Evaluating Soil Conditions for Site Redevelopment Using GIS

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Abstract : This paper describes how GIS became the cornerstone for both data management and data presentation for a Naval Air Station redevelopment project. A database was created that combined historical data collected during construction of the base with data from previous environmental explorations and new explorations conducted for site redevelopment. The GIS, which incorporated customization and data from other software applications, was used in early stages of project planning to develop various maps depicting generalized subsurface conditions. The GIS approach provided substantial time savings over more traditional methods used in the past, and helped to champion the use of GIS within our organization.

Project Description

This paper describes the use of GIS on a major site redevelopment project. The site is a former Naval Air Station in southeastern Massachusetts spanning three towns and encompassing over 2000 acres. The facility began operations in 1941 and was used to support aircraft that patrolled the North Atlantic during World War II. Over the years, on-site activities included aircraft maintenance, refueling, personnel training and housing, and administrative support services. The facility was closed in 1997. Figure 1 shows an aerial photo of the site area.

Plans are currently being generated for redeveloping the site using sustainable and smart growth practices. These plans call for a new mixed-use office park and commercial and retail businesses, both residential and senior housing, recreational areas, and schools. The project is expected to take approximately ten years to complete.

Figure 1: Site Area

GZA GeoEnvironmental, Inc. is one of many engineering firms working on this project. Initially, our involvement was to be limited to providing geotechnical services related to new roads and bridges that were to be constructed on the site during redevelopment. However, it soon became apparent to us that we could contribute to the project in another area.

During initial discussions, we learned that our client envisioned having certain capabilities related to managing and mapping the large volume of data associated with the site. For example, they wanted to be able to "click" on the location of a soil boring shown on a base map and display the boring log for that soil boring on the computer screen. They also wanted to be able to interactively identify where certain subsurface conditions existed on the site, and use that information when developing the redevelopment Master Plan. For instance, as part of the Master Planning process, several major infrastructure issues, including wastewater disposal, had to be addressed. One potential solution included constructing an on-site treatment plant and discharging the treated effluent on-site. Once the site is fully redeveloped, there will be a need to dispose of about 400,000 gallons per day (gpd) of treated wastewater. This will require a leaching area of about 8 acres. Therefore, there was a need to determine where wastewater disposal/groundwater recharge areas could be located on the site based on several hydrogeologic conditions. GIS seemed like the natural tool to accomplish these tasks.

Other factors supporting the use of GIS included the sheer volume of data that needed to be reviewed in a short amount of time. For example, hydrogeologic data from over eight hundred on-site soil borings needed to be studied and readily accessed during the project. With such a large volume of data, we felt that a relational database management system was better suited to the task of data management than the spreadsheet that was initially being used for this purpose. Because we were at the very beginning of the project, it was the ideal time to switch from spreadsheets to a relational database management system. Once the data was in a database, this would open the door to using GIS. The GIS would establish a data management system that could grow with the project and be accessible to the design team members.

Project Scope

The Master Plan for site redevelopment also called for the creation of on-site drinking water/supply wells that will remove groundwater from the site. To limit the potential long-term environmental and economic impacts of groundwater withdrawal, this groundwater will need to be replenished. One of the options during base redevelopment was to use the treated wastewater to replenish or recharge the groundwater being withdrawn from the site. However, for recharging to work properly, the correct hydrogeologic conditions must exist. The initial use of GIS on the project was as a tool to help locate suitable hydrogeologic conditions for a wastewater disposal/groundwater recharge area.

The hydrogeologic conditions required for a wastewater disposal/groundwater recharge area are related to soil type, hydraulic conductivity, depth to groundwater, and the saturated thickness of the soil/aquifer. Soil type refers to how a soil is classified. For example, soils can be classified as gravel, sand, clay, silt, and combinations of these basic types. Soil types containing predominantly sands and gravels are generally well suited for groundwater recharge due to the larger particle sizes, greater pore space area, and higher hydraulic conductivities. Soil types containing predominantly silts and clays, on the other hand, have much lower hydraulic conductivities and are not desirable for groundwater recharge/wastewater disposal due to the much smaller particle sizes and pore space area. Hydraulic conductivity is a measure of how easily water or effluent can move through soil, and is a function of the size of the pores between the particles. The depth to groundwater is important because there must be at least a four- foot vertical separation between the top of the groundwater level and the bottom of the leaching field/disposal area. Hence, areas where the groundwater level is close to the surface are generally unsuitable for large leaching/disposal areas. The saturated thickness of an aquifer defines how much water or effluent (quantity and rate) can pass through a section of the aquifer. As the saturated thickness increases, the quantity of flow through the aquifer also increases. Based on the prevailing soil conditions at the site, the saturated thickness was taken as the difference between the groundwater elevation and the top of bedrock elevation. Hence it was important to know where the top of bedrock was at the site based on the historical boring data. It was also very important to try to exclude questionable shallow top of bedrock elevations from the database to develop a better indication of the saturated thickness.

Although the GIS will be used for a number of tasks over the course of the project, it was used initially to organize the data and to help identify locations on the site that would be suitable for use as treated wastewater disposal/groundwater recharge areas. This paper will now focus on how GIS was used for this purpose.

GIS Aspects

Our initial challenge was not an unusual one. All of the relevant data for locating the wastewater disposal/groundwater recharge area was stored in one large spreadsheet (about three inches thick when printed on 11x17 paper). We needed to move these data from the spreadsheet into an Access database. The data in the spreadsheet was organized by the soil boring name. Unfortunately, not all of the names of the soil borings were unique. These duplicate soil boring names existed because numerous consultants had worked on this site over the years and frequently each one worked independently of the others. Clearly, having multiple borings (data points) with the same boring number presented a problem for the GIS. Attribute data could not be Joined or Linked to the GIS Soil Boring Layer until each soil boring had a unique name. Consequently, a new soil boring naming convention was established to correct this problem.

Once this new naming convention was implemented, the spreadsheet was imported into a new Access database "as-is". This created one large database table. The data was then normalized as needed using Access "Create Table" queries. Some of these queries used aggregate functions such as minimum, maximum, and average. At the conclusion of this process, we had a database that could be used in the GIS.

Initial Approach

Once the initial database was completed, it was connected to features shown on a site base map that had been generated in AutoCAD. This established the initial site GIS. At the time this work was performed, GIS was still relatively new to our Company, and most engineers were used to working in a CAD environment. The maps that were requested from the GIS were the same types of maps that were typically done using CAD. For example, maps labeled with the depth to bedrock at every soil boring, and labeled with the depth to groundwater at every soil boring were requested. Additional maps were also requested. Each one was to have the soil borings labeled with some piece of data from the database.

Using GIS to automatically label the soil borings with the requested data was a substantial improvement over having to manually look up the data in a spreadsheet, write it on a printed base map, and then type it in to the CAD drawing. However, there was still one major problem that had to be dealt with: over 200 soil borings needed to be labeled on each map, and many of these soil borings were in close proximity to one another. In short, there simply wasn't enough room on the map to be able to easily read all of the labels. A considerable amount of time had to be taken to position all of these labels so that they could each be read on the map. Even after the labels were repositioned, however, it was still difficult to visualize spatial trends and understand what the data was telling us. Figure 2 provides a general idea of how all of these labels looked, and shows how ArcView labeling was used to concatenate two fields in the database, the soil boring ID and the elevation at the top of bedrock. However, it was still difficult to get a feel for how the data varied spatially. This was true for each of the labeled maps that were produced.

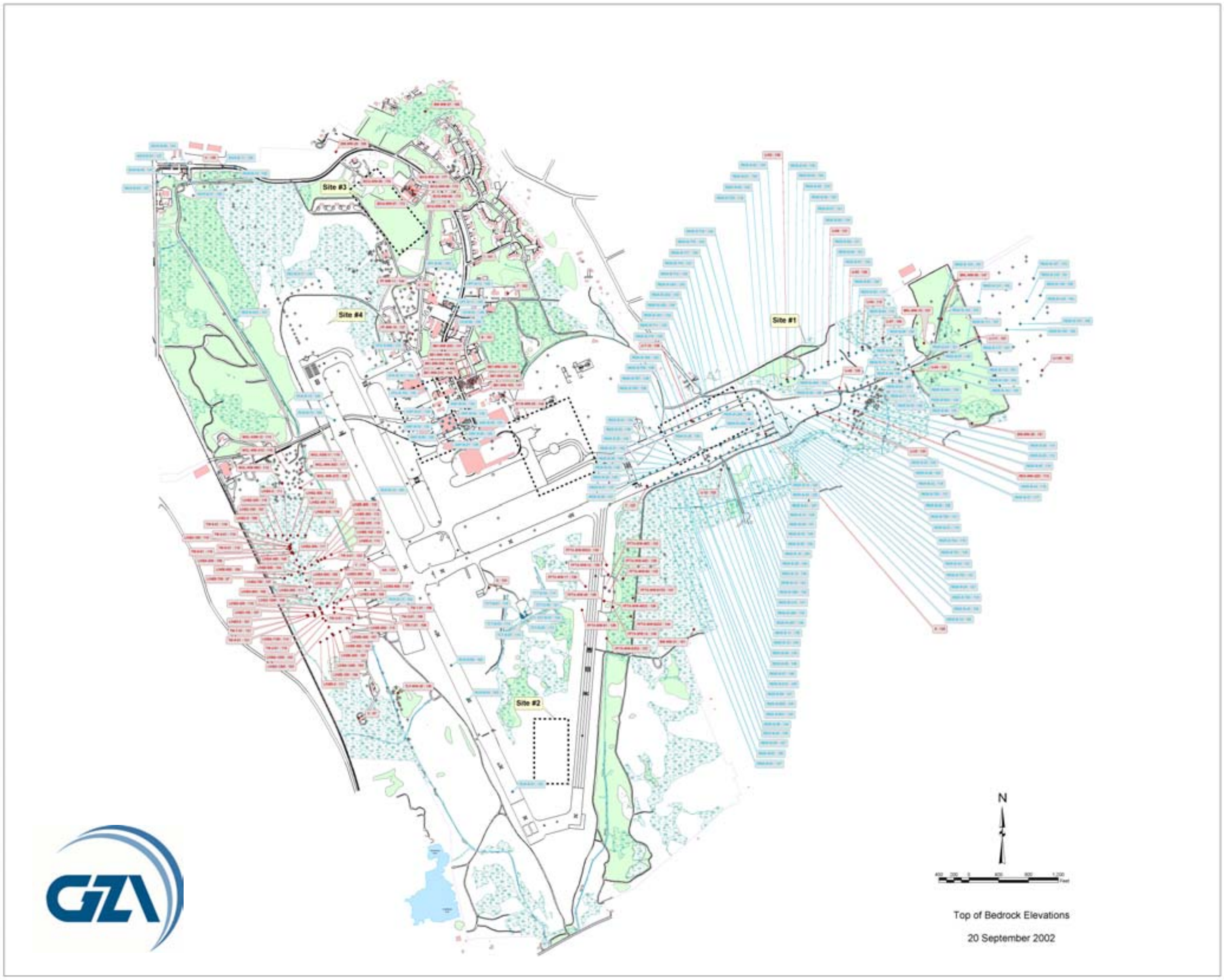

Figure 2 : Typical Labeled Map

Revised Approach

Because of the shortcomings associated with the labeled maps, we decided to produce contour maps from the data. These contour maps would display gradationally-colored contour bands rather than just contour lines. We felt that data presented in this format would be much easier to understand and would more effectively illustrate the spatial variation in the data. In addition, this format is typically more aesthetically appealing than a map with hundreds of labels, or simply labeled contour lines.

To produce such a contour map, a raster approach was used in which data values are assigned to raster grid cells. These data values can be computed using a number of methods. Each of these methods assigns data values to grid cells by interpolation of the known data values. In each method, the interpolated values are typically computed using some form of a weighted average of the surrounding data points. The exact interpolation technique varies from method to method. The Minimum Curvature method was used to produce a raster grid for these data. This type of contour map was produced for top of bedrock elevations and maximum groundwater elevations. Figures 3 and 4 show these maps.

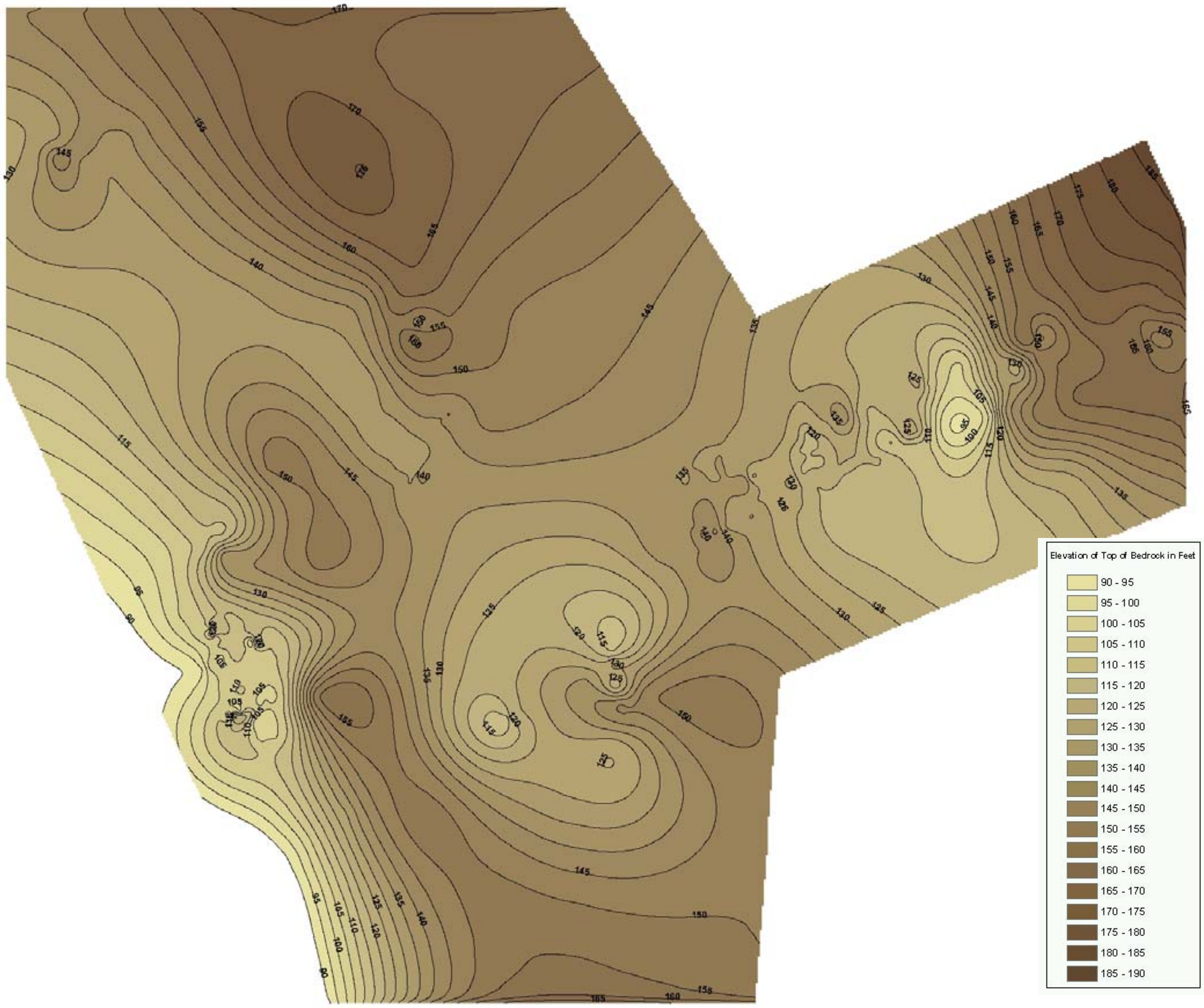

Figure 3 : Top of Bedrock Elevations in Feet

Initially, we wanted to use Spatial Analyst to create the raster grids. We also had the Surfer contouring software package available for this purpose. When using Spatial Analyst, the interpolation process seemed to take an excessively long time. After about fifty minutes, the Spatial Analyst grid had still not been created. Execution of the program was halted, and Surfer was tried instead. The interpolation process was completed in 2 to 3 minutes using Surfer. Because Surfer was much faster than Spatial Analyst and it was more widely available in our office, all subsequent creation of raster grids was accomplished using Surfer.

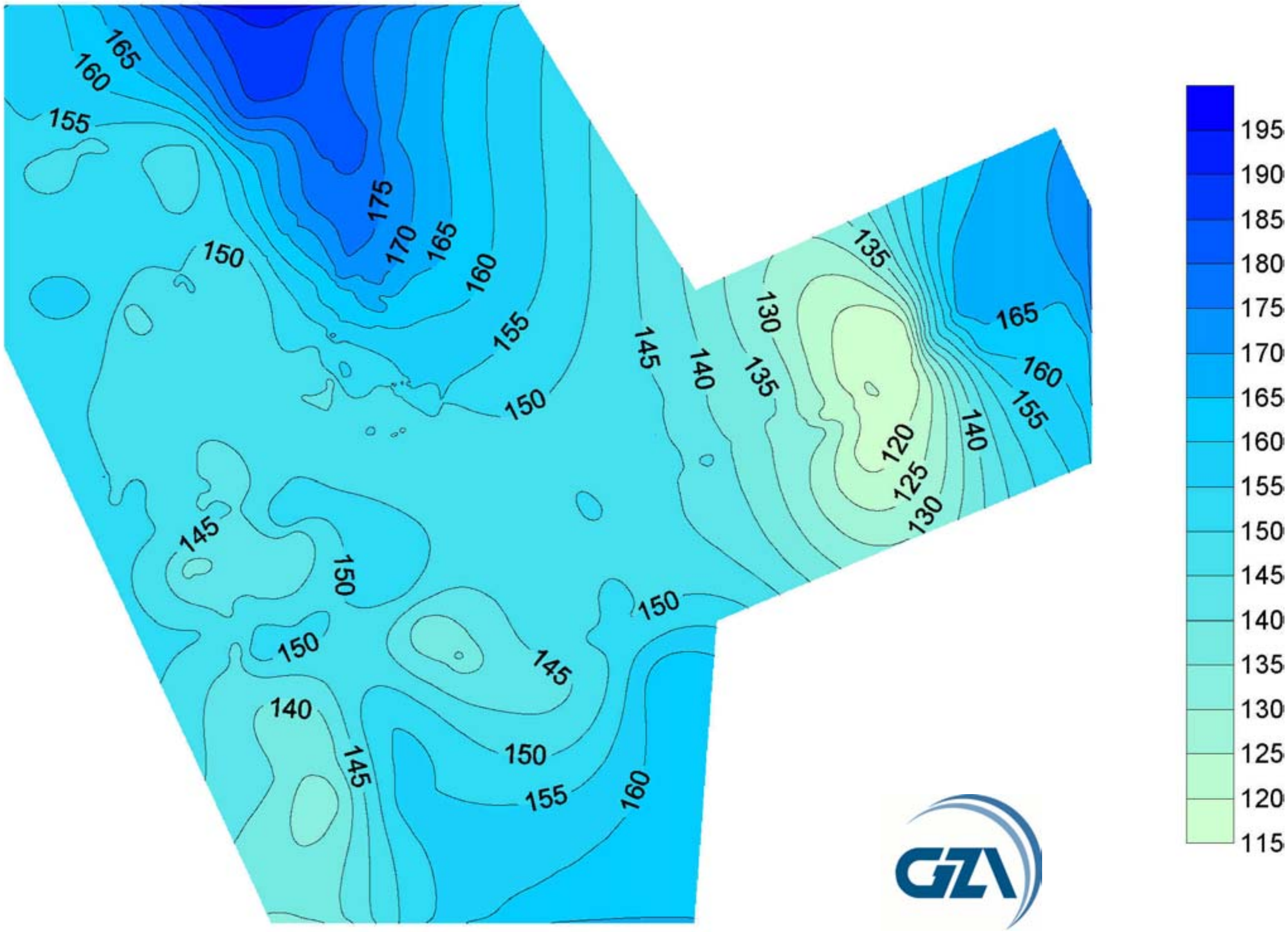

Figure 4 : Maximum Groundwater Elevations in Feet

In order to use the Surfer grids in ArcView, the Surfer grids had to be converted into ArcGIS Grid format. This was accomplished with the help of an ArcScript that was downloaded from the ESRI Web site. The procedure was as follows: In Surfer, the Surfer grid was converted into an ASCII file format using simple menu selections. Next, the ArcScript called “grd2asc_inverse.exe” was run. This script converted Surfer’s ASCII file format into an ASCII file format that was compatible with ArcGIS. Finally, ArcToolbox was used to import the converted ASCII grid file to an ArcGIS raster grid format. Once this was done, the ArcGIS grid was added directly to the Map Document (mxd file). Finally, the SetNull function in Spatial Analyst had to be used to convert Surfer’s null grid values into ArcGIS null grid values. ArcMap was then used to assign colors to the grid cells and Spatial Analyst was used to generate contour lines from the raster grid.

The next map that was needed to help locate a groundwater recharge area was a map showing the maximum saturated thickness of soil across the site. The saturated thickness of soil on this project was defined as the thickness of soil above bedrock that is saturated with groundwater (refer to Figure 5). To be consistent with the previous maps, a raster map was developed to illustrate the maximum saturated thickness. This was easily done using Surfer again, wherein the “Top of Bedrock” grid was subtracted from the “Maximum Historical Groundwater Elevation” grid to produce the Maximum Saturated Thickness grid (this capability is also available in Spatial Analyst). Each cell in this new grid represented the computed maximum historical saturated soil thickness. The grid was then added to ArcMap where colors were assigned to the raster grid cells. Spatial Analyst was then used to generate contour lines based on the raster grid. The resulting map is shown in Figure 6.

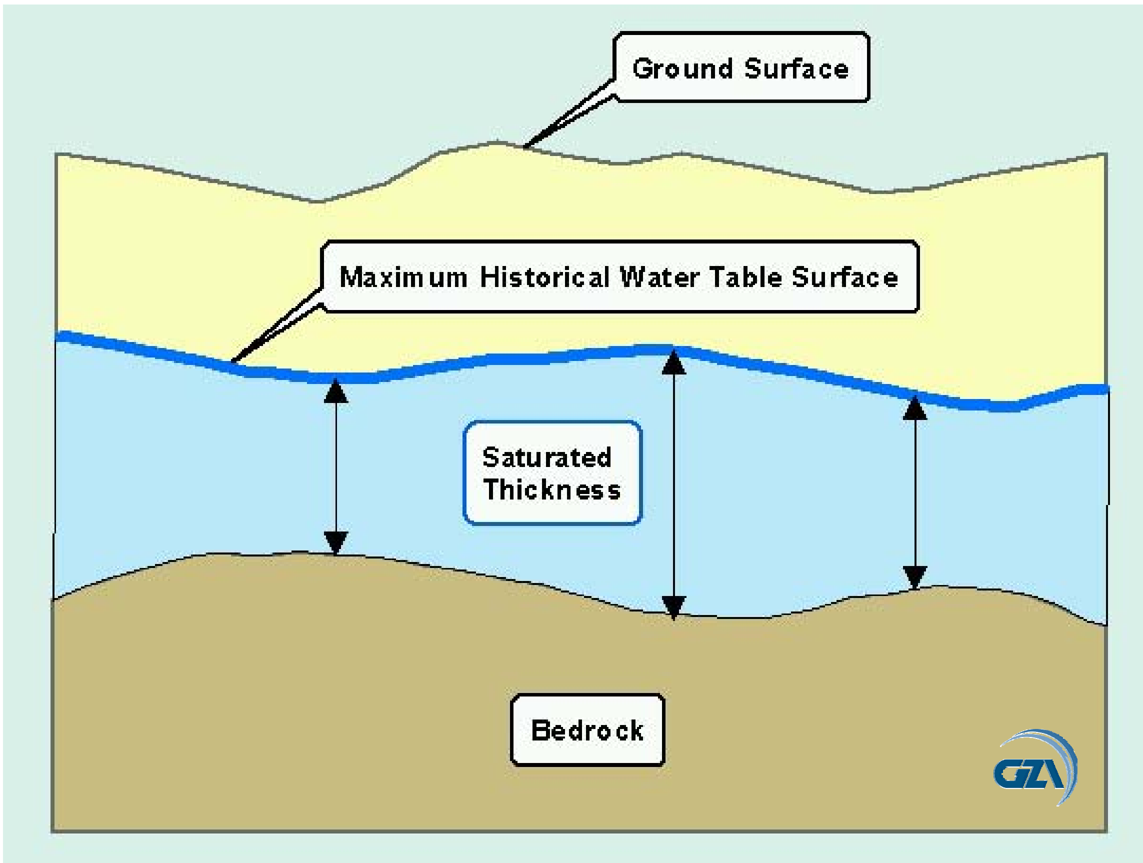

Figure 5 : Saturated Thickness

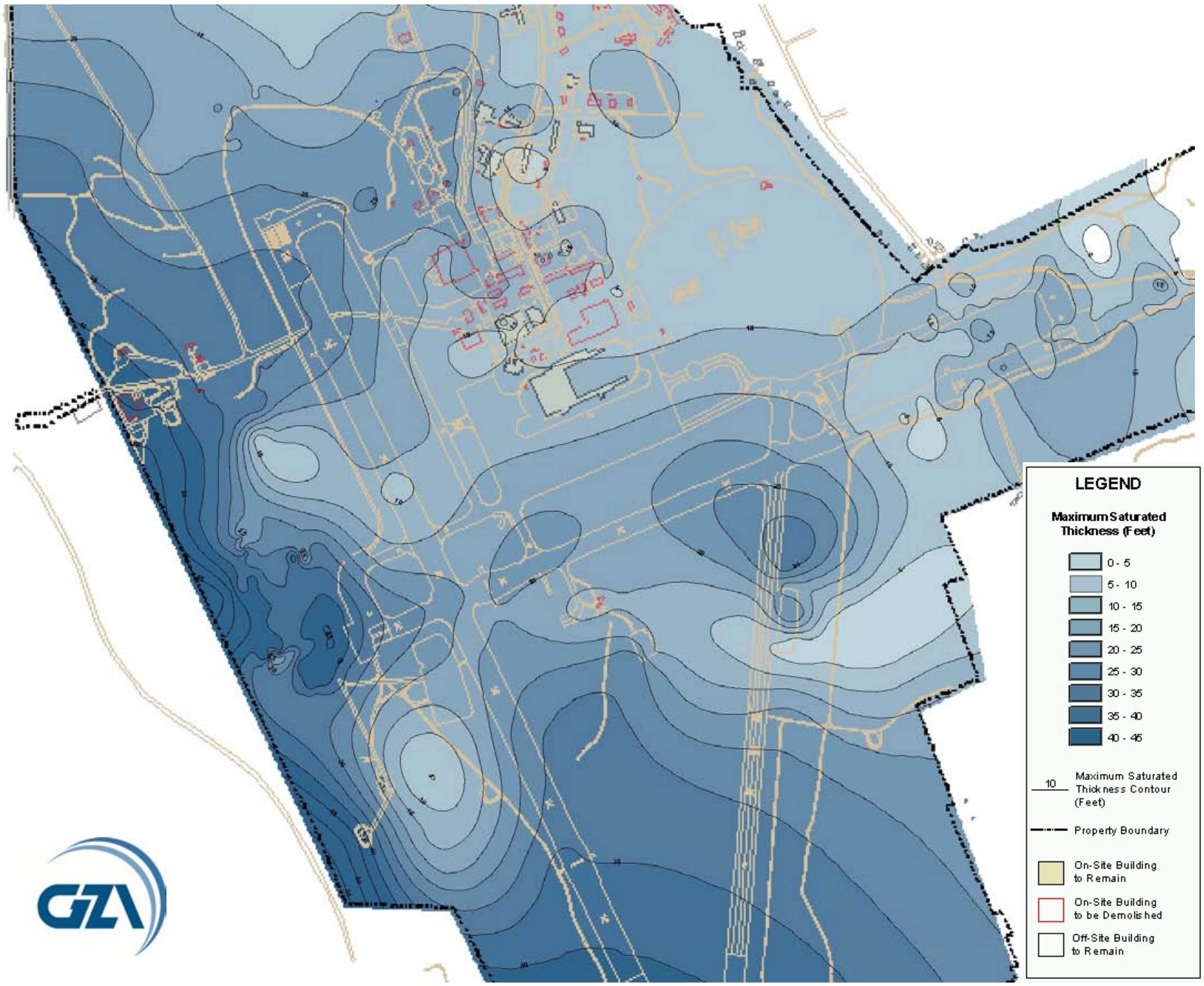

Figure 6 : Maximum Saturated Thickness

Having an appropriate soil type (gravel, sand, fill, etc.) is critical to creating an efficient wastewater disposal/groundwater recharge area. Therefore, a map of soil types was needed. Producing a soil type map for the site presented its own set of challenges, primarily because soil types varied both horizontally and vertically. This created a one-to-many relationship wherein one soil boring may have many soil types associated with it since soil type can vary with depth. In ArcMap, this meant that soil type data had to be Linked, not Joined, to the Soil Boring Layer.

Because of the variation of soil type with depth, a 2-D contour map was not an appropriate way to display the soil type data. To identify predominant soil types across the site, engineers needed to see labels on the map that showed how soil type varied with depth at each soil boring. This presented an obstacle since ArcMap does not directly allow one to produce labels from a Linked table. To get around this limitation, we wrote some ArcObjects code. This code included ArcObjects code that was downloaded from the ArcObjects Online Web site. Using this ArcObjects program and standard ArcMap labeling techniques, each soil boring was labeled with three pieces of data for each recorded sample depth: depth from ground surface, corresponding elevation at that depth, and the soil type. In addition to automatically generating these labels, the program was modified so that it automatically changed the background color of the text box to green, rather than use the default color of yellow, if a certain soil type (SD – Stratified Drift) was present at that soil boring. This eased the burden for the engineers reviewing the map. The presence of Stratified Drift soils (i.e., sands and gravels) was important for a disposal/recharge area, and the color coding made it very easy for the engineers to quickly identify those locations that deserved further consideration as potential disposal/recharge areas. Figure 7 shows what these automated labels looked like. Engineers then reviewed these maps and used them to hand sketch polygons representing generalized soil types. These hand drawn polygons were then digitized into ArcMap. The resulting generalized soil map is shown in Figure 8. Uncolored areas on this map indicate regions where there was little or no soil data available.

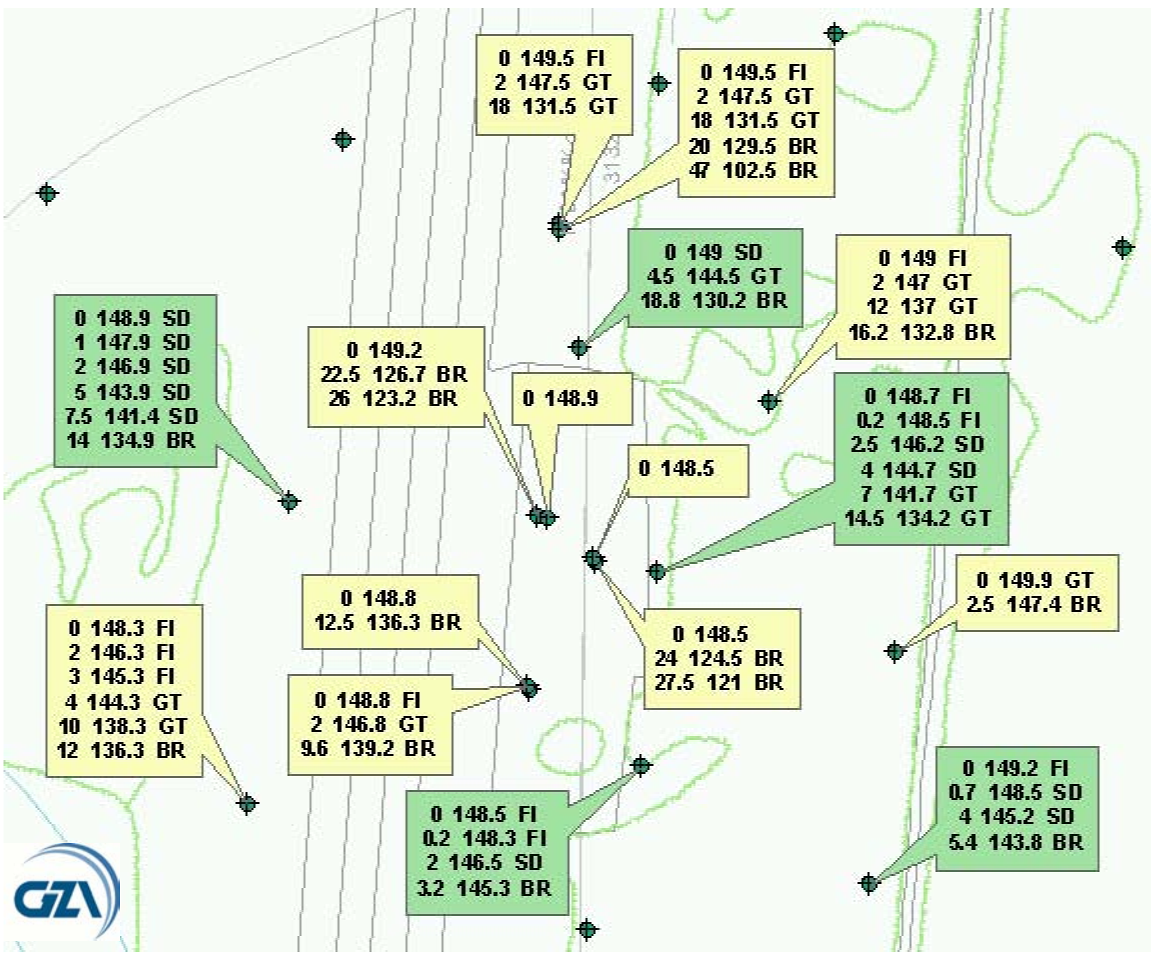

Figure 7 : Labels showing Depth, Elevation, and Soil Type Code

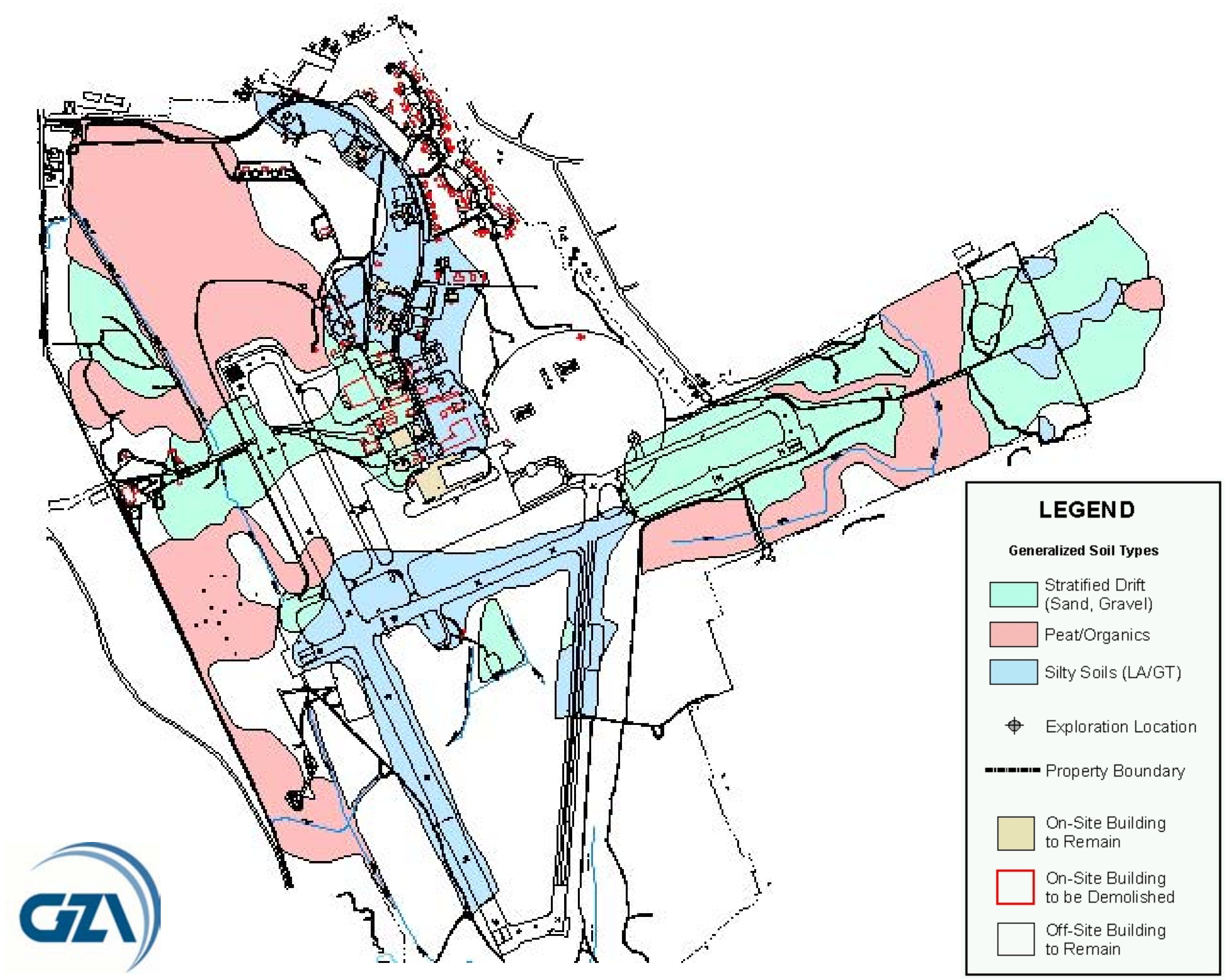

Figure 8 : Generalized Soil Types

Finally, a map showing hydraulic conductivity of the subsurface soils was developed. Hydraulic conductivity indicates the relative ease with which water can move through soil. For purposes of a wastewater disposal/groundwater recharge area, soils with higher hydraulic conductivity are better than soils with low hydraulic conductivity. For this map, we simply used standard ArcMap labeling techniques. Each soil boring was labeled with two fields from the database: the boring name and the hydraulic conductivity measured at that boring. Also, two label classes were created so that the colors of the labels could automatically be set according to the magnitude of the hydraulic conductivity. Green labels were used to indicate higher conductivity values and red labels were used to indicate lower hydraulic conductivity values. The soil boring symbols themselves were colored in a similar fashion. Figure 9 shows what the labels and map looked like. We then combined the depth to groundwater, hydraulic conductivity, and soil type data in one map to help identify potential disposal/recharge areas. This map is shown in Figure 10.

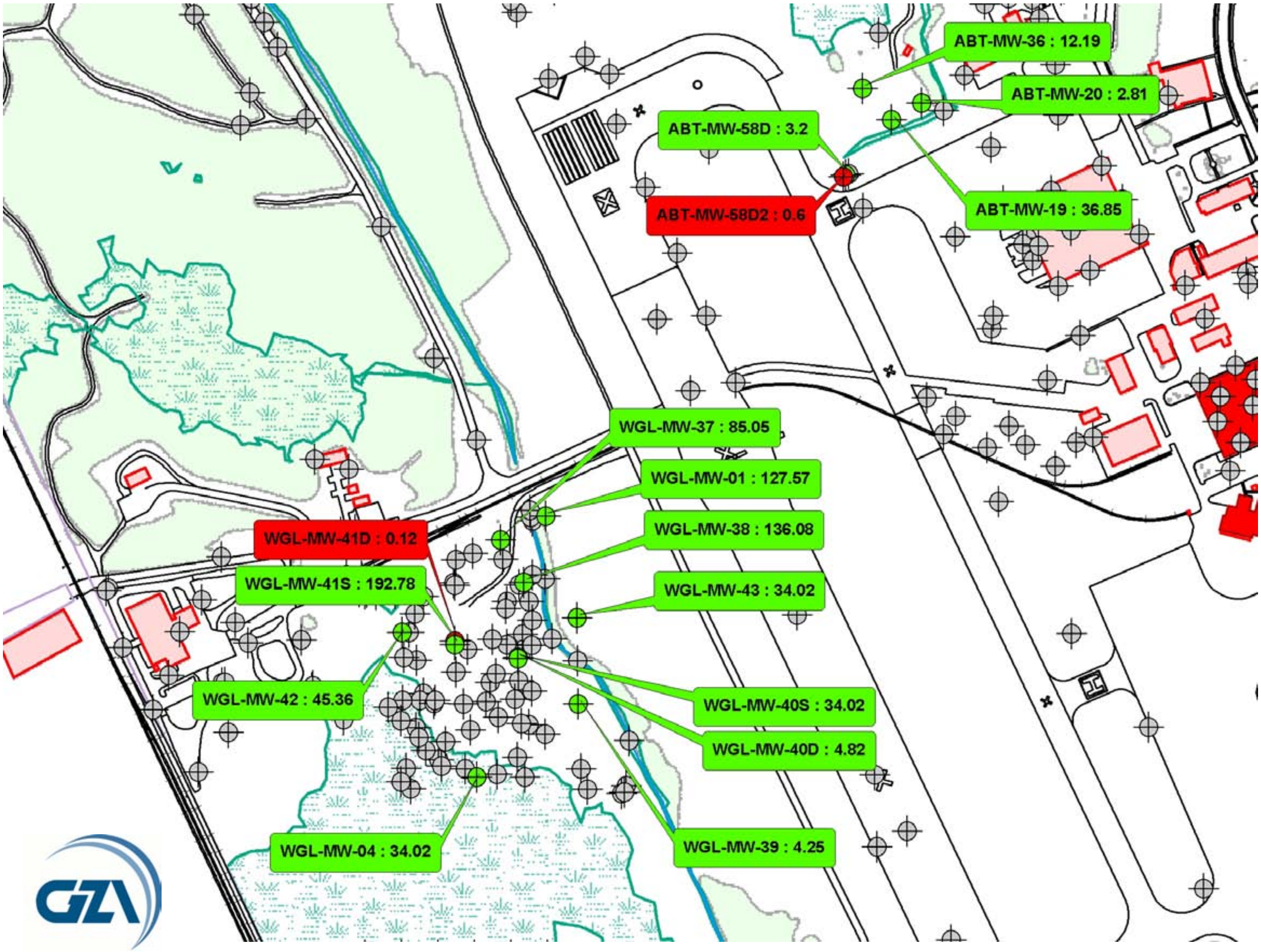

Figure 9 : Hydraulic Conductivity Labels

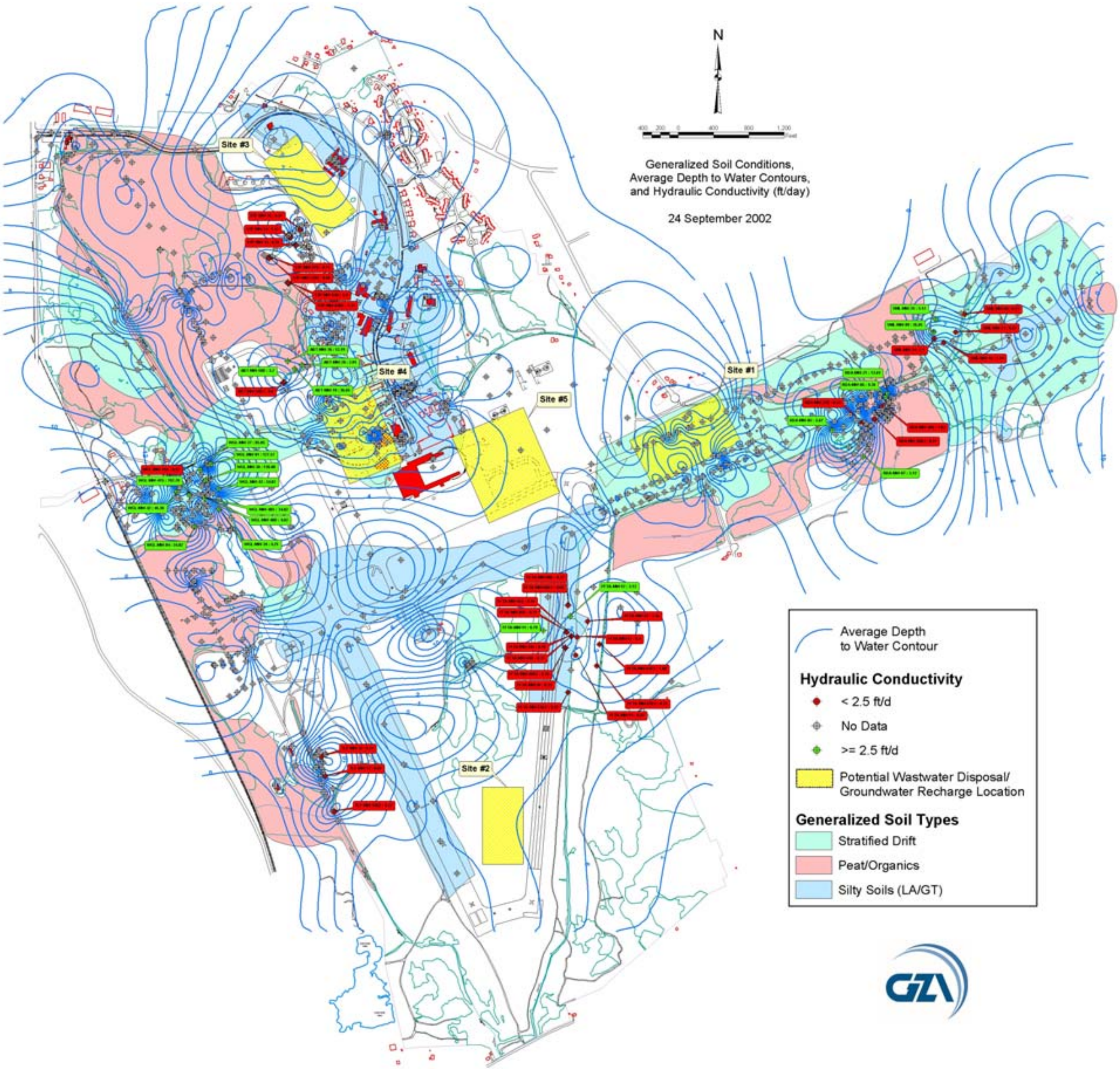

Figure 10 : Combined Data for Site Selection

In addition to the depth to groundwater, saturated thickness, hydraulic conductivity, and soil type, we also evaluated the wastewater disposal/groundwater recharge areas for potential environmental issues. These issues included, but were not limited to, whether or not there was any historical evidence of contaminated soils in the area, and if the Navy was actively working in an area to remediate the subsurface soils. Our desire was not to locate a wastewater disposal/groundwater recharge area in an area of known contamination to avoid such issues as increased excavation or soil disposal costs, and causing the migration of contaminants to other areas of the site.

At this point, our engineers had all of the information that they needed to recommend locations for the wastewater disposal/groundwater recharge areas on the site. Using all of the maps that had been created, they analyzed the data and identified five locations on the site that appeared suitable for disposal of treated wastewater. A summary of the various siting criteria for the five sites is presented below. The more promising of these areas will be studied in greater detail through a follow-up phase of field investigations and in-situ permeability testing to collect more detailed data and more accurately quantify spatial requirements for the wastewater disposal/groundwater recharge areas.

Summary of Wastewater Disposal Siting Criteria

Site No.	Generalized Soil Type	Average Depth to Groundwater (ft)	Depth to Bedrock / Refusal (ft)	Maximum Saturated Thickness (ft)	Environmental / Hazardous Material Permitting Issues
1	SD	2 - 8.5	10 – 20	5 - 15	No
2	UK	3.5 - 4.5	25 – 30	25 +/-	No
3	UK	3.5 - 7.5	12 – 17	3 - 10	No
4	SD	3 -8	15 – 22	5 - 15	Yes
5	UK	4 - 5	12 – 20	5 - 15	Yes

<u>Benefits of GIS</u>

The maps produced using GIS proved to be valuable in many ways. Perhaps most importantly, our client liked the various maps that were produced and was pleased with their aesthetic appeal as well as the clear way in which the data was presented. The maps far exceeded the quality of maps that had been produced in the past for this project. Our client requested additional copies of the maps and actually used them to help "sell" the site to prospective developers.

In addition to pleasing our client and the project developer, the use of GIS on this project also pleased our own staff. As previously mentioned, at the time this work was done, GIS was relatively new to our Company. This project helped open the eyes of many engineers and managers to GIS technology and its capabilities. Some of the maps produced for this project were put on display around the office. Since that time, GIS awareness and use within our office has increased significantly.

Conclusion

Using GIS, we were able to create maps in significantly less time than using our traditional CAD procedures. In fact, if we had used CAD, we would not have been able to complete this work in the time frame that was allotted. Because of the automation afforded by using GIS, our engineers were able to analyze far more data than they would have been able to using our traditional CAD methods. Consequently, the GIS maps were more accurate than they would have been if they had been created in the usual way. This was of considerable value to our engineers in their efforts to identify a suitable location for a wastewater disposal/groundwater recharge area.

This project will continue for many more years, and we anticipate that numerous consultants will be involved along the way. Because a GIS database was created for the site at the very early stages of site redevelopment, there is now an excellent data management, data analysis, and data presentation tool available to all project participants going forward. In addition, since ArcGIS is so widely used within the industry, data exchange between the various design teams should be quick and easy.

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