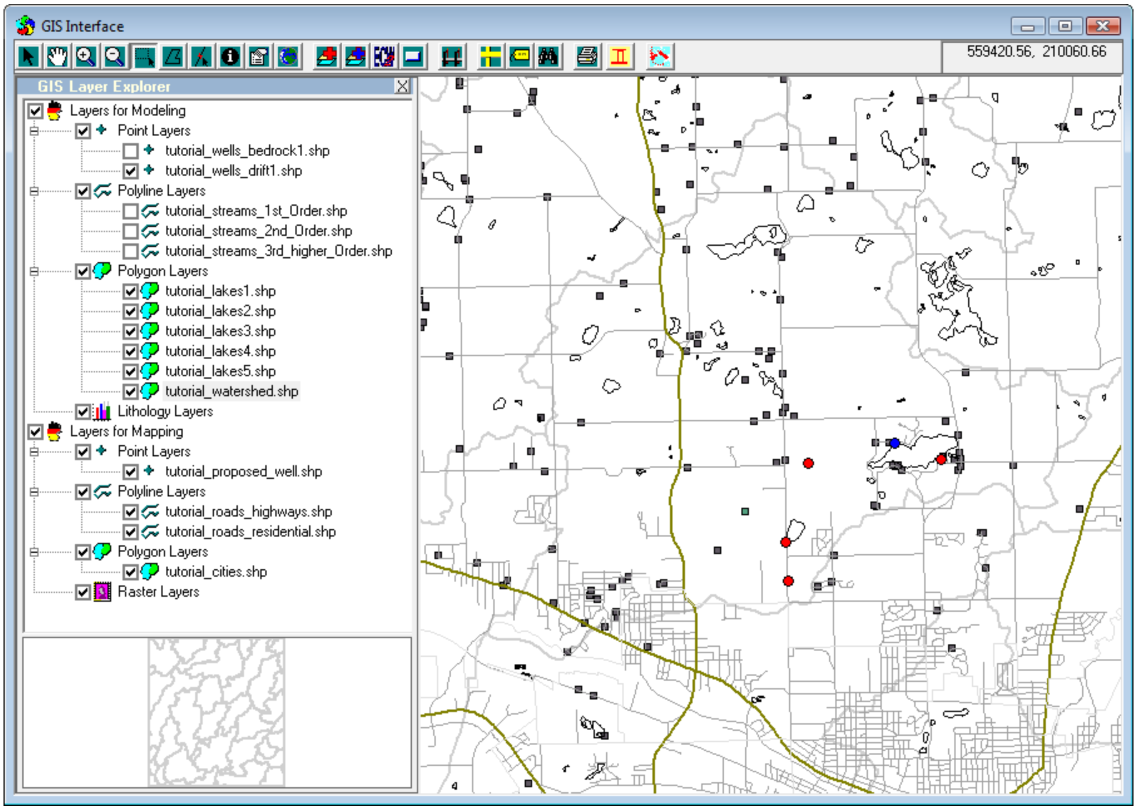


Figure 5.2 Wellogic data vs Model prediction with more display options

The selected points can also be viewed in GIS-interface. Model predictions above Wellogic data are highlighted with red circles while those below are highlighted in blue cirlcles as shown in Figure 5.3 (a). Beside the selected points on the plot, there are more options of displaying data in GI. You can select to display all data points outside or inside the selected confidence interval. Or you can choose to display error between model prediction and data values for all points in the data as shown in Figure 5.3 (b).

To see points displayed in GI, simply go to GI and you will see the points displaying already. It is possible that when you switch to the GI, it still shows the Wshed-1961 polygon area in red. To get rid of red area, simply click the 'Draw Selection box'  button and then click once anywhere outside the polygon and you will see the display.

(a)



(b)

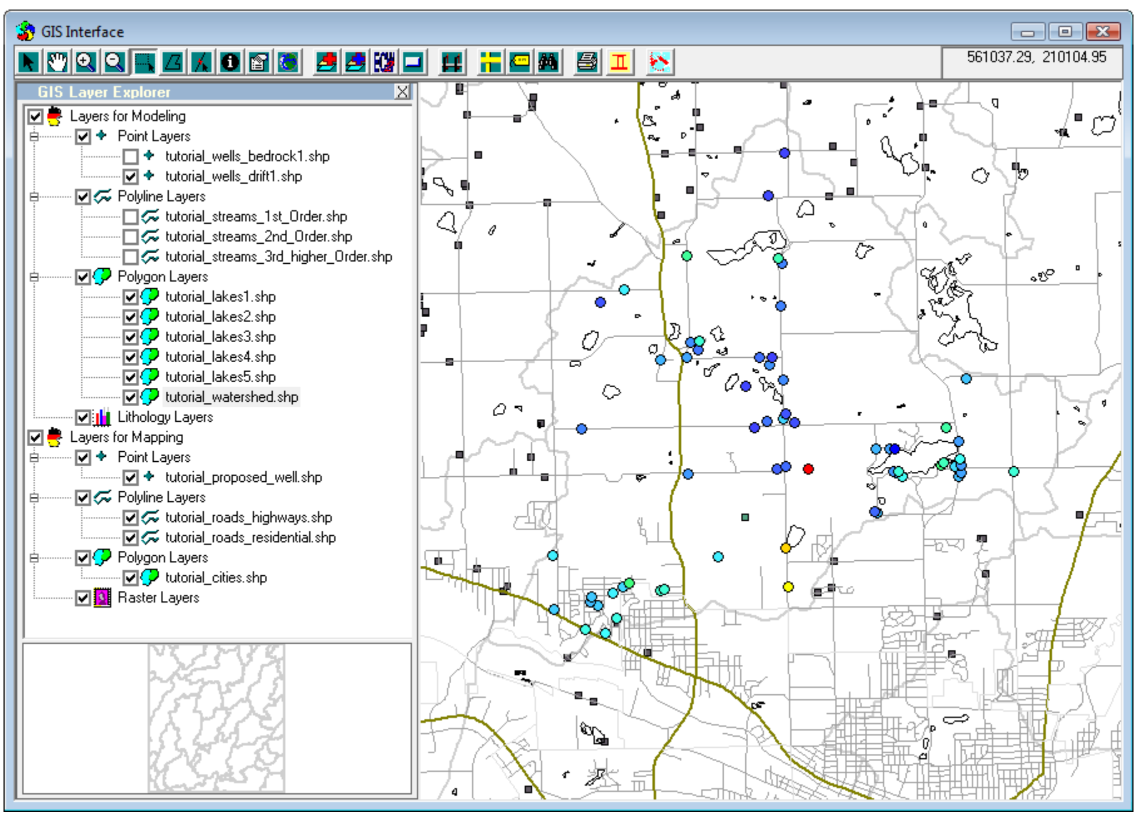


Figure 5.3 Data comparison in GIS-interface

Similar to drift aquifer, you can also compare bedrock aquifer heads predicted by the model to the ‘tutorial_wells_bedrock1.shp’ data for the second model layer.

Locations of extreme data values and error distribution as shown in Figure 5.3 are helpful in determining if the pattern of variation between data and model is random or systematic. If systematic trends are identified, the calibration can be guided accordingly.

5.2. Comparing Model Baseflow against NHD Baseflow Estimates

Cumulative baseflow estimates were made using the GIS data for Wabascon Creek and Wabason Tributary as follows:

Wabascon Creek	18.5 cfs	or	45,260 m^3/d
Wabascon Tributary	6.5 cfs	or	15,976 m^3/d

To compare baseflow of streams with the model’s prediction you can do water balance for both streams as follows:

Step 1: Open ‘Attribute Explorer’ (see Chapter 4,User’s Manual)

Step 2: By clicking on any polyline name in LHP, you can see the same being highlighted with thick red line in the model area of IGW Main Window. One by one, click every polyline which represents a stream arc of Wabascon Creek. In the ‘Head Dependent Flux’ area, make sure that each of these lines is selected as ‘Two way’ and the corresponding name is ‘River’.

Step 3: Now click on the polyline which represents Wabascon Tributary (there is only one polyline for this) and make sure that in the ‘Head Dependent Flux’ area, it is selected as ‘One way’. From the dropdown list, select a different name for it, e.g. Ditch.

Step 4: Finally, make sure that all stream arcs making a small tributary to the west of Wabascon Creek are selected as ‘One way’ and have a different name e.g. ditch.

You may notice that using the above steps, you have given three different names to three different streams in the model (i.e., river, ditch and drain). These names will separate these streams for water budget.

Step 5: Now select Wshed-1961 polygon in LHP of AE and at the bottom of RHS check the box before ‘Zone Budget’.

Step 6: Make sure that you also check box for ‘Water Budget’ in TPS (also see User’s Manual Section 4.1.3)

Step 7: Descritize and run the model. The water budget will display as shown in .

Step 8: Compare values of Wabascon Creek and Wabasco Tributary given above with River and Ditch budget in the Water balance (see User's Manual Section 14.3) as shown below.

	NHD Data	Net Model Prediction
Wabascon Creek	45,260 m^3/d	49,166 m^3/d
Wabascon Tributary	15,976 m^3/d	7,261 m^3/d

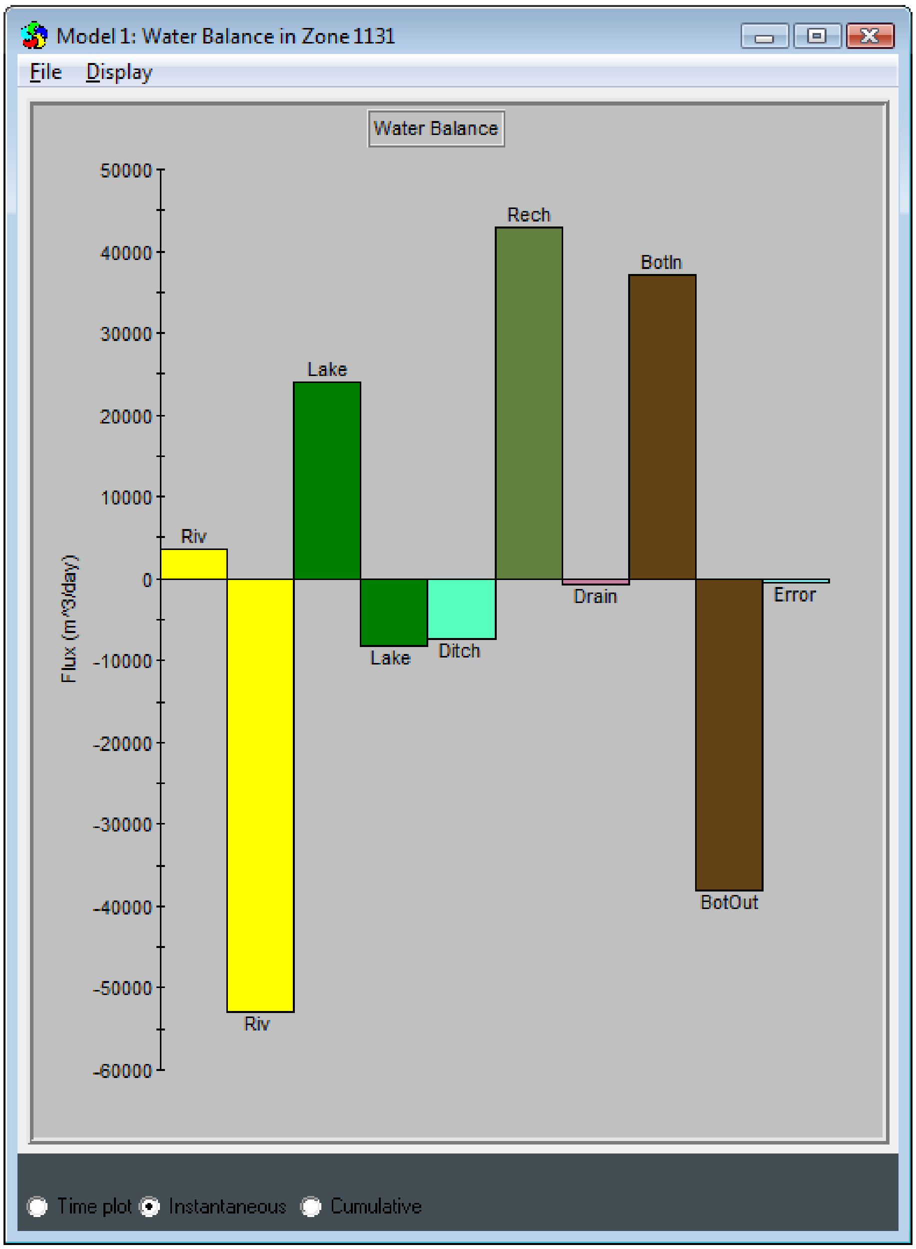


Figure 5.4 Water budget

You may notice that NHD estimates are different from model prediction. However, this prediction is before model calibration. You can adjust model parameters during calibration process as explained in the next section.

5.3. Adjusting Modeling Parameters

As a hydrogeologist and a modeler, you can draw many inferences from how data compares to the model. Based on your hydrologic intuition/experience, you can adjust the model parameter(s) to better align the trend-line with the data. The following steps show how you may change/adjust hydraulic conductivity, recharge rates, streams leakance and make adjustments in the model boundaries for sake of calibrating the model.

5.3.1. Adjusting Hydraulic Conductivity

Hydraulic conductivity K was imported in the model through raster data throughout the model domain. To increase or decrease K you can use a multiplier value as follows:

Step 1: Open 'Attribute Explorer' (see Chapter 4,User's Manual)

Step 2: In LHP select the first hierarchical level for zones (Zones 1001) under Layer1. See Figure 5.5 .

Step 3: Select 'Physical Properties' tab in the RHP

Step 4: Check box next to 'Conductivity'

Step 5: Type in a multiplier value in the box next to 'Conductivity'

Step 6: Input values of K in the model layer will be multiplied by this factor when you will descritize the model.

Step 7: You may similarly change the multiplier in for Layer 2.

5.3.2. Adjusting Recharge Rate

Recharge rate was imported in the model through raster data throughout the model domain. To increase or decrease recharge by a factor, you can:

Step 1: Open 'Attribute Explorer' (see Chapter 4,User's Manual)

Step 2: In LHP select the first hierarchical level for zones (Zones 1001) under Layer1.

Step 3: Select 'Sources and Sinks' Properties' tab in the RHP

Step 4: Check box next to 'Recharge'

Step 5: Check box next to 'Rate'

Step 6: Type in a multiplier value in the box next to 'Rate'

Step 7: Input values of recharge from raster data in the model layer will be multiplied by this factor when you will descritize the model.

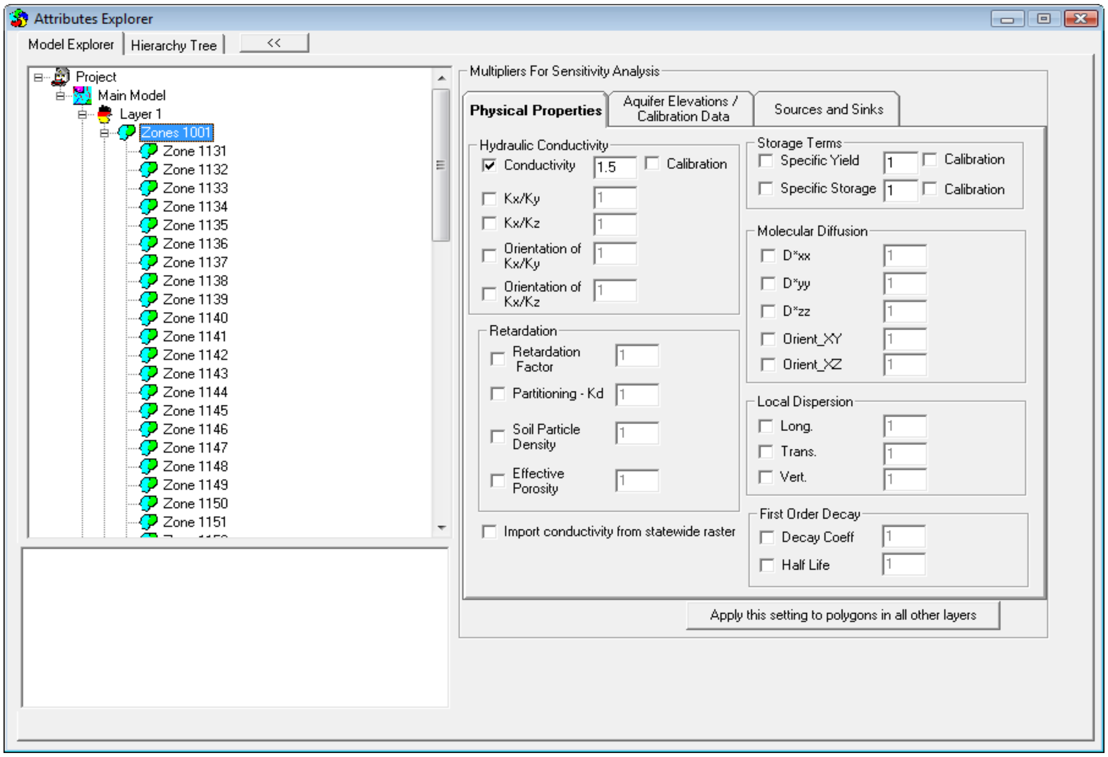
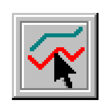


Figure 5.5 Multipliers for sensitivity analysis

5.3.3. Adjusting Streams Leakance

The streams were imported from GIS data in the model as one-way or two-way head dependent flux. Since there is no data available in the databases on stream leakance, IGW assigns default leakance values to stream arcs based on the order of the stream. These default values can be adjusted during the process of calibration. To change stream leakance:

Step 1: Select the stream arc in IGW Main Window using 'Select/Edit Polyline' button (you can also select the stream from AE window by clicking once on it name in LHP)



Step 2: Open AE

In the 'Head Dependent Flux' area in RHP, you will see the selected option between 'Two way' or 'One way'. Click the '…' button next to the selected option. 'Edit Polyline Attributes' window opens as shown in Figure 5.6.

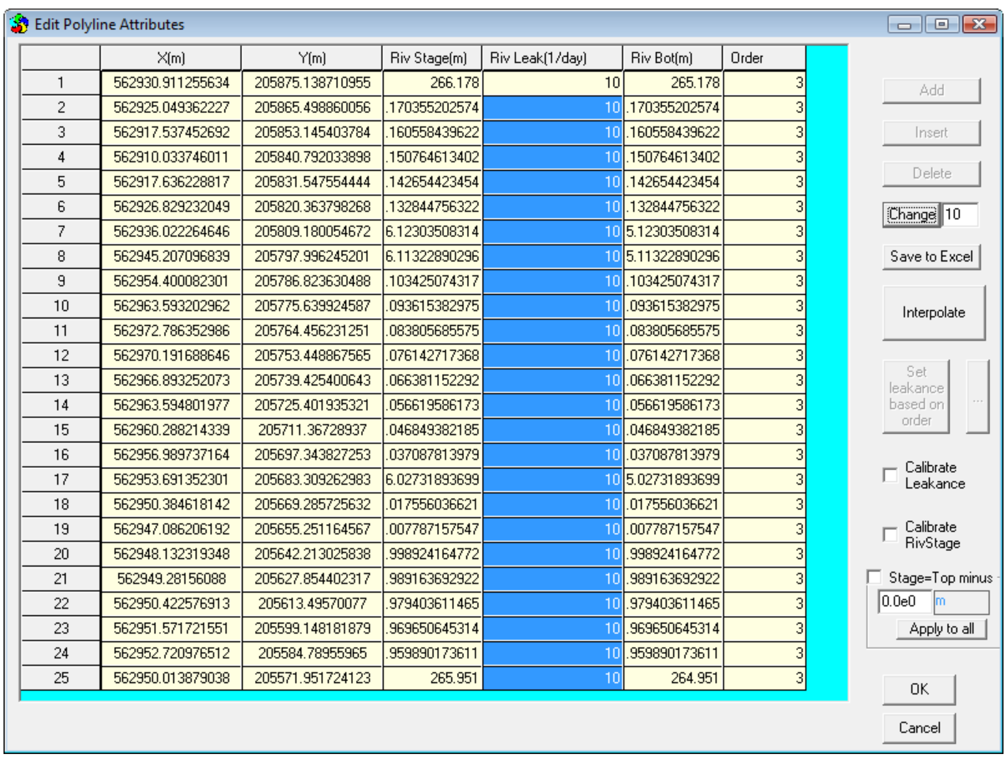
Step 3: Click once in the column heading 'Riv Leak(1/day). The entire column will be selected.

Step 4: Enter the desired value of leakance you want to assign to the field opposite to 'Change button'

Step 5: Click 'Change' button

Or
Step 5a: You can do linear interpolation of values across any column in the table. You can also do linear interpolation within a portion of the column. To do linear interpolation, enter the desired values in the first and last desired cells of the column using the Change button. Click to select the first cell, and then holding the shift-key, click in the last cell. This will select all the cells from the first to the last cells. When cells are selected, just click on the 'Interpolate' button. You will see the linearly interpolated values from the first to the last cells selected. (Also see Chapter 8 User's Manual)

Step 6: Changes in stream leakance will take effect when you will descritize the model.



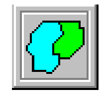
	X(m)	Y(m)	Riv Stage(m)	Riv Leak(1/day)	Riv Bot(m)	Order
1	562930.911255634	205875.138710955	266.178	10	265.178	3
2	562925.049362227	205865.498860056	.170355202574	10	.170355202574	3
3	562917.537452692	205853.145403784	.160558439622	10	.160558439622	3
4	562910.033746011	205840.792033898	.150764613402	10	.150764613402	3
5	562917.636228817	205831.547554444	.142654423454	10	.142654423454	3
6	562926.829232049	205820.363798268	.132844756322	10	.132844756322	3
7	562936.022264646	205809.180054672	6.12303508314	10	5.12303508314	3
8	562945.207096839	205797.996245201	6.11322890296	10	5.11322890296	3
9	562954.400082301	205786.823630488	.103425074317	10	.103425074317	3
10	562963.593202962	205775.639924587	.093615382975	10	.093615382975	3
11	562972.786352986	205764.456231251	.083805685575	10	.083805685575	3
12	562970.191688646	205753.448867565	.076142717368	10	.076142717368	3
13	562966.893252073	205739.425400643	.066381152292	10	.066381152292	3
14	562963.594801977	205725.401935321	.056619586173	10	.056619586173	3
15	562960.288214339	205711.36728937	.046849382185	10	.046849382185	3
16	562956.989737164	205697.343827253	.037087813979	10	.037087813979	3
17	562953.691352301	205683.309262983	6.02731893699	10	5.02731893699	3
18	562950.384618142	205669.285725632	.017556036621	10	.017556036621	3
19	562947.086206192	205655.251164567	.007787157547	10	.007787157547	3
20	562948.132319348	205642.213025838	.998924164772	10	.998924164772	3
21	562949.28156088	205627.854402317	.989163692922	10	.989163692922	3
22	562950.422576913	205613.49570077	.979403611465	10	.979403611465	3
23	562951.571721551	205599.148181879	.969650645314	10	.969650645314	3
24	562952.720976512	205584.78955965	.959890173611	10	.959890173611	3
25	562950.013879038	205571.951724123	265.951	10	264.951	3

Figure 5.6 Edit Polyline Attributes window

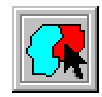
5.3.4. Adjusting Model Boundaries

Model boundary in the model was based on the watershed boundary selected for Wshed-1961. During the calibration process, you might feel that adjusting the boundary may improve the model calibration. To make any changes in the model boundaries you can:

Step 1: Draw a new model boundary in IGW Main window around the current model boundary by simply using 'Create Zone/Assign Properties' button as shown in Figure 5.7. Notice the larger change in boundary in southeast part of the domain.



Step 2: Click on 'Select/Edit Zone' button and right-click in the new model boundary polygon.



Step 3: Click 'Copy' in the popup menu

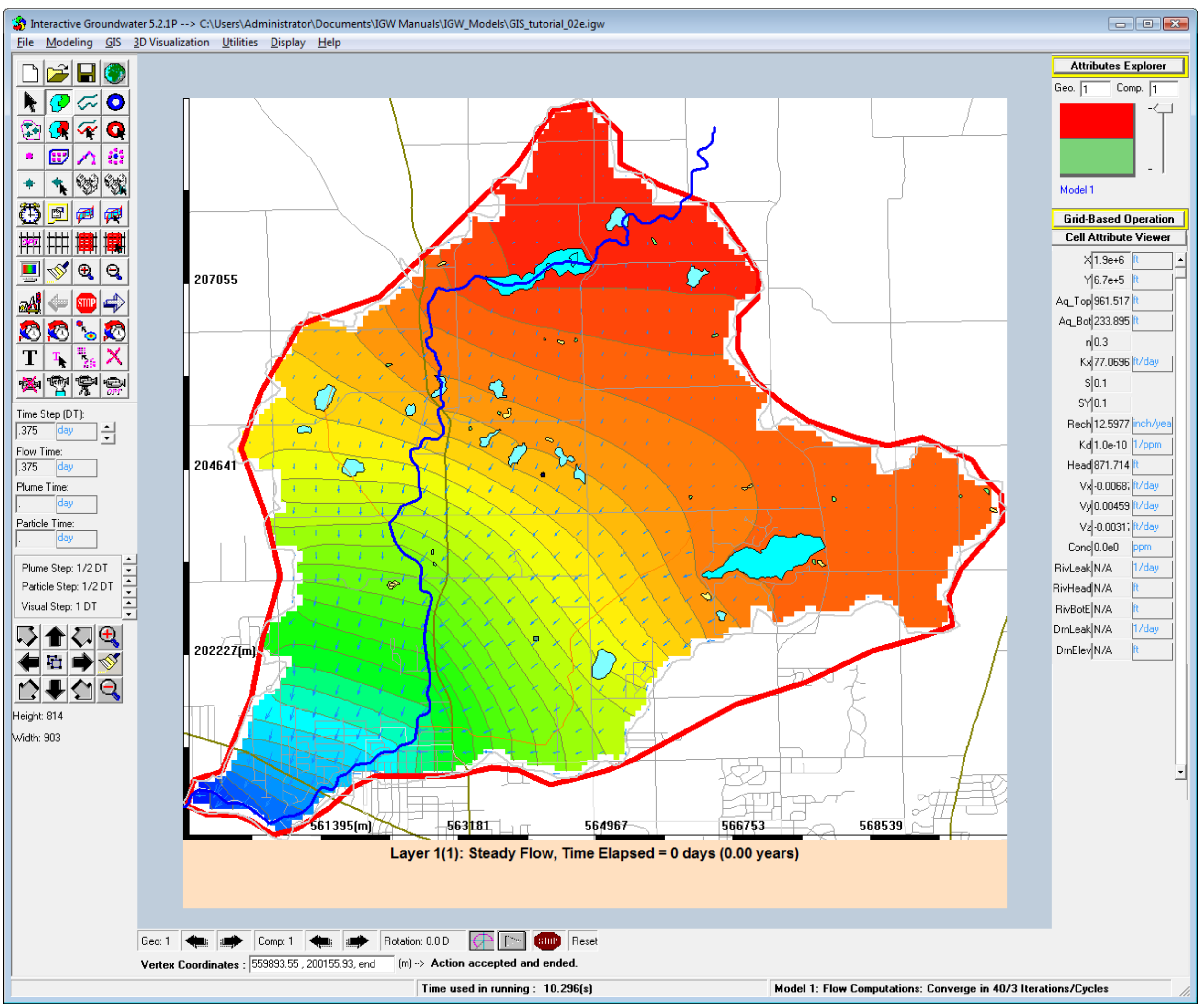
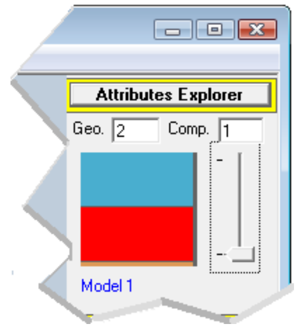


Figure 5.7 Adjusted model boundary.

Step 4: Switch to Layer 2 using the slider button.



Step 5: Right-click in the model area

Step 6: Click 'Paste' in the popup menu

Step 7: Switch back to Layer 1.

Step 8: Open AE

Step 9: Make sure that new boundary layer is selected in the LHP

Step 10: Select 'Physical Properties' tab in RHP. Check box next to 'Conductivity' and select 'Using Raster Data', 'Statewide Raster' and 'Drift_H2' options.

Step 11: Select 'Aquifer Elevations' tab in RHP. Check box next to 'Top Elevation' and select 'Using Raster Data' and 'State-wide DEM' options.

Step 12: Check box next to 'Bottom Elevation' and select 'Using Raster Data' and 'State-wide Raster' options.

Step 14: Select 'Sources and Sinks' tab in RHP. Select 'Prescribed Flux' sub-tab. Check box next to 'Recharge' and select 'Raster Data', 'Statewide Raster'.

Step 15: Now select Wshed-1961 polygon in Layer 1 by clicking once on the zone name in LHP.

Step 16: At the bottom of RHP, select 'For Display' under 'Zone Type'

Step 17: Now select new boundary polygon for Layer 2 in the LHP

Step 18: Select 'Physical Properties' tab in RHP. Check box next to 'Conductivity' and select 'Using Raster Data', 'Statewide Raster' and 'Bed Rock' options.

Step 19: Select 'Aquifer Elevations' tab in RHP. Check box next to 'Bottom Elevation' and select 'Constant' and 'Thickness' options and enter 164.04 ft (or 50 m) in the thickness field.

Step 20: Now select Wshed-1961 polygon in Layer 2 by clicking once on the zone name in LHP.

Step 21: At the bottom of RHP, select 'For Display' under 'Zone Type'

New boundary will take effect when the model is descritized. Figure 5.8 shows active model domain within the new model boundary.

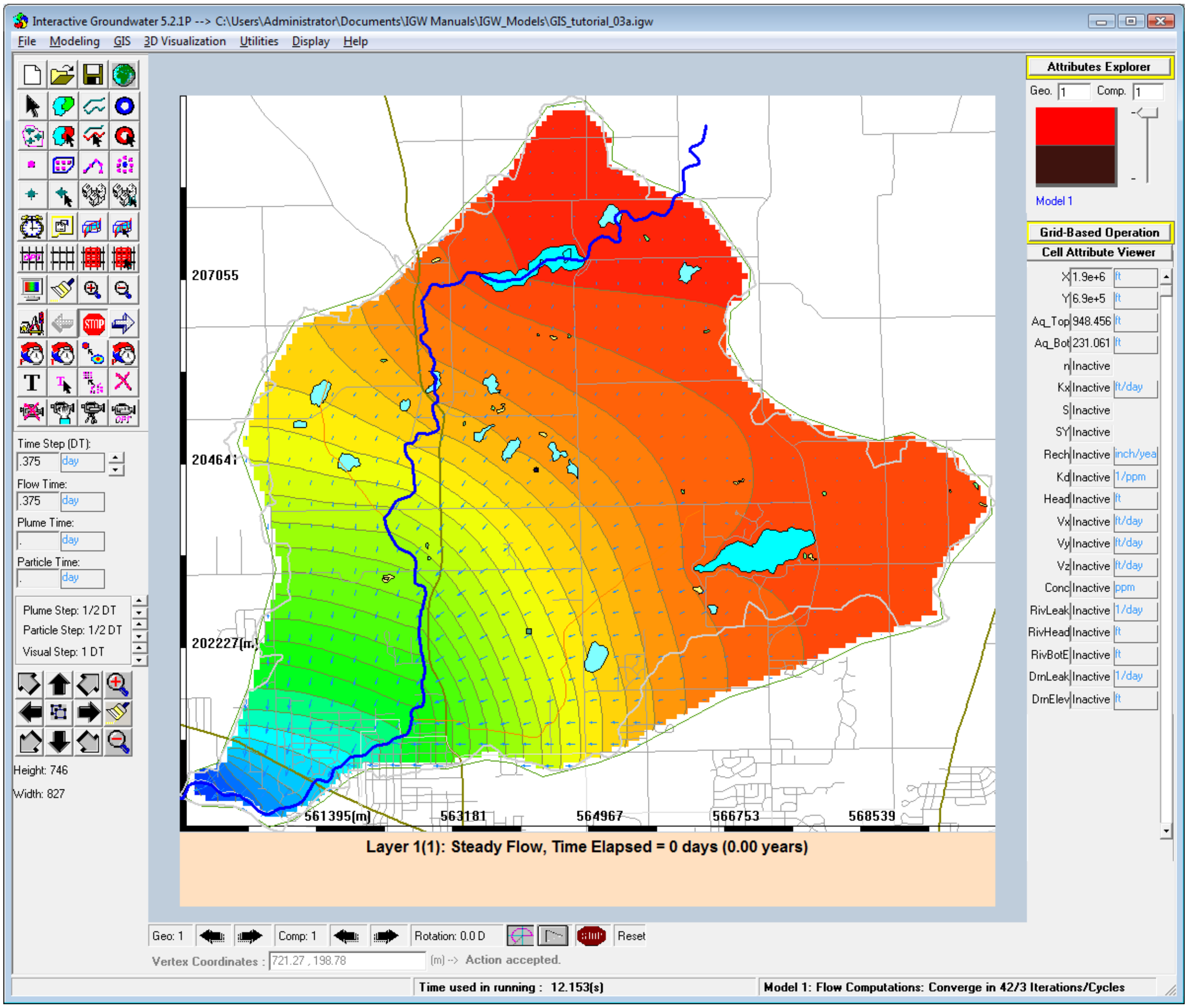


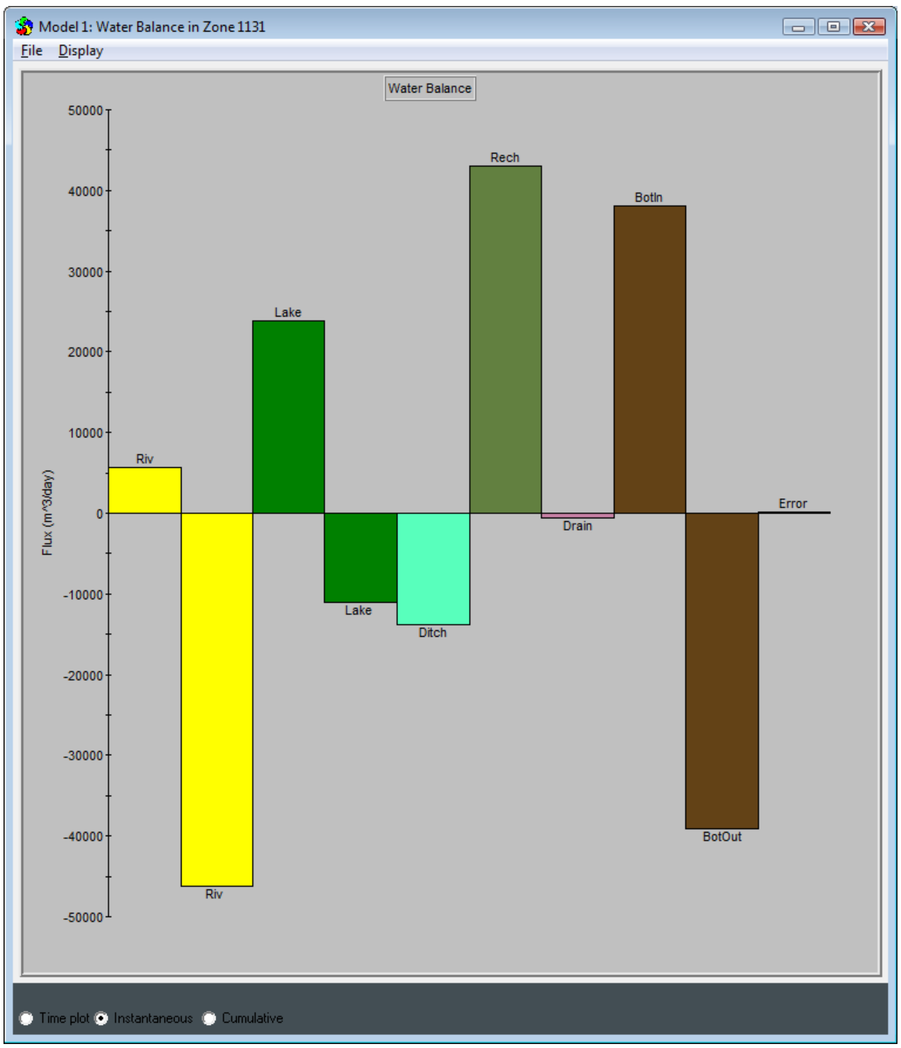
Figure 5.8 Modified model boundary after descritization and running the model.

R	Specific changes in the model have not been recommended as part of model calibration exercise. Only IGW functions have been explained. It is expected that the user will explore/adjust modeling parameters at his/her own to improve the trend line and water budget.

Chapter 6 PERFORMING ROUTINE MODELING TASKS

In this chapter you learn to perform some routine modeling tasks in a groundwater model built using GIS data. Using model calibration explained in the previous chapter, following water balance and static water levels were achieved. Figure 6.1 shows the final water balance and Figure 6.2 shows the comparison of Wellogic data with static water level in drift and bedrock aquifers. It may be noted that this calibration is only for tutorial purposes and intricate modeling issues regarding modeling assumptions and boundary conditions were not scrutinized as part of this tutorial.

You may like to calibrate your model at your own and then perform the modeling tasks as explained in the following sections.



	NHD Data	Net Model Prediction
Wabascon Creek	45,260 m^3/d	40,545 m^3/d
Wabascon Tributary	15,976 m^3/d	13,826 m^3/d

Figure 6.1 Water balance after calibration

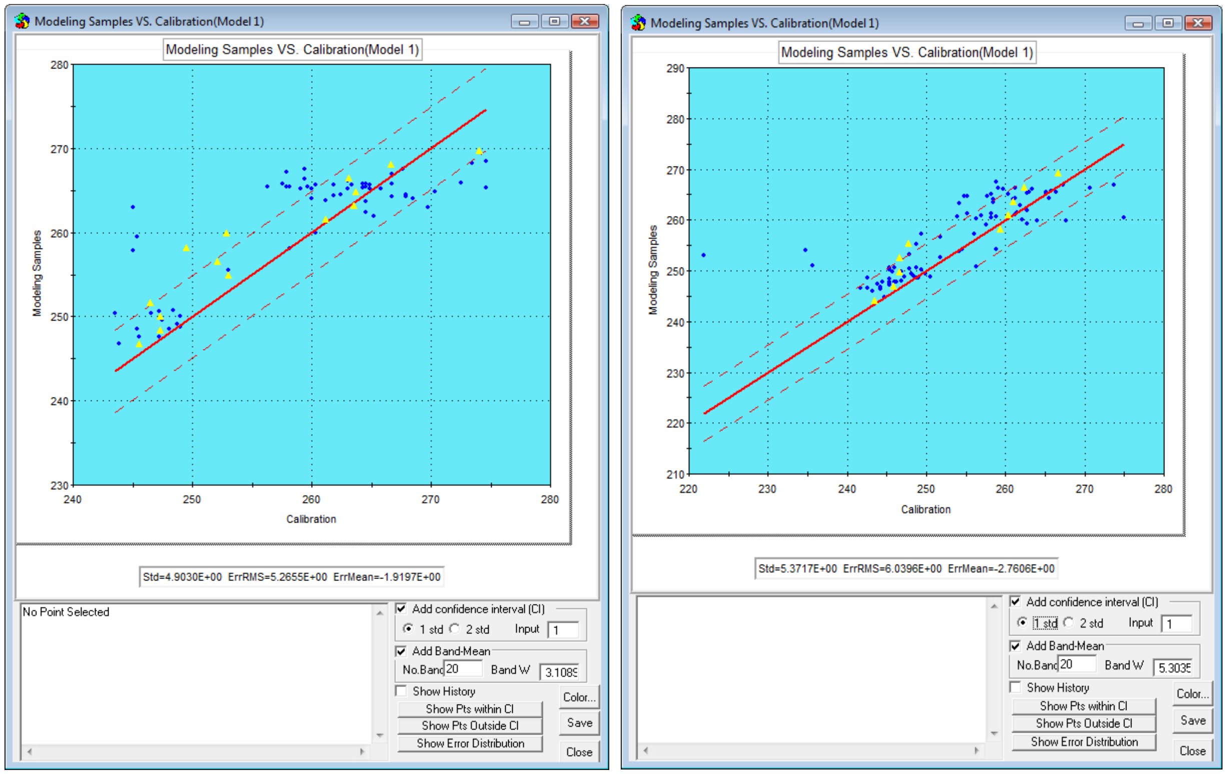


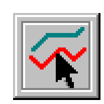
Figure 6.2 Head comparison for drift (left) and bedrock (right) layers in the model after calibration

6.1. Particle Tracking

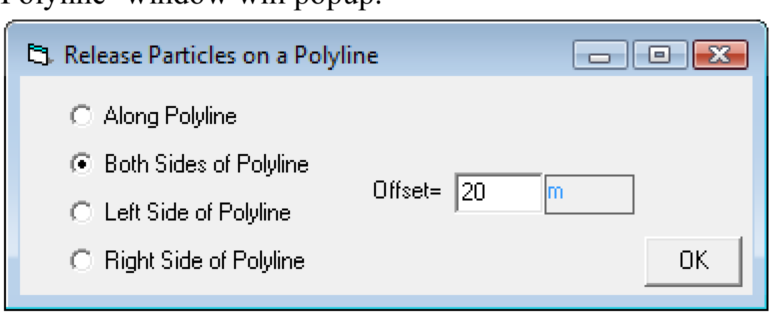
IGW allows for forward and reverse particle tracking. Please also see IGW 5.0P Tutorial, Chapter 9, and User's Manual, Chapter 10.

To delineate groundwater capture zone for Wabascon Tributary you can:

Step 1: Select the polyline representing Wabascon Tributary using 'Select/Edit ployline' button.

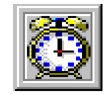


Step 2: Right click on the selected polyline, and then click 'Release particles along this Pline' from the popup menu. 'Release Particles on a Polyline' window will popup.



Step 3: Choose 'Both Sides of Polyline' option and type the offset distance of points from the line. Click OK

Step 4: Select time step and simulation length options in 'Simulation Time Parameters' window by clicking 'Set Simulation Time Parameters' button



Step 5: The particles will be released on either sides of the polyline. Click the 'Run Model Backward' button.

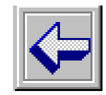


Figure 6.3 shows delineation of capture zone for Wabascon Tributary. The delineation will also depend on the final parameters you chose for the calibrated model and may not look exactly the same as shown below. This scenario addresses the narrative requirement of estimating groundwater contribution area for Wabascon Tributary.

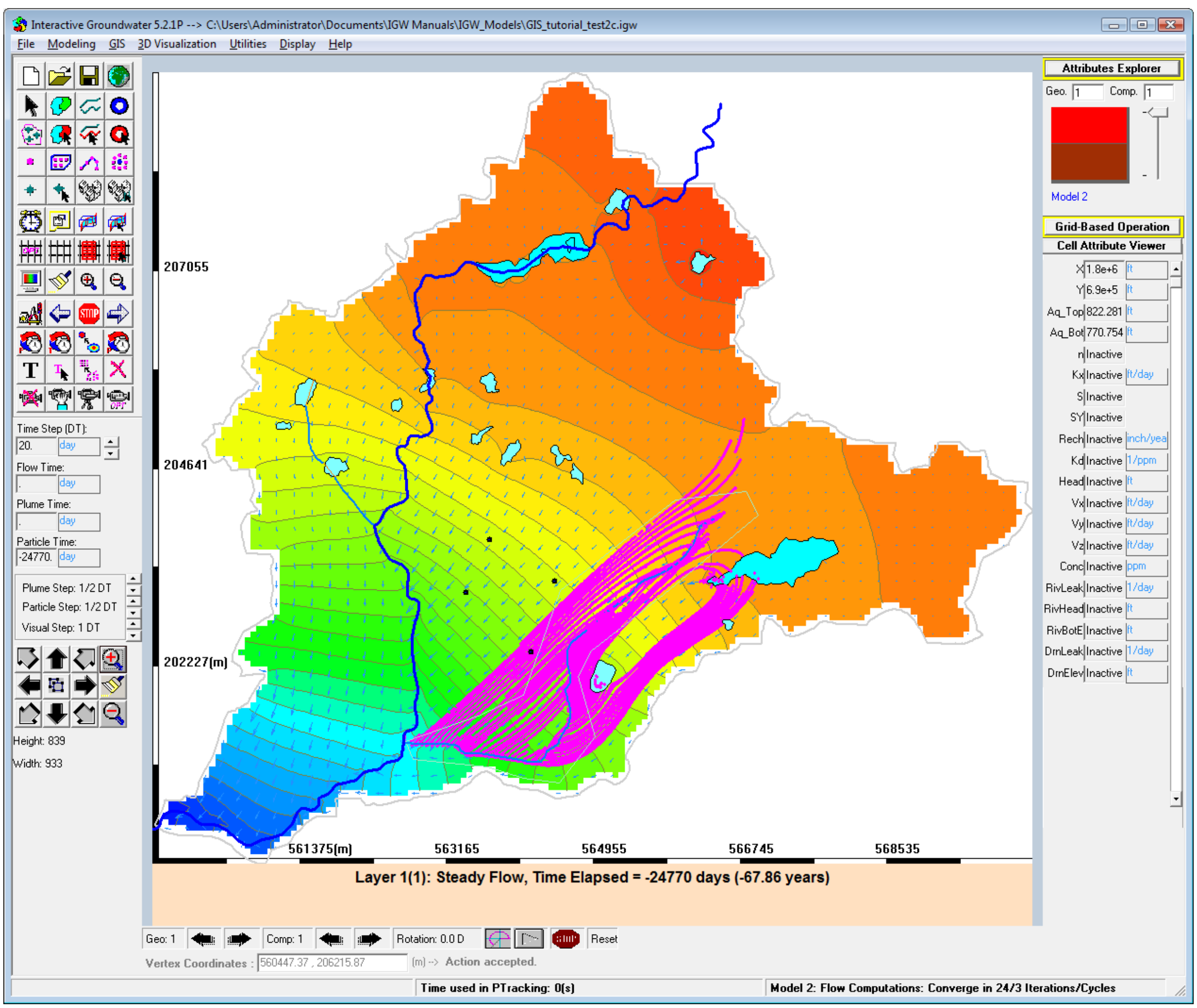


Figure 6.3 Capture zone delineation using reverse particle tracking

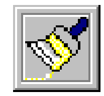
6.2. Water Balance

In order to assess the impact of proposed pumping well on Wabascon Tributary you can use water balance as explained earlier in Section 5.2.

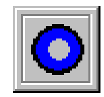
There is a narrative requirement of assessing the well impact when it pumps from drift aquifer and when it pumps from bedrock. You may follow these steps to make the required assessment:

Step 1: Go to GI and make sure that ‘tutorial_proposed_well.shp’ is checked in the ‘GIS Layer Explorer’.

Step 2: Switch to IGW main window and click ‘Refresh’ button so that the proposed well location shows on the map.



Step 3: Click the ‘Add Well’ button and then click at the well location in the model area. The well is added at that location. (see User’s Manual Chapter 9, and IGW 5.0P Tutorial Section 3.5



Step 4: Go to AE and add pumping rate of 2500 gpm for the well.

Step 5: Then select ‘None’ so that no pumping scenario may be simulated.

Step 6: Switch to Layer 2 and add another well by repeating steps 3 to 5 above. Now you have two 2500 gpm wells for both layers in the model at the proposed location but none is pumping at the moment.

Step 7: Switch to Layer 1 and select Wshed-1961 polygon in LHP of AE and at the bottom of RHS check the box before ‘Zone Budget’.

Step 8: Descritize and run the model (no wells is pumping).

Step 9: The water budget will show base flow in Wabascon Tributary (as Ditch). Note this value as no-pumping scenario.

Step 10: Go to AE and select ‘Pumping’ for the well in Layer 1.

Step 11: Descritize and run the model (well pumping from drift aquifer).

Step 12: The water budget will show base flow in Wabascon Tributary (as Ditch). Compare this number with step 9. The difference is the impact on creek in terms of baseflow reduction due to pumping from drift aquifer.

Step 13: Go to AE and select ‘None’ for the well in Layer 1 and ‘Pumping’ for the well in Layer 2.

Step 14: Repeat steps 11 and 12. Compare water budget numbers with step 8. The difference is the impact on creek in terms of baseflow reduction due to pumping from bedrock aquifer.

The above steps will fulfill the narrative requirement of assessment of impact due to pumping on Wabascon Tributary.

6.3. Surface Water-Groundwater Interaction

This task will give you a brief introduction of IGW's surface-water – groundwater interaction features. In this task you will assess the impact of pumping on lake levels close to the well as shown in Figure 6.4.

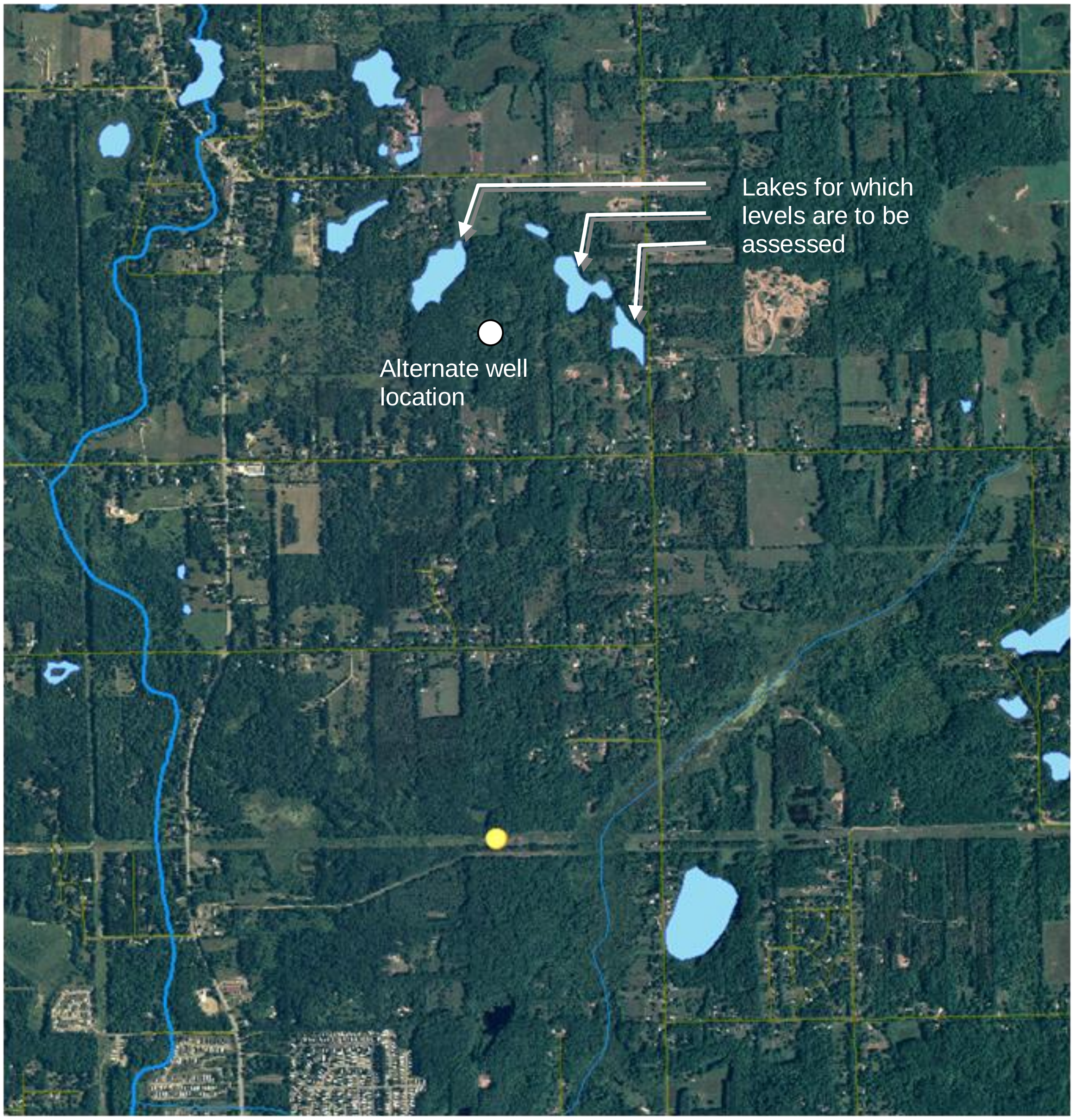
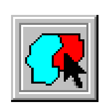


Figure 6.4 Lakes near alternate well location

Step 1: Install a pumping well in drift layer at the alternate location as explained in the previous section. Also make sure that wells at the proposed location are switched off by selecting 'None'

Step 2: Select one of the three lakes near alternate well as shown in Figure 6.4 by using 'Select/Edit Zone' button.



Step 3: Go to AE, select 'Sources and Sinks' tab and then 'Head-Dependent Flux' sub tab.

Step 4: Check 'Head-Dependent Flux (Two-way)' option.

Step 5: Under 'Stage' select 'TopE –' and enter zero in numeric field next to it [This will set the initial lake level at the data value from GIS file]

Step 6: Check 'Modeling SW, Qsw=' box and select 'Constant'. Add zero in the numeric field [This will set out-flow rate from the lake equal to zero]

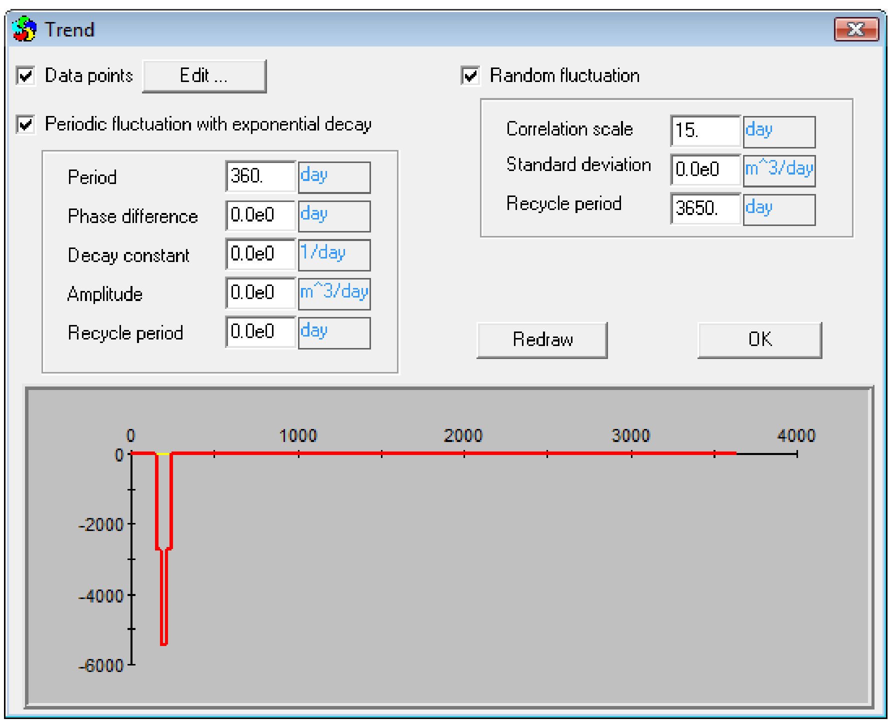
Step 7: Repeat steps 2 to 6 for the other two lakes. These steps will setup these lakes for surface water-groundwater interaction.

Now you will set up the well for transient simulation. The initial rate of pumping is zero and then a constant pumping rate of 2500 gpm is applied to the well. The pumping continues and lake levels are monitored as they drop. To simulate this scenario:

Step 8: Go to AE and select the well you put at the alternate location.

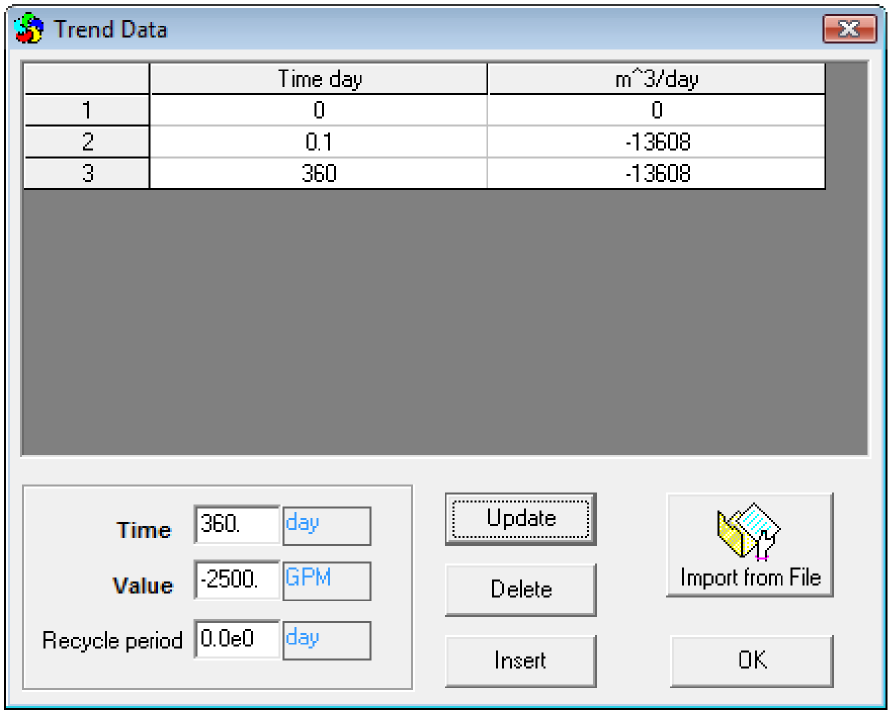
Step 9: Select 'Pumping' and the 'Transient'

Step 10: Click on 'Transient' button. Trend Window pops up.



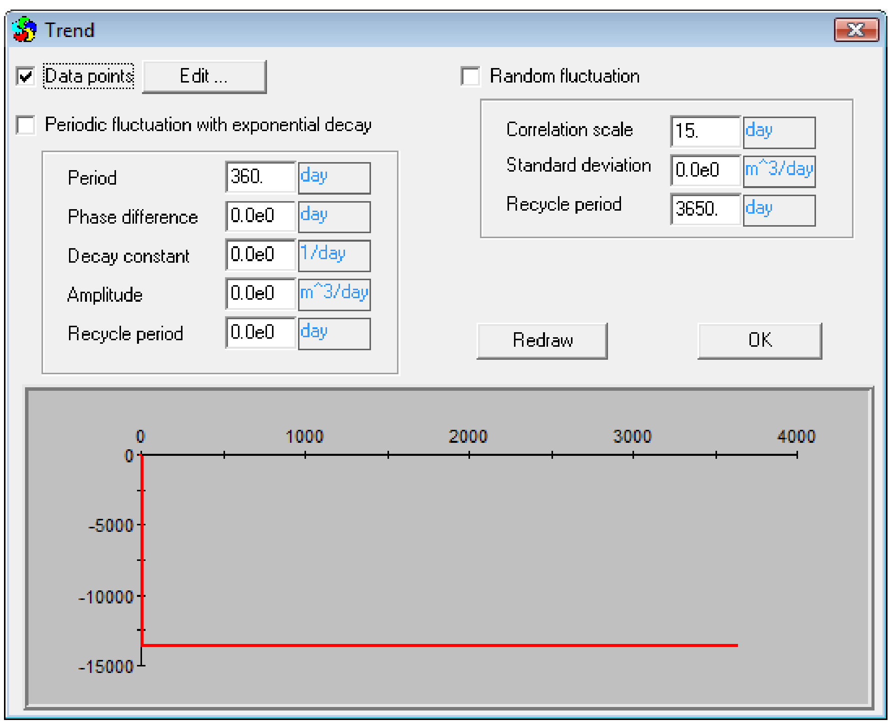
Step 11: Check 'Data points' options and click 'Edit' button. Trend data window shows up.

Step 12: Enter 0, 0.1 and 360 in 'Time day' column and 0, -13608, -13608 in the ‘m^3/day’ column.

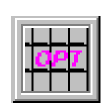


Step 13: Click OK in ‘Trend Data’.

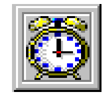
Step 14: In the ‘Trend’ window, click ‘Redraw’. Updated trend shows up in the window. Click ‘OK’



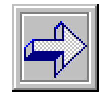
Step 15: Descritize the model



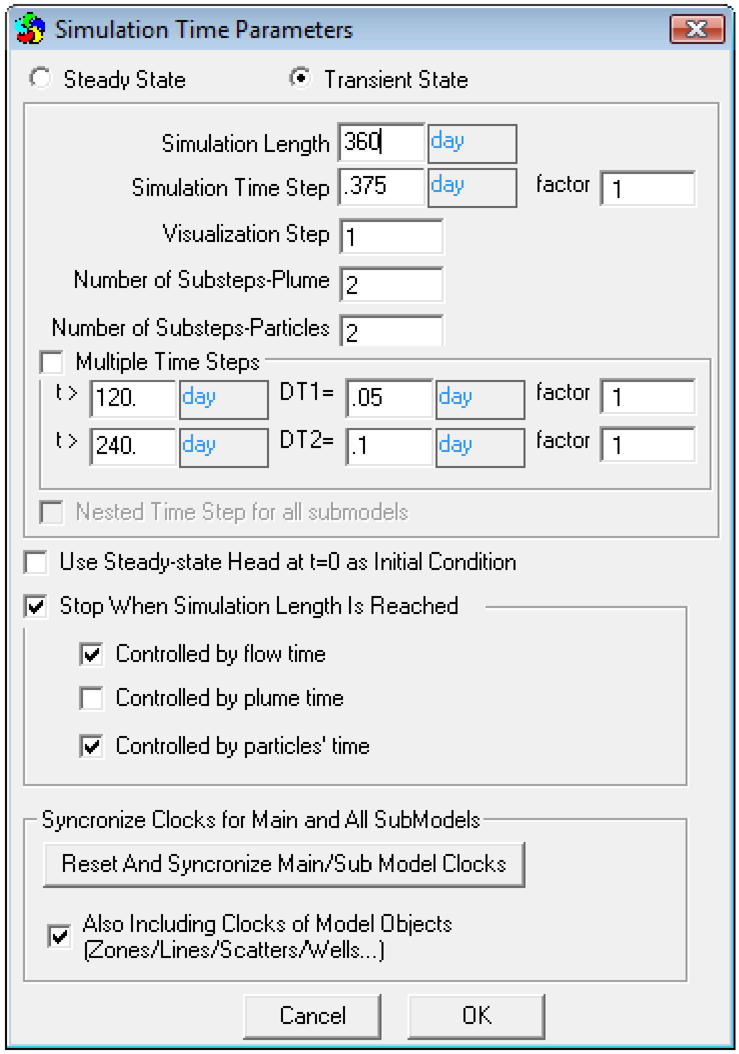
Step 15: Click ‘Set Simulation Time Parameters’ button and select ‘Steady State’ in the ‘Simulation Time Parameters’ window



Step 16: Run the model the model by clicking ‘Run Model Forward’ button



Step 17: Again click ‘Set Simulation Time Parameters’ button and select ‘Transient State’ in the ‘Simulation Time Parameters’ window.

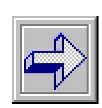


Step 18: In the ‘Simulation Length’ field, add 360 days

Step 19: In the ‘Simulation Time Step’ field, choose a small value e.g. 0.375 day

Step 20: Click OK

Step 20: Click ‘Run Model Forward’ button



Step 20: As the model starts running, ‘Model1: Surface Water Head vs Time’ window pops up. The window keeps updating with every time step.

As the model starts running, 'Model1: Surface Water Head vs Time' window pops up. The window keeps updating with every time step. You may stop the simulation when drop in lake levels reaches a steady state as shown in Figure 6.5.

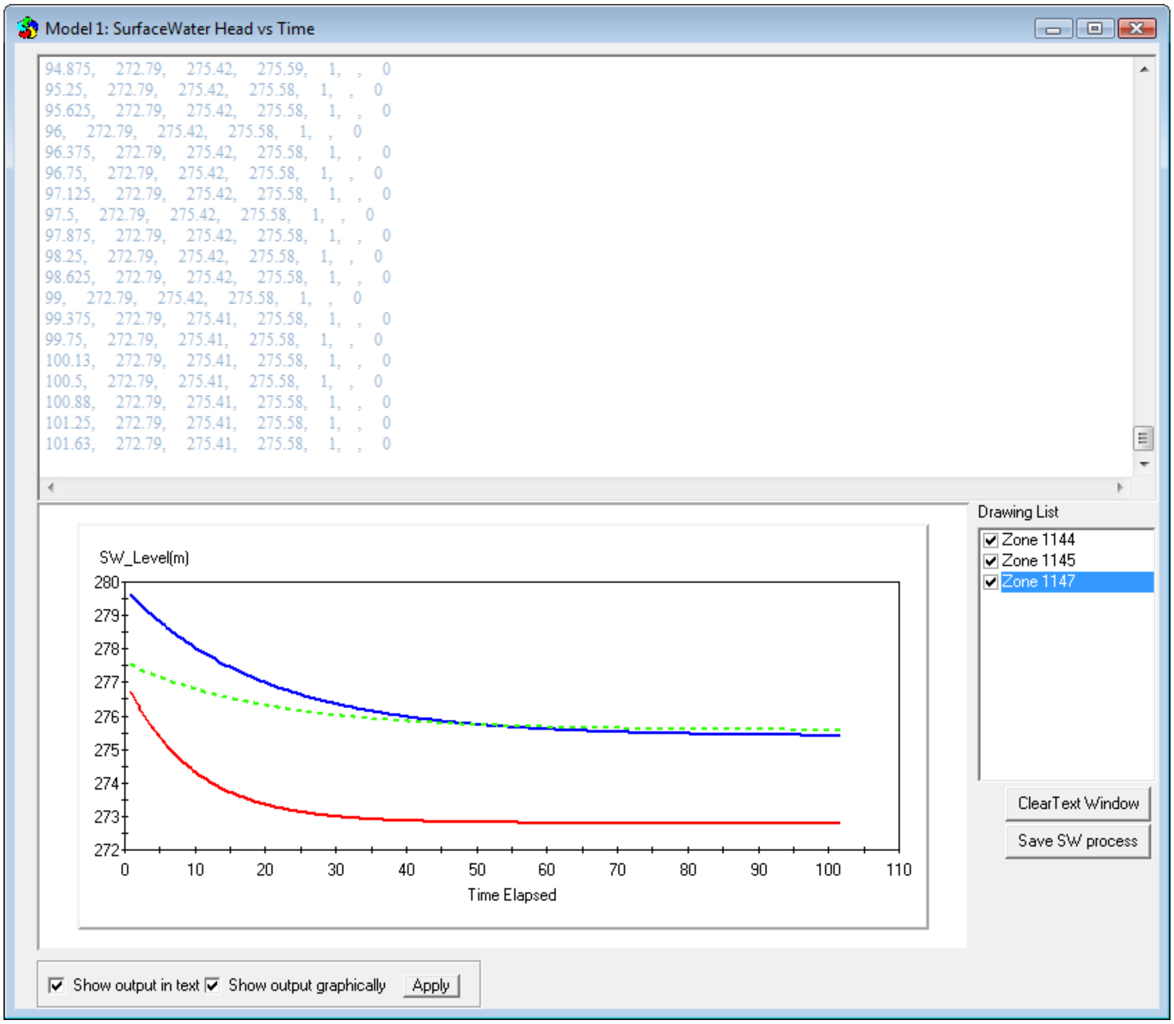


Figure 6.5 Drop in surface level of the lakes due to alternate pumping location.

Surface water-groundwater interaction scenario provides estimate of drop in lake levels due to pumping at the alternate well location which was one of the narrative requirements.

6.4. Conclusion

This tutorial was designed as a brief introduction to some advanced features of GIS-enabled groundwater modeling in IGW. Cross referencing to other documents have been made. It is recommended that user may attempt this tutorial after getting familiarized with basic modeling in IGW 5.0P Tutorial. User's Manual remain an important reference for modeling tutorials which covers more intricate details on features and function within IGW.

Thanks for doing these tutorial exercises. Your feedback will be appreciated.