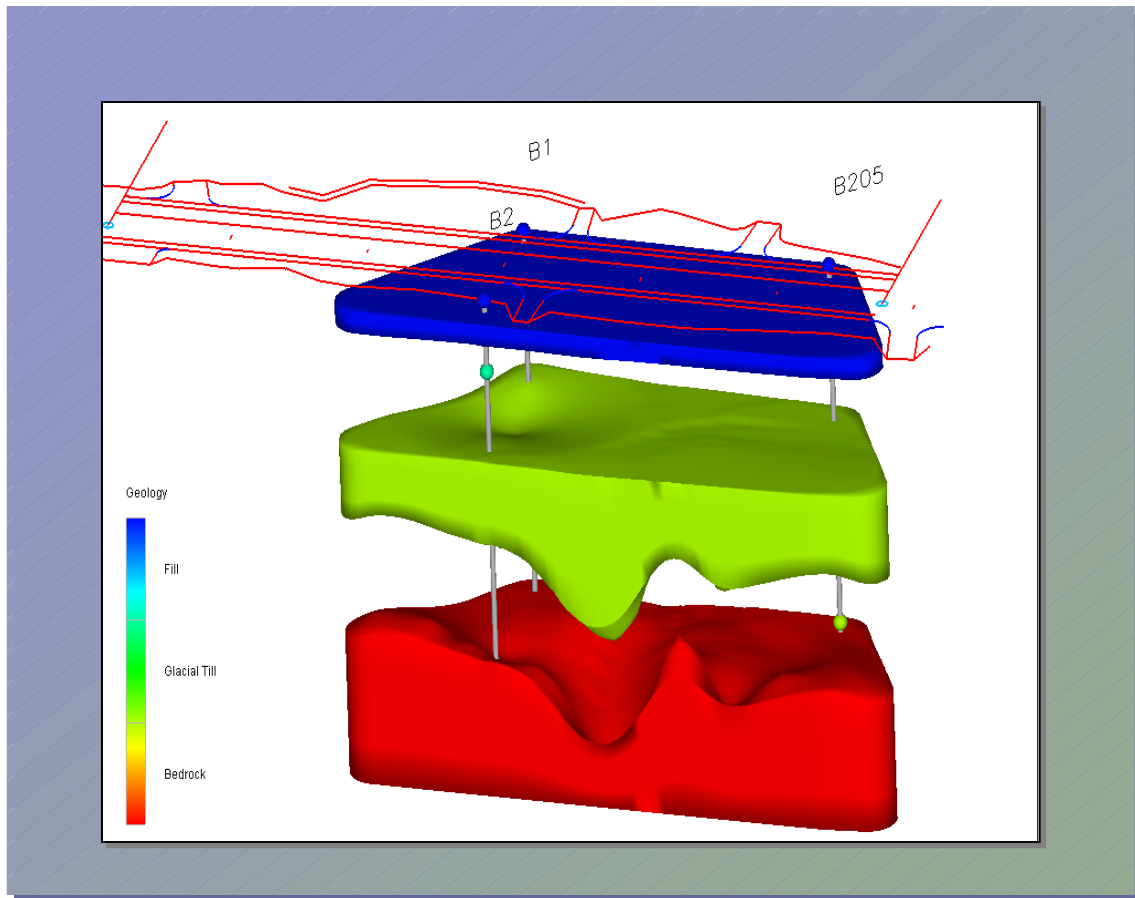


New Hampshire
DOT
Research Record



Development of a Geotechnical GIS for Subsurface Characterization with Three Dimensional Modeling Capabilities

Final Report

Prepared by the New Hampshire Department of Transportation, in cooperation with the U.S.
Department of Transportation, Federal Highway Administration

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<p>The New Hampshire Department of Transportation initiated this research to develop a geographical information system (GIS) that visualizes subsurface conditions three dimensionally by pulling together geotechnical data containing spatial references. It incorporates several geotechnical projects ranging in size from a fairly small roadway project to a much larger roadway by-pass project. The research procedure encompassed taking subsurface data housed on one of the Department's computer servers and exporting the data as text delimited files into a GIS running a 3D modeling extension. A statewide GIS layer was created to access all the available subsurface data so existing data in close proximity to new projects could easily be recognized. The GIS utilizes the data to observe the existing subsurface conditions three dimensionally. By observing where the least confident data was located, the 3D modeling extension helped to determine where and how many additional explorations were needed to adequately map the subsurface conditions to a defined level of confidence. For each project, soil and bedrock surfaces were identified and the bedrock surface was exported into a CAD system where project cross sections were drawn depicting the bedrock depths along the new roadway centerline. The results of the research indicated that a GIS containing existing subsurface data running a 3D modeling extension could adequately map bedrock surface elevations with a minimal amount of additional subsurface explorations. It also demonstrates how new and existing soil density and bedrock surface elevation data can easily be observed three dimensionally on a computer screen.</p>			
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Characterization with
Three-Dimensional Modeling Capabilities**

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ABSTRACT

The New Hampshire Department of Transportation initiated this research to develop a geographical information system (GIS) that visualizes subsurface conditions three dimensionally by pulling together geotechnical data containing spatial references. It incorporates several geotechnical projects ranging in size from a fairly small roadway project to a much larger roadway by-pass project. The research procedure encompassed taking subsurface data housed on one of the Department's computer servers and exporting the data as text-delimited files into a GIS running a three-dimensional (3D) modeling extension. A statewide GIS layer was created to access all the available subsurface data so existing data in close proximity to new projects could easily be recognized. The GIS utilizes the data to observe the existing subsurface conditions three dimensionally. By observing where the least confident data was located, the 3D modeling extension helped to determine where and how many additional explorations were needed to adequately map the subsurface conditions to a defined level of confidence. For each project, soil and bedrock surfaces were identified, and the bedrock surface was exported into a CAD system where project cross sections were drawn depicting the bedrock depths along the new roadway centerline. The results of the research indicated that a GIS containing existing subsurface data running a 3D modeling extension could adequately map bedrock surface elevations with a minimal amount of additional subsurface explorations. It also demonstrates how new and existing soil density and bedrock surface elevation data can easily be observed three dimensionally on a computer screen.

INTRODUCTION

This research was conducted to develop a technique to pull together and visualize all of the state's spatially located subsurface information collected by the New Hampshire Department of Transportation (NHDOT). The spatially referenced data was composed of test borings, test pits and geophysical data that must be combined together for an analysis to occur. Bedrock surfaces must be identified, and the depth to bedrock must be exported into a highway design software package where cross sections can be drawn to depict the depth to bedrock along the new roadway centerline.

Others have attempted to develop, or are in the process of developing, a geographical information system (GIS) for geotechnical data. In 1991 Bakeer et. al. developed a GIS titled "Prototype Geotechnical Information System ⁽¹⁾. This prototype system estimated soil properties and generated synthetic logs and profiles based upon data obtained from earlier soil investigations and depositional history. In 2003, Graettinger et. al. developed a statewide geotechnical-GIS application tool for storing graphical and attribute geotechnical data that was accessible both spatially and through queries for the Alabama Department of Transportation ⁽²⁾. The Geo-GIS was designed with four GIS point layers: Project, bridge, foundation, and soil borings. All the layers were linked to an attribute database and to a hypertext markup language (HTML) page. The state of Rhode Island has proposed research to develop a user-friendly, web-based geotechnical database that will incorporate GIS oriented approaches to the analysis of subsurface data as it pertains to transportation issues. The Federal Highway Administration is also in the process of developing a geotechnical database program that will have GIS components. Although these GIS's contain geotechnical data, they do not bring the data together

three-dimensionally (3D) and are not capable of exporting geological layers into a highway design software package.

METHODS

This research was performed using spatially referenced test boring, test pit and geophysical data housed on the NHDOT Bureau of Material and Research's computer server and incorporating it into a GIS ⁽³⁾. Through a unique 3D modeling extension ⁽⁴⁾, 3D models of the subsurface were developed depicting soil and bedrock depths for several geotechnical projects.

Participants

The principal author is a geologist at the NHDOT. He used data collected by himself and the Earth Scientist staff from the Geotechnical Section of the NHDOT Bureau of Materials and Research. These individuals were selected because they collect and enter test boring data into a networked computer system on a project-by-project basis in the course of their normal duties. The NHDOT drilling staff was responsible for the drilling of the test borings.

Apparatus

To conduct this study a Dell Precision 330 computer with two hard drives totaling 50 GB, 512 MB memory and a Pentium 4, 1.40 GHz processor were used. The computer ran the Windows XP Professional operating system ⁽⁹⁾. Specialized software was not developed for this project. The project utilized "off the shelf" software, which included ArcGIS 9 ⁽³⁾, EVSPro 7.91 ⁽⁴⁾, Excel 2000 ⁽¹⁰⁾, MicroStation V8 ⁽⁵⁾, and gINT 6.1 ⁽⁷⁾. The test borings were conducted with NHDOT drill rigs, and the geophysical surveys were conducted using NHDOT geophysical equipment.

Design

By utilizing the capabilities of a GIS, exploration locations at specific areas throughout the state were tracked. They were displayed as point and line features containing attribute data with project and exploration specific information. A GPJSwitchboard Program ⁽⁸⁾ was written to extract all the test boring and test pit information stored on the Bureau's server, which the GIS used to develop the attribute data for the explorations. The GPJSwitchboard Program allowed the user to combine separate test boring or test pit database files together and then develop a geological hierarchy for the project. By "clicking-on" a button, a specialized text file was written containing the data necessary to develop a 3D model. The text file was then loaded into one of several existing 3D applications that depict the project's subsurface conditions three dimensionally.

Data modification was limited to the renaming of geologic layers. Inconsistent naming conventions were occasionally encountered when multiple Earth Scientists worked on the same project and classified the soil and rock samples differently and independently. The data was statistically analyzed using kriging statistics before it was visually displayed. A kriging analysis is a weighted moving average interpolation that minimizes the estimated variance of a predicted point with the weighted average of its neighbors. The analysis includes calculating the standard deviation for each estimated point within the model and then using the standard deviation to compute the model's confidence. To change the confidence values displayed within the 3D model, the confidence bounds can be changed to a value that is within a factor of the confidence bound value of the actual depth ⁽⁶⁾.

Based upon information in the exploration databases, the GPJSwitchboard Program created three different types of text files for use in the 3D modeling applications. The first file type was called a geology file (6). It was a point-oriented text file that contained the same number of entries for each exploration location. For explorations where geologic layers were absent or where explorations had not extended deep enough to encounter layers that were known to be present, flags were used to allow for the automated processing of the data. The second file type was called a geology multi-file (6). This file was a surface-oriented text file. This text file contained information on geologic layers, whereby spatial coordinates and depths defined every known point within the layer. Each layer was then stacked upon one another in order of the project's geological hierarchy. This text file format was ideal for including points along geophysical lines that contained depths to bedrock and the different soil layers. The third text file format was called a chemistry file (6). It was used to construct a three dimensional block diagram based upon the soil densities that were derived from the number of blow counts it takes to drive a two foot, split spoon soil sampler, 12 inches with a 140 pound weight. This file type was used to construct a 3D block diagram depicting where the loose and dense soils were located within the limits of a project.

To create bedrock lines on the project cross-sections, 3D contours of the bedrock surface were finalized and imported into a highway design software package. The contoured bedrock surface was saved as a CAD file and loaded into specific highway design software. This software was used to create cross sections depicting the bedrock depths at specific intervals along the proposed roadway centerline.

Procedure

Based upon the design of this project, a procedure was developed to identify, export, and visualize previously collected subsurface data through a structured query language (SQL) program called the GPJSwitchboard Program and a GIS running a 3D modeling extension. Using an exploration's unique northing and easting coordinates, data extracted from individual exploration databases were combined into a single statewide exploration geodatabase. By utilizing the capabilities of a GIS, exploration locations at specific areas throughout the state were tracked over time. To help visualize the locations of the exploration features, other statewide GIS layers were used as base maps. Through a simple "mouse-click", attribute data with project and exploration specific information were displayed within a "pop-up" table. Individual exploration databases were identified and through the GPJSwitchboard Program, geological hierarchies were developed. By "clicking-on" a button, specialized text files were written containing the data necessary to develop a 3D model. The text files were loaded into one of several existing 3D applications and a 3D fence or block diagram of the subsurface was developed using the 3D modeling extension.

Four geotechnical projects were identified through the use of the GIS for the GPJSwitchboard program to work with. The GPJSwitchboard program would be used to combine several exploration databases, develop geological hierarchies and then develop a geology file, a geology multi-file, or a chemistry file for the projects. Once the text files were created, they were loaded into the GIS's 3D modeling extension, and an existing 3D application was used to display the data in three-dimensional form. One geotechnical project used the test boring database program to directly create a pre-geology text file that could be used to display 3D boring locations and layer depths. One geotechnical project included a 3D application that conducted a confidence

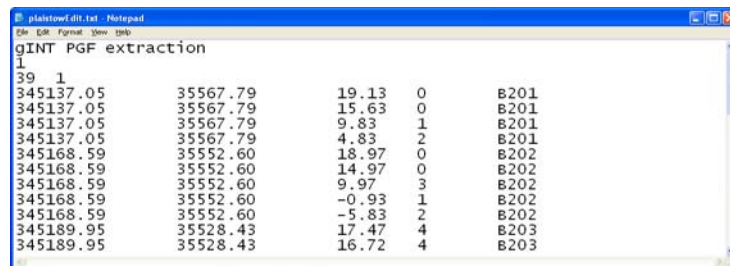
interpretation so additional exploration locations could be identified to increase the accuracy of the model. One geotechnical project included both test boring and geophysical data, and a final geotechnical project included soil density data. For one of the projects, the contoured bedrock surface was exported into highway design software (5). This allowed bedrock lines to be drawn on the project cross-sections at specific locations along the new roadway alignment.

RESULTS

The above procedure was followed on four geotechnical projects conducted by the NHDOT. These projects ranged from relatively small roadway projects to a much larger highway by-pass project. Each project proposed new roadway alignments and structures that require subsurface information for foundation design purposes. These projects were located in Plaistow, Keene, Northwood and Rochester, New Hampshire.

Plaistow Project

In the town of Plaistow, a fairly straightforward project encompassed using the simplest text file form, the pre-geology file. Within the test boring project database program, data is exported through a drop-down menu in the form of a text file that is specially structured to be used by the 3D modeling extension. This text file contains the geographic coordinates of the test borings, the test boring names, and the depths below the ground surface to the different geologic layers (Figure 1). Within the GIS, the 3D modeling extension is initiated, the specially structured text file is loaded, and the test borings are displayed in a 3D viewer (Figure 2). 3D tubes represent the test borings and spheres on the tubes represent depths at which there are changes in the geologic layers. To develop a 3D model and to better understand the subsurface conditions, the pre-geology file is converted to a more complex geology multi-file using the "create geologic surface" and the "layer definitions" in the "Pre Geology (6) module of the 3D modeling extension. Through interactive mouse clicking, a new text file is created where each geologic layer is represented as a surface with spatial coordinates, depth values, and boring numbers for every known point within the layer. Once the more complex text file is created, it is loaded into an application using the "Krig 3D Geology"(6) module, and the viewer displays a 3D subsurface block diagram (Figure 3). A simple mouse driven process is used for zooming and rotating the block diagram. This process is the simplest approach to observing a 3D subsurface characterization within the limits of a project.



```
gINT PGF extraction
1
39 1
345137.05      35567.79      19.13  0      B201
345137.05      35567.79      15.63  0      B201
345137.05      35567.79      9.83   1      B201
345137.05      35567.79      4.83   2      B201
345168.59      35552.60      18.97  0      B202
345168.59      35552.60      14.97  0      B202
345168.59      35552.60      9.97   3      B202
345168.59      35552.60      -0.93  1      B202
345168.59      35552.60      -5.83  2      B202
345189.95      35528.43      17.47  4      B203
345189.95      35528.43      16.72  4      B203
```

Figure 1: Text file sample

Specially structured pre-geology text file, exported directly from the test boring database to be used by the 3D software extension.

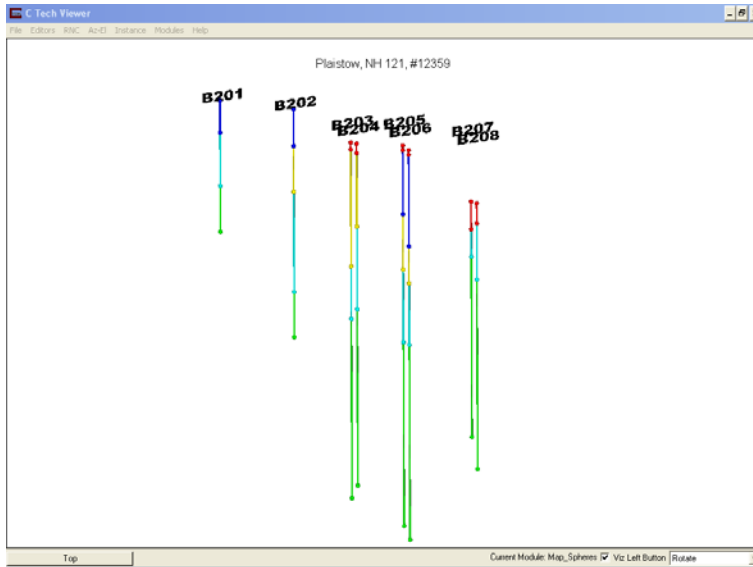


Figure 2: 3D boring logs

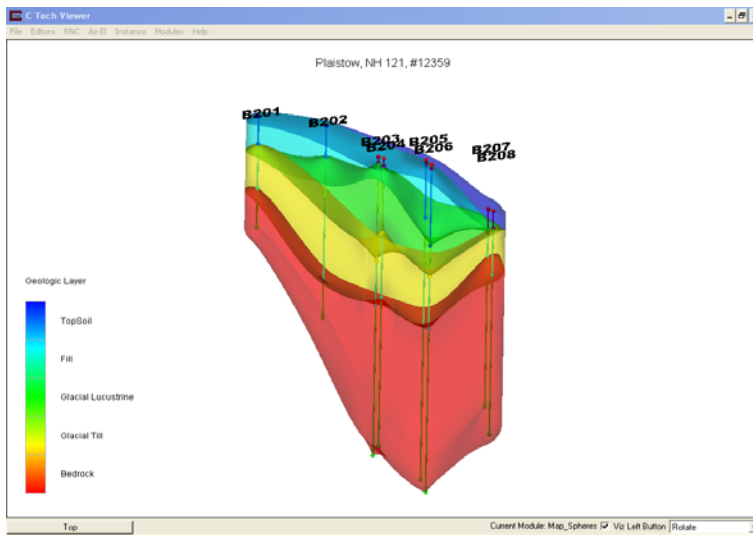


Figure 3: 3D block diagram

3D block diagram of the subsurface conditions and boring logs

Keene Project

Another approach is to use a slightly more advanced text file format. This text file can be developed using the GPJSwitchboard Program (Figure 4). This approach was used for a large by-pass project located in the city of Keene. Several test boring databases were selected and a

geology file was created having the same number of entries for each boring location regardless of what the boring encountered or its depth. The flag value of 1×10^9 was used to represent geologic layers not encountered in the boring and the flag value of -1×10^9 was used to represent geologic layers that were expected to be encountered if the test boring would have gone to a greater depth (Figure 5).

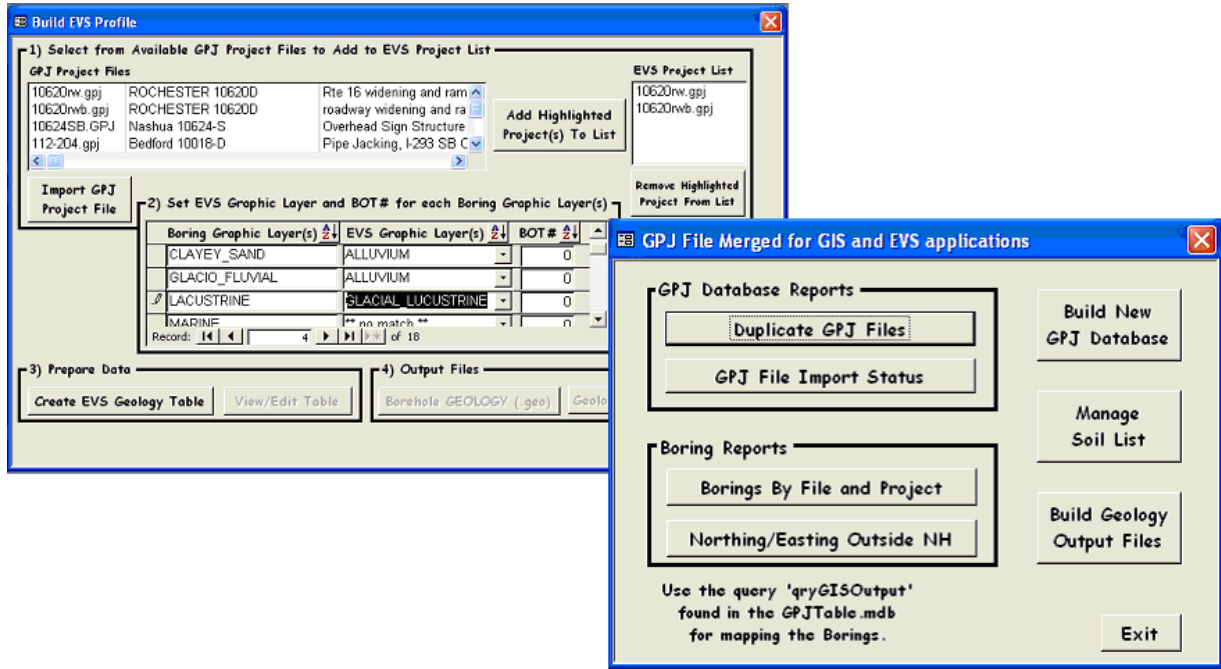


Figure 4: GPJSwitchboard program screens

GPJSwitchboard program that was developed using structured query language (SQL) statements to extract data from the test boring databases, to develop geological hierarchies, and to build specialized text files.

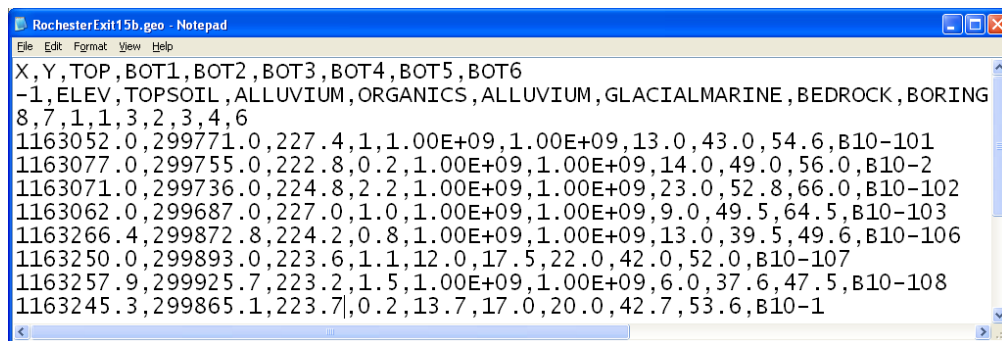


Figure 5: Geology file format

This is a geology file exported directly from the test-boring database. $1.00E+09$ is a flag that tells the program that this is a missing layer in this boring.

Using the “Map Spheres”⁽⁶⁾ module, the 3D modeling extension is able to display 3D boring tubes in the viewer. Using the “Krig 3D Geology” module, a 3D block diagram is created representing the project’s subsurface conditions. Digital orthoquads and the project’s new highway alignment were draped over the surface of the 3D model to help visualize the project’s location (Figure 6).

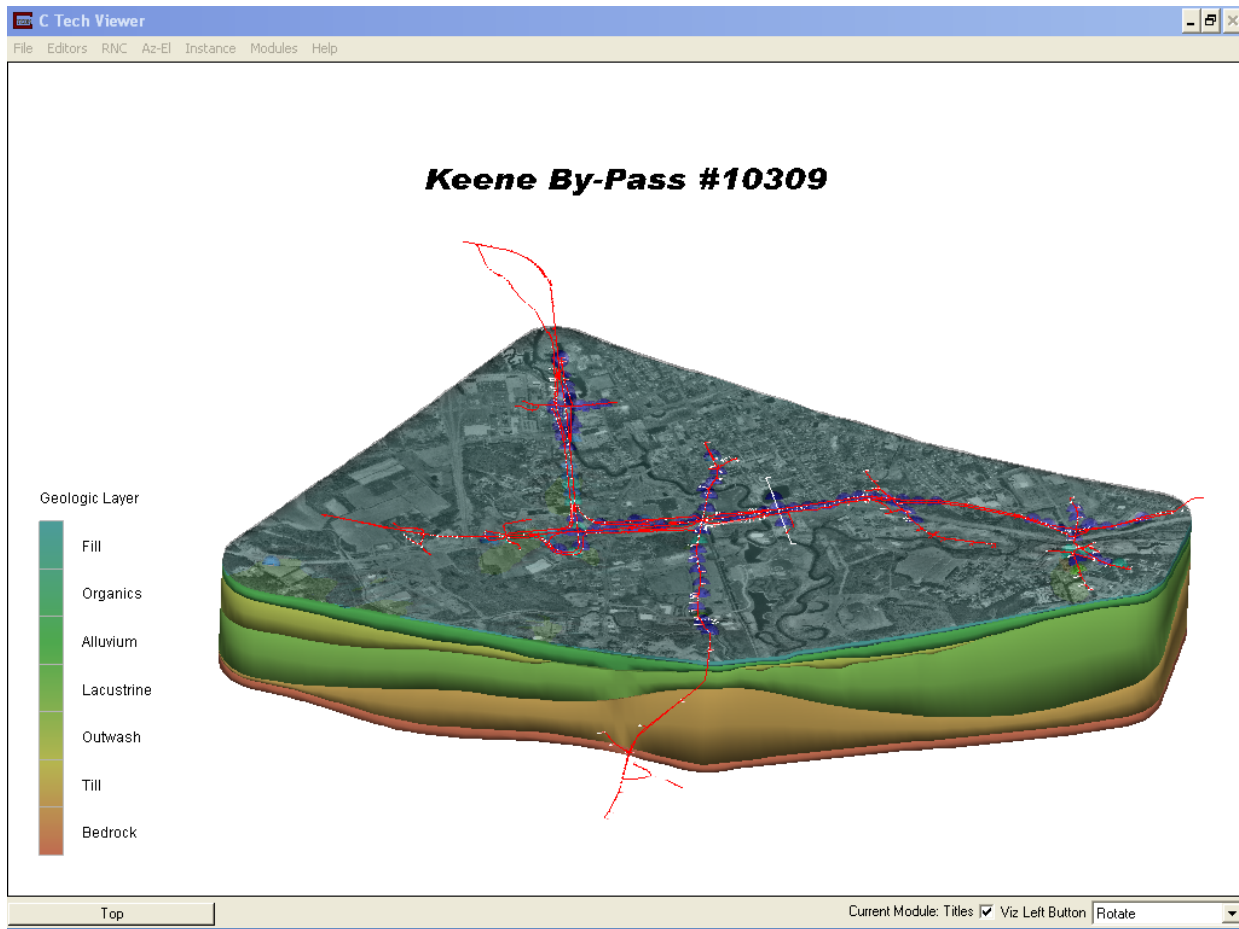


Figure 6: 3D project visualization.

3D block diagram of the subsurface conditions with boring logs, digital orthoquad, and new highway alignment draped onto the surface.

To observe the subsurface conditions directly beneath the new highway alignment, the model is viewed at a smaller scale, and fence diagrams representing the areas between the test borings are developed utilizing several different modules. Utilizing the “Krig Z”⁽⁶⁾ module and additional kriging parameters, a confidence interpretation of the bedrock surface is displayed below the fence diagrams (Figure 7). At this scale, pinch outs and depths to different geologic layers at

specific locations along the alignment can be observed and compared to the displayed confidence interpretations below.

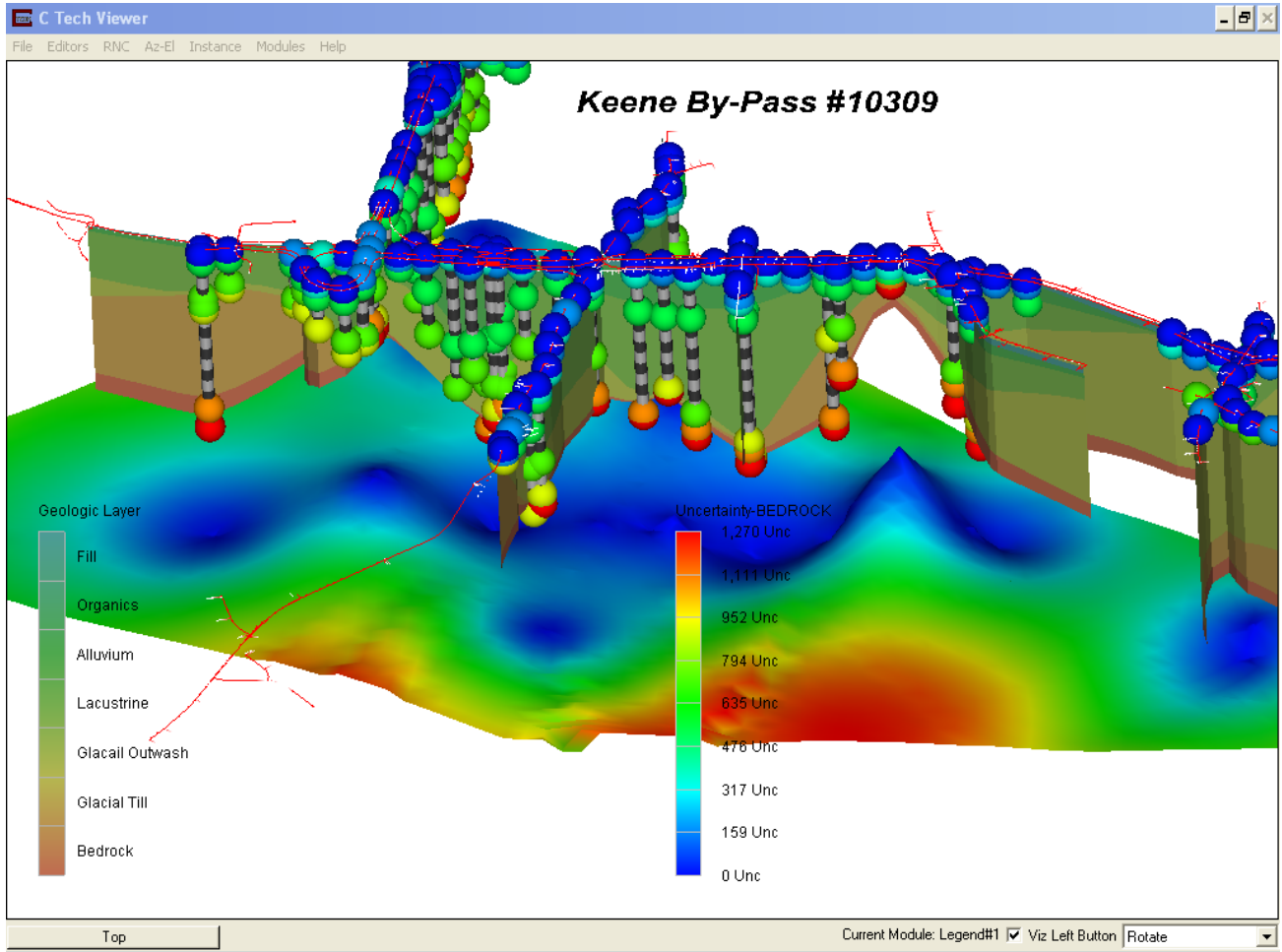


Figure 7: Keene 3D fence diagrams

Keene 3D fence diagrams with bedrock confidence levels displayed below.

To isolate the bedrock surface over the entire area of the project, a 3D block diagram is used with an exaggerated z-scale, the above lying soil layers turned off, and contour lines are draped onto the bedrock surface (Figure 8). The contours were saved as a CAD file using the “Write DXF”⁽⁶⁾ module and then loaded into highway design software where cross sections depicting the bedrock depths at specific intervals along the proposed highway centerline were developed. From these cross sections, bedrock quantities were calculated, and highway cuts and fills were designed (Figure 9).

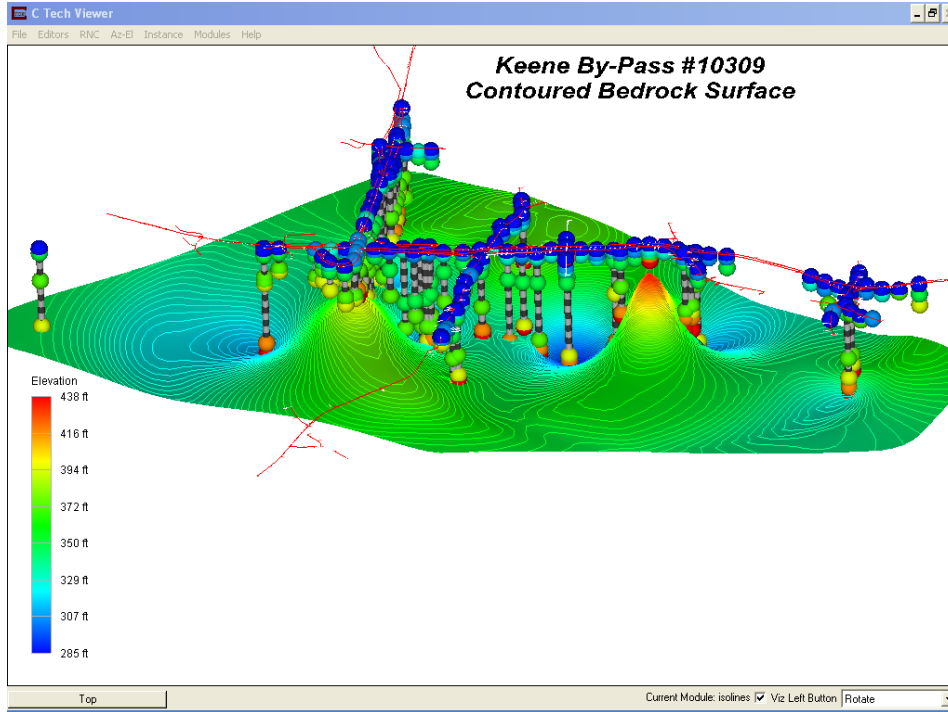


Figure 8: Contoured bedrock surface

Contoured bedrock surface from the Keene by-pass project

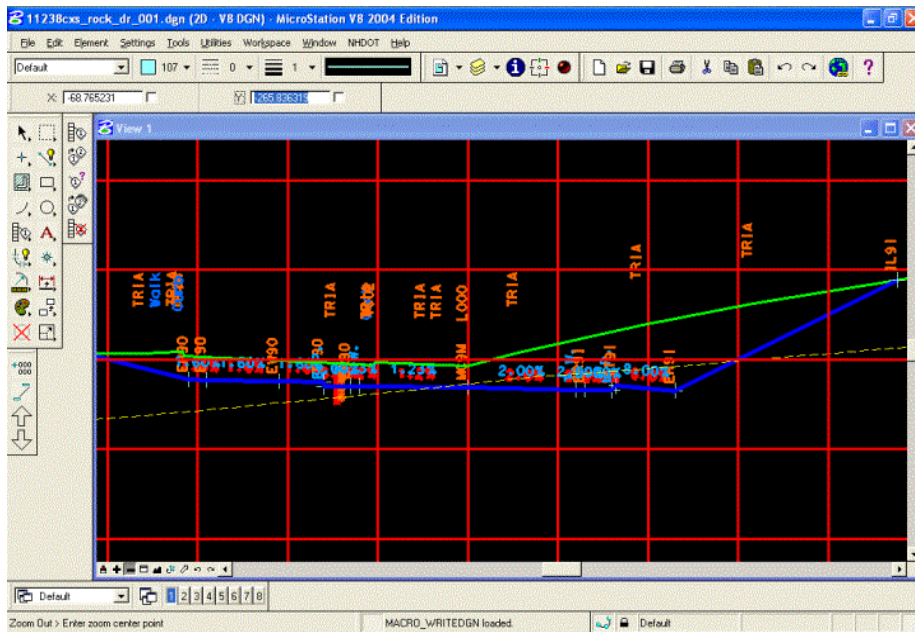


Figure 9: Cross section

Cross section developed from the bedrock contour lines and displayed in a CAD program for the Keene project.

Northwood Project

In the town of Northwood a small roadway project combined a geophysical investigation with traditional test borings. Resistivity imaging (Figure 10) and ground penetrating radar were used to augment the test boring data in an attempt to help finalize the location of a tunnel crossing under a heavily traveled road. The text file, utilizing the geology multi-file format, was created using the GPJSwitchboard Program and a geological hierarchy was created (Figure 11). This format is the same file format that was created using the "create geologic surface" in the "Pre Geology" module for the Plaistow project described earlier. This text file represents each geologic layer as a surface with spatial coordinates and depth values for every known point within the layer. Through the use of a global positioning system, spatial coordinates were collected along the geophysical lines, and the depth to bedrock was calculated at specified distances along each line. Using a text editor, data from the geophysical lines was incorporated into the geology multi-file. Figure 12 displays an exploded 3D block diagram utilizing the test boring and geophysical data contained in the geology multi-file. Based upon the subsurface conditions displayed in Figure 12, it was determined that the area to the right of borings B1 and B2 would be the ideal location for the proposed tunnel crossing.

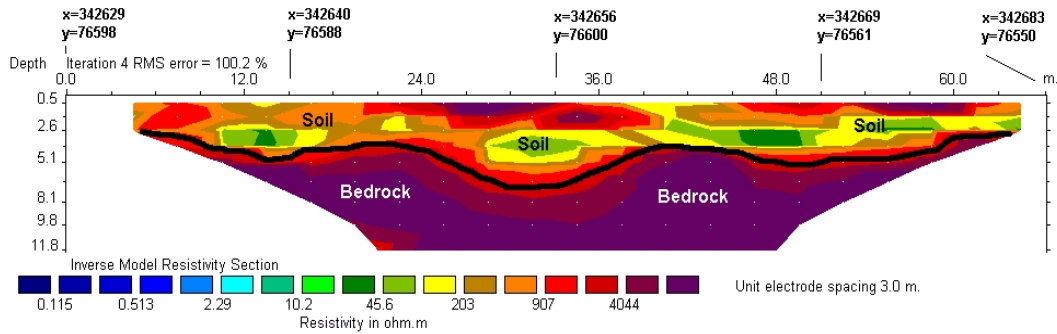


Figure 10: Geophysical profile

Geophysical profile for the Northwood project.

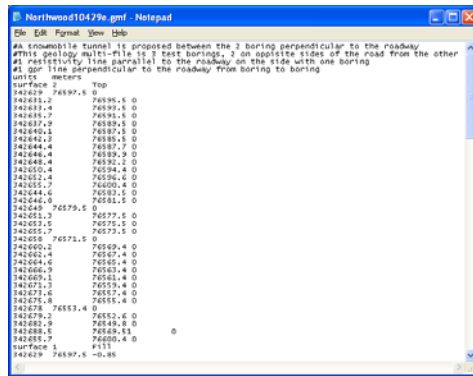


Figure 11: Geology multi-file text file

The more complex geology multi-file representing geologic layers or surfaces.

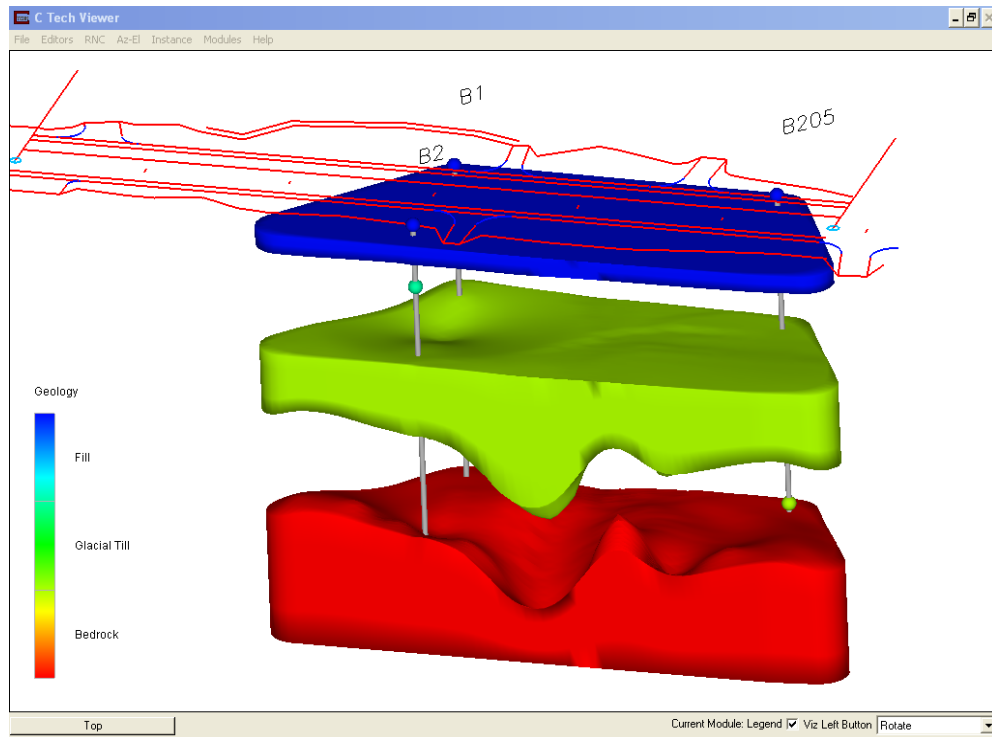


Figure 12: Exploded 3D block diagram

Exploded 3D block diagram of the geologic layers based upon the test boring and geophysical data.

Rochester Project

In the city of Rochester, a subsurface investigation was conducted for a new bridge over the Cocheco River. By using the GPJSwitchboard Program, another text file format was created (Figure 13). This text file format makes it possible to construct a 3D block diagram based upon the soil densities that are derived from the number of blow counts it takes to drive a two foot, split spoon soil sampler 12 inches with a 140 pound weight. The GPJSwitchboard Program extracted this data from the test boring databases and a kriging analysis was done on the data. Figure 14 displays a 3D block diagram based upon the soil densities that are contained in this text file. The locations of the low or high-density soils can easily be observed within the block diagram. This model was used to help determine the type and depth of a new bridge foundation based upon the soil densities collected during the subsurface investigation.

Rochester.csv - Notepad

File Edit Format View Help

X	Y	Sample Elevation	Blow Counts	Boring ID	Top Elevation
1207					
1163572.14	290771.11	-2	6	BDP1	230.4
1163572.14	290771.11	-4	16	BDP1	230.4
1163572.14	290771.11	-6	18	BDP1	230.4
1163572.14	290771.11	-8	7	BDP1	230.4
1163572.14	290771.11	-10	12	BDP1	230.4
1163572.14	290771.11	-12	23	BDP1	230.4
1163572.14	290771.11	-14	16	BDP1	230.4
1163572.14	290771.11	-16	7	BDP1	230.4
1163572.14	290771.11	-21	8	BDP1	230.4
1163572.14	290771.11	-26	10	BDP1	230.4
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1169585.16	284671.23	-18	3	B101	196.64
1169585.16	284671.23	-20	2	B101	196.64
1169254.02	284890.99	-2	7	B102	192.06
1169254.02	284890.99	-4	8	B102	192.06

Figure 13: GPJS text file

A text file format created by the GPJSwitchboard program that includes the split-spoon sampler blow counts.

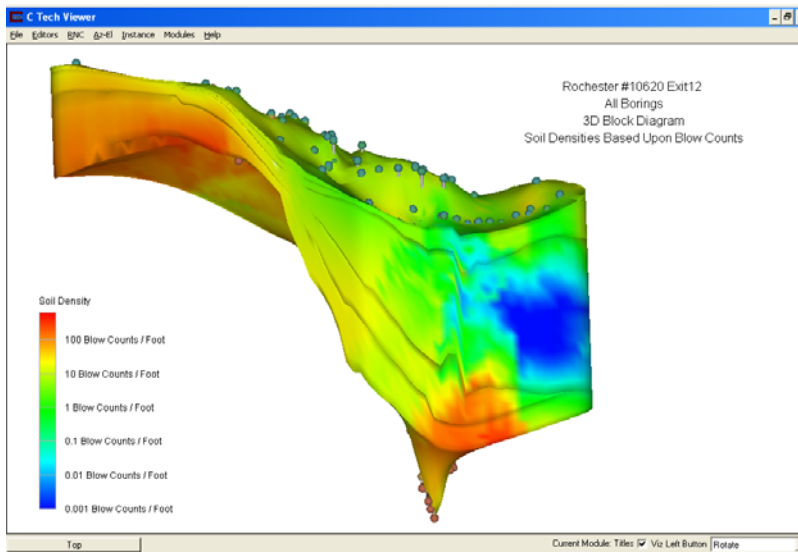


Figure 14: 3D block diagram

3D block diagram looking east over the Cocheco River showing the locations of the soft and hard soils.

Using the GIS

Within the GIS, exploration locations are represented as point or line features. These features are updated on a monthly basis to include recently completed geotechnical projects. To help locate existing project areas throughout the state, the statewide GIS layers of “Towns”, “Hydro_All” and “Routes” are used as base maps for the exploration point and line features (Figure 15). When new geotechnical projects are initiated, the GIS is checked for locations where existing subsurface data are already available. By clicking on a specific feature, a table opens up and attribute data about the exploration can be viewed. The GPJSwitchboard Program is then used to combine exploration databases, to develop geological hierarchies, and to write the specialized text files. By utilizing the existing subsurface data, the 3D modeling extension’s fence, block, and confidence diagrams can help determine the optimal amount of additional subsurface explorations required to achieve the desired level of confidence for an upcoming project.

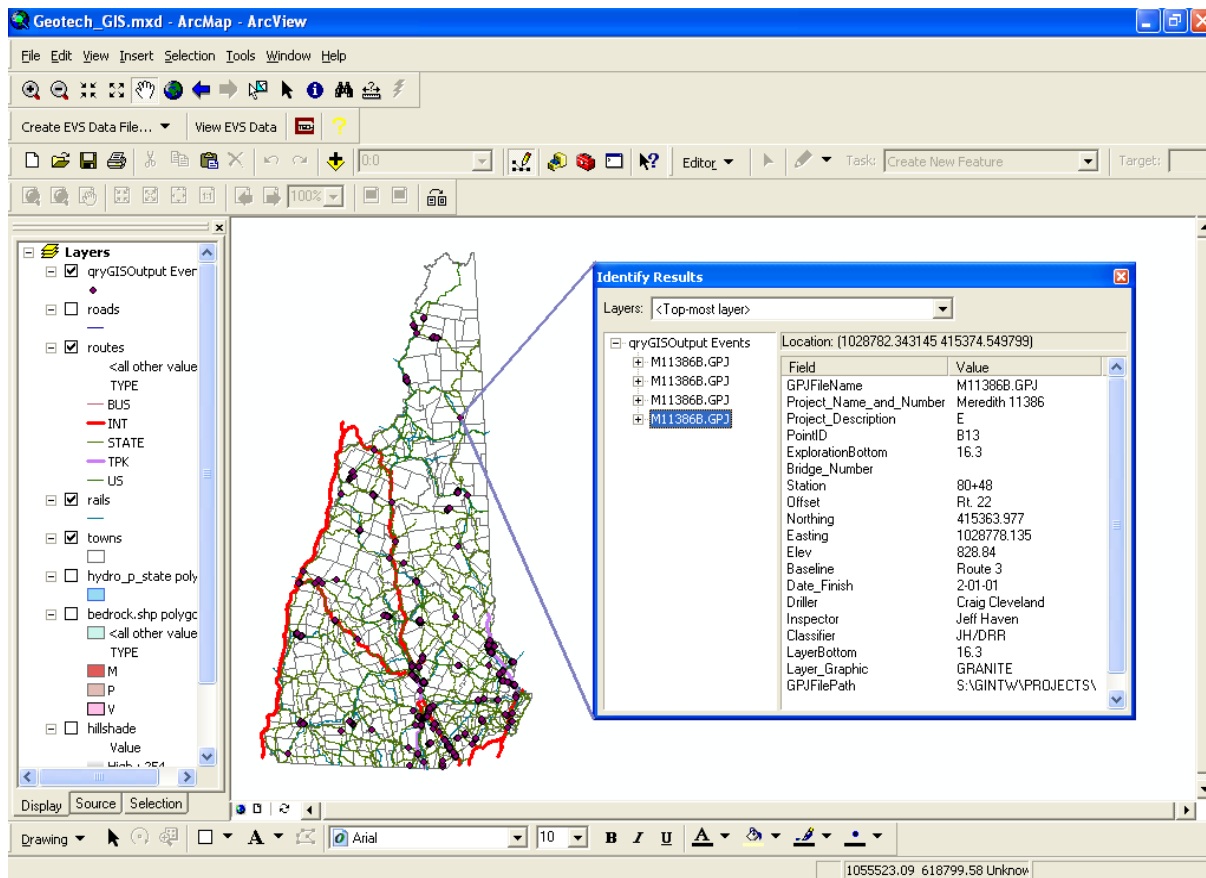


Figure 15: GIS file

Statewide map of existing exploration locations displaying the point or line features with town lines, hydro, and routes as a base map.

ACCURACY

The 3D modeling extension's capability of predicting bedrock depths was demonstrated by looking at a small subset of the Keene test boring data. A bridge project on NH Route 9 over West Street was included within the larger Keene by-pass project. A subsurface investigation for this bridge was conducted, which included both preliminary and final stages of drilling. The preliminary stage included 16 test borings that were 100 to 300 feet apart. After the preliminary stages of drilling were completed, a 3D block diagram was created depicting the subsurface bedrock elevations and a bedrock uncertainty map at the elevation of the bedrock surface (Figures 16 & 17). As expected, the areas with the least uncertainty surround the areas where the test borings encountered bedrock, and the areas of highest uncertainty were the areas where bedrock was not encountered.

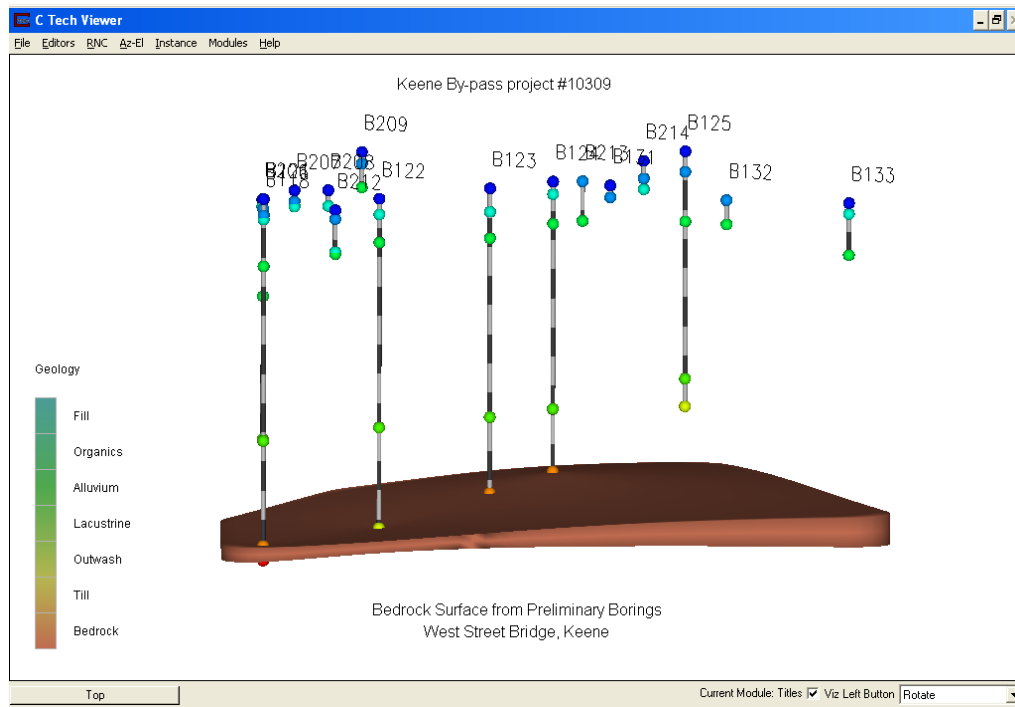


Figure 16: 3D Bedrock Surface Diagram

Bedrock surface diagram for the West Street Bridge Project after the preliminary stage of drilling.

To check the uncertainty and to see how well the 3D modeling extension created the 3D block diagram, eight additional test borings were drilled at the actual locations of where the new bridge foundation will be located. They ranged from 30 to 100 feet apart from one another and covered an area of approximately 30,000 square feet. A couple of the final test borings were within 30 feet of the locations of a few of the preliminary test borings (Figure 18).

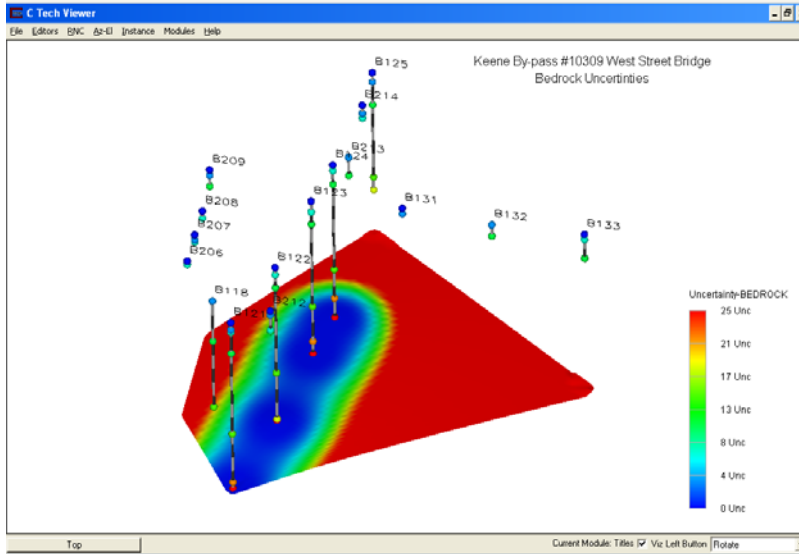


Figure 17: 3D Bedrock Uncertainty Diagram

Bedrock uncertainty map for the West Street Bridge Project after the preliminary stage of drilling.

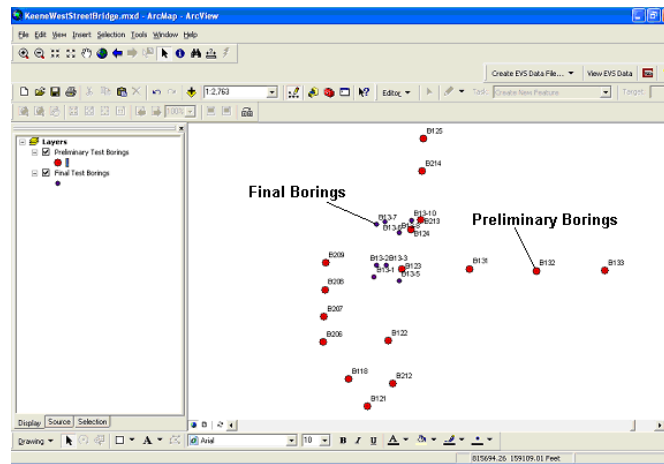


Figure 18: Boring diagram

Layout of the preliminary (red) and final (blue) test borings

A new block diagram was created from the test boring data collected during the final stage of drilling and was superimposed upon a block diagram that was developed from the preliminary stage of drilling (Figure 19). The block diagram created from the final stage of drilling displays greater variations in its bedrock surface as compared to the bedrock surface that was created from the preliminary stage of drilling. Figure 20 displays bedrock contour lines that were developed from the preliminary test boring data and show a one-foot variation in bedrock depth over an area of approximately 30,000 square feet. According to these contours, the final test borings should have encountered bedrock between the elevations of 360.5 and 361.5 feet. The

final test borings actually encountered bedrock between the elevations of 356.1 and 369.8 feet, and they were outside the range of the bedrock surface elevations derived from the preliminary test boring data. At certain locations, the actual bedrock elevation was lower by as much as three feet, and at other locations, it was higher by as much as eight feet.

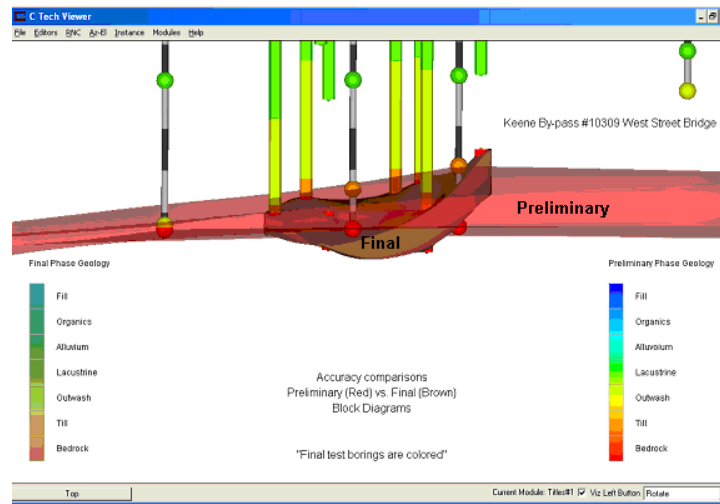


Figure 19: Final 3D bedrock surface diagram

Final 3D bedrock surface superimposed upon the preliminary bedrock surface.

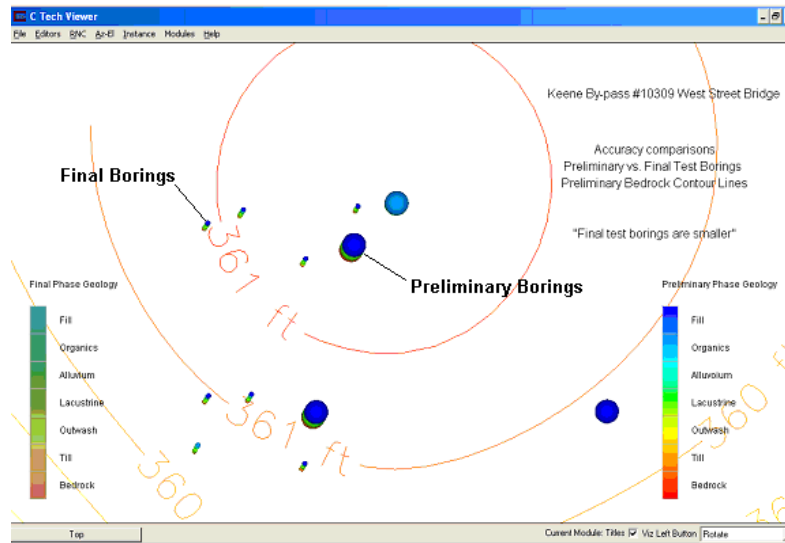


Figure 20: Bedrock contour diagram

Contours of the bedrock surface that are based upon the preliminary test borings. The large spheres are the preliminary test borings and the small spheres are the final test borings.

If the sole reason for conducting the final stage of test borings was to accurately map the bedrock surface elevation in the vicinity of the new bridge location, then how many of the eight additional test borings were actually required? Figures 21 and 22 display cases where two and four of the final eight test borings were used in conjunction with the preliminary test boring data to develop new bedrock surface contours. To check the accuracy of the new bedrock surface contours, the elevations at which the remaining final test borings encountered bedrock were used.

Table 1 displays the differences between the new bedrock surface contours and the elevations at which the remaining final test borings encountered bedrock. When the contours were based upon the preliminary test boring data and bedrock elevations from one final test boring on each bridge abutment, an elevation difference of 6.4 feet or less was obtained. When the contours were based upon the preliminary test boring data and bedrock elevations from two final test borings on each bridge abutment, an elevation difference of 4.8 feet or less was obtained. This example demonstrates that the 3D modeling extension was capable of mapping the bedrock surface elevation to within 6.4 feet of its true value with two additional test borings. To determine the quantity of additional test borings required to supplement the preliminary test boring data, the extent of any variations in the bedrock surface elevation and the experience of the project engineer must be taken into consideration.

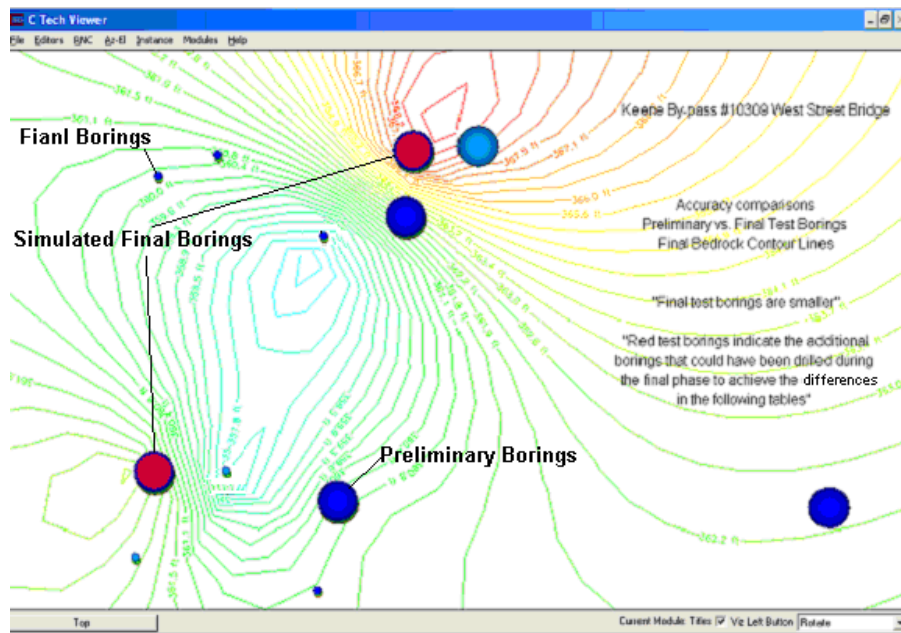


Figure 21: Contour Development Diagram

Two of the eight final test borings (red) are simulated as being drilled and contours are developed based upon the preliminary borings and the additional two borings.

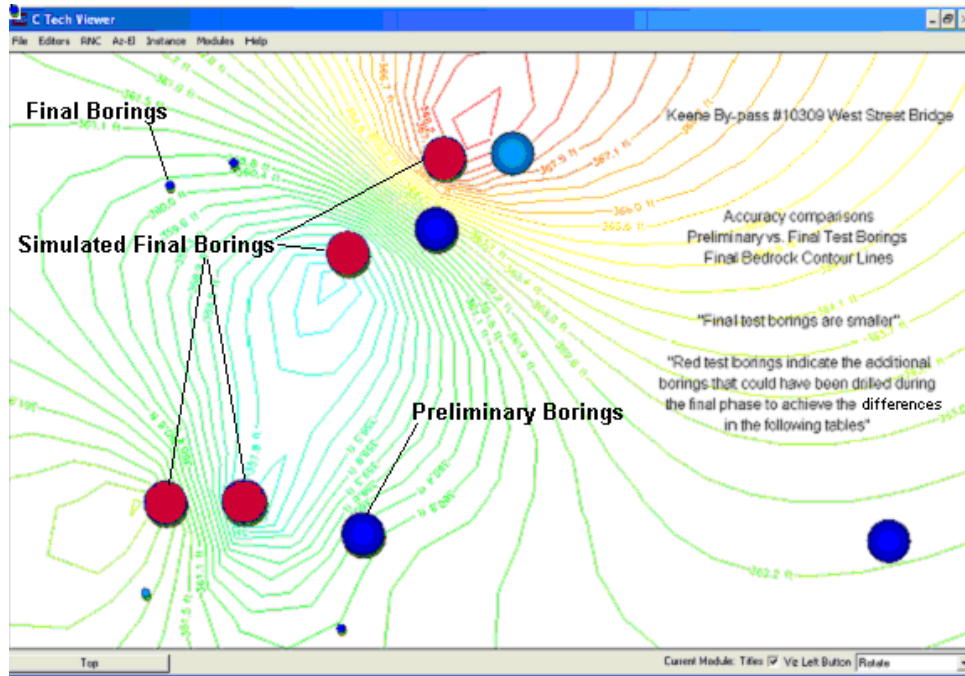


Figure 22: Contour Development Diagram

Four of the eight final test borings (red) are simulated as being drilled and contours are developed based upon the preliminary borings and the four additional test borings.

Table 1: Bedrock Elevations

The differences between the actual bedrock elevations taken from the final test borings and the bedrock elevations based upon the contours developed from the preliminary and simulated test borings.

Table 1

**Contours Based upon Preliminary Borings
& 2 Selected Final Borings**

<u>Final Boring</u>	<u>Actual Elevation</u>	<u>Contoured Elevations</u>	<u>Difference</u>
B13-6	364.2	362.9	1.3
B13-7	360.2	361.8	1.6
B13-8	356.1	362.5	6.4
B13-1	360.2	362.9	2.7

Table 1 cont'd

B13-3	356.3	362.3	6
B13-5	365.5	361.7	3.8

**Contours Based upon Preliminary Borings
& 4 Selected Final Borings**

<u>Final Boring</u>	<u>Actual Elevation</u>	<u>Contoured Elevations</u>	<u>Difference</u>
B13-6	364.2	360.6	3.6
B13-7	360.2	360.2	0
B13-1	360.2	362	0.2
B13-5	365.5	360.7	4.8

DISCUSSION

It is not possible to conduct explorations everywhere within the limits of a project. For this reason, interpretations of the subsurface must be made at areas between the explorations. As the number of explorations increase, the 3D model's confidence values improve, resulting in a better subsurface interpretation. If an accurate depth to bedrock or precise soils information is required at a specific location, then this location should be explored and the 3D modeling extension should not be relied upon for this information. Additional test borings or geophysical explorations can be added until the 3D modeling extension is predicting the depths around this area to a confident level. When explorations are placed outside of this area, they only help to define the geological surfaces over the entire area of the project and not over the specific area of interest.

It can be said that "garbage-in" leads to "garbage- out". Accurate interpretations must be made from the test boring, test pit, and geophysical data before they are input into the 3D modeling extension. When geophysical explorations are conducted, they are performed along a line containing many points. Each point contains depth values to the different geologic layers that help to improve the confidence values within the model. The confidence interpretations can be used to demonstrate how well the 3D modeling extension was interpreting the subsurface, or they can be used to help locate additional explorations that will improve the model's confidence. When bedrock elevations have large variations over short distances or when the preliminary borings are a long distance from the location of the final borings, a greater number of explorations will be required to achieve the desired level of confidence during the final phase of drilling.

A pre-geology file can be directly exported from a test boring database and works well when the number of test borings is limited. A 3D model can then be created from the pre-geology file by converting it into a geology multi-file by picking depths for each geologic layer on every test boring tube displayed within the model. Confusion is created when large quantities of test borings are imported because it is difficult to simultaneously pick soil or bedrock depths on every test boring tube. When geologic layers are pinching out and geophysical explorations have not been conducted, the geology file format works well. When geophysics is included as part of the subsurface investigation, a text editor must be used to add the geophysical data into the

geology multi-file. This type of text file takes the greatest amount of time to develop because every point on each geological layer that was identified through geophysics must be entered into the text file.

IMPLEMENTATION

The authors recommend that training be given to key members of the geotechnical staff on developing 3D modeling applications through the software manufacturer. It is also recommended that the 3D modeling extension and the GIS software be maintained on a yearly basis through annual maintenance contracts. Finally, it is recommended that the Geotechnical GIS with 3D modeling capabilities be implemented for routine use by the geotechnical staff at the Bureau of Materials and Research. The implementation of the GIS can be accomplished through one of several different techniques.

The first approach could be done in conjunction with the Department's ArcIMS implementation. ArcIMS is an Internet based GIS that enables users to access GIS information with a web browser. As a GIS layer, all the point and line exploration features and their associated data throughout the state can easily be viewed. Specific project databases can be identified, and through the GPJSwitchboard program, specialized text files can be developed. By utilizing the Bureau's one license for the 3D modeling extension and ArcGIS, 3D modeling applications can be developed as explained within this report.

A similar approach would be to install ArcExplorer, a free GIS reader, on individual computers throughout the Bureau. The same point and line exploration layer can be viewed and specific project databases can be identified, and through the GPJSwitchboard program, a specialized text file can be developed. As mentioned above, the Bureau's one license for the 3D modeling extension and ArcGIS can be used to develop 3D modeling applications as explained within this report.

A final approach for implementation could be to buy multiple copies of ArcGIS and the 3D modeling extension and install these on either individual desktop computers, the computer network or a combination of the two. Utilizing the same approach as mentioned above, the point and line exploration features and their associated data throughout the state can be loaded into the GIS and easily be viewed. Specific project databases can be identified, and through the GPJSwitchboard program, a specialized text file can be developed for use in 3D modeling applications.

CONCLUSION

The development of the Geotechnical GIS with 3D modeling capabilities has proven to work well, and its use and maintenance requires little additional work. A new database was not developed and very little additional data entry was required. Existing data already contained on the Bureau's server was the source of information. Through the GPJSwitchboard Program, the database tables extruded from the test boring databases are updated on a monthly basis to include the newest statewide subsurface information. Once an update has occurred, a new statewide subsurface exploration layer is created and the existing exploration locations and attribute data are visible within the GIS viewer as point and line features. New projects initiated in close proximity to the existing subsurface data can easily be recognized, and through a "mouse click",

the existing data can be displayed in the form of a table. Specific test boring databases are identified, and through the GPJSwitchboard Program, a geological hierarchy and a specialized text file is developed. The 3D modeling extension is then used to view the existing data and to help determine where and how many additional explorations are needed to achieve the desired level of confidence for the project. The Geotechnical GIS with its 3D modeling capabilities is a powerful tool. It helps to optimize subsurface exploration programs by rapidly assessing potential subsurface conditions at areas where information already exists.

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