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Harnessing the Power of Relational Databases for Managing Subsurface Geotechnical and Geologic Data

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ABSTRACT

Knowledge of surface and subsurface geology as well as geotechnical properties is fundamental to the planning and development of transportation systems. Through dynamic linkage of readily available spatial geographic information system data and subsurface borehole data stored in a relational database, we have created a spatially referenced, digital catalog of borehole data for two pilot areas in Rhode Island. The borehole database is populated with data from Rhode Island Department of Transportation geotechnical reports and supplemental data from the U.S. Geological Survey groundwater site inventory system as well as local storm-water and sewer projects. Most of these data were previously stored in paper format, making historical or inter-project data comparisons very difficult, if not impossible. Consolidation of these data in a single relational database yields two primary benefits: Historical data are readily accessible for review and, therefore, can be easily incorporated into the planning stages of new projects, and sophisticated analysis of the region becomes possible with access to data from multiple projects with both spatial and temporal layers. Geologic data include bedrock geology, surface outcrops, unconsolidated materials, soil type, topographic and orthophotographic base maps, and location of boreholes and wells. Subsurface data include land-surface elevation, depth to water table, depth to bedrock, and presence or absence of fill, high and low blow-count zones, and organic sediment. The digital catalog is distributed on a CD-ROM that includes ArcView® project files and an Access® relational database. The borehole data are also accessible through the Internet (http://geo.uri.edu/borehole/index.asp), with public retrieval access for all users but data entry restricted to registered users only.

INTRODUCTION

Knowledge of surface and subsurface geology is fundamental to the planning and development of new or modified transportation systems as well as to other land-use issues. The drilling and collection of borehole information therefore is an essential (and often expensive) initial step in highway and environmental projects. In developed regions, such as the northeastern United States, most transportation corridors have an extensive history of drilling because of the widespread construction and maintenance of bridges, roads, rail systems, and sewer systems. After their initial acquisition and use, however, borehole and well log data too often are hidden in file cabinets, where they typically are not readily available for use in future projects. This results in duplication of the drilling and collection of borehole data, at considerable added expense. Thus, ready access to a database of previous drilling data not only would be a vital information source but also would permit substantial cost savings.

Ideally, such a repository of borehole data would contain a record of all recent drilling that had occurred in the state (i.e., within the last 25 years or so), stored in an internally consistent format that included relevant information about the subsurface geology, hydrology, and rock mechanics. Moreover, this library would be easily accessible (i.e., a website accessible to the public) and capable of incorporating new subsurface data as it became

Table 1. *Spatial data included as shape files in the digital borehole database.*

Geologic Layers	Cultural Layers	Environmental Layers	Transportation Layers
Well-boring data	Study area	Public water supply	Roads
Depth to bedrock	Streams	Wetlands	Railroad tracks
Bedrock geology	Ponds	Land use	Bike paths
Glacial deposits	Town boundaries	Greenway corridors	Bridges
Geologic contacts	Town names	Community and non-community well-head protection areas	
Bedrock outcrops	7.5' Quadrangle boundaries	Hazardous waste site	
Soils	Topographic quadrangles	Leaking underground storage tanks	
Groundwater reservoirs	Digital orthophotographic quadrangles	Rhode Island point discharge elimination system	
Groundwater recharge areas	Historic sites	Flood zones	
	Historic districts		
	Geodetic markers		
	Benchmarks		

available. Unfortunately, this rarely is possible: drilling records are often lost or stored in inaccessible places, and driller's logs vary widely in terms of their detail and format. Records and accompanying location maps may become separated, or crucial location information may simply be lacking. Borehole records for a site of interest may reside in disparate places, making it difficult to compile information, and duplicate records may not be available, making it hard to borrow or copy them.

Commercially available software, such as gINT®, is used by some engineering companies and permits storage of borehole data (as well as associated field and laboratory measurements) in a database, but these data are not part of a spatial relational database or geographic information system (GIS). To address this need, we have created an integrated database model consisting of spatially defined themes stored in a GIS and tabular data derived from borehole and well logging records. Our database development has evolved through three phases, from a basic borehole location catalog (version 1.0) to a simplified relational database that incorporates key subsurface information (version 2.0) to our current product (version 3.0: GeoInfoDB), which culminates in a truly multidimensional, integrated relational database capable of storing a complete lithologic and geotechnical record of the borehole with accompanying tabular, graphic, and spatial data. This integrated relational database addresses the need for unifying diverse types of information necessary for effective assessment and planning in environmental modeling and land-use planning (Peuquet et al., 1993; Beavis et al., 1999; Seetoh et al., 1999).

VERSION 1.0

Borehole Catalog

Based on discussions with the Rhode Island Department of Transportation (RIDOT) and others, we developed a borehole database that facilitates the planning of transportation systems in Rhode Island and serves as a model for other states and regions (Hermes et al., 2002). To do this, we conferred with the transportation and drilling communities as a pre-requisite for development of a borehole data protocol that was user-friendly (by drillers, engineers, etc.) and that captured the essential information. This protocol formed the basis for development of a template used to enter data into an Access® database. Subsurface geologic and hydrologic data associated with the boreholes are an integral component of the database and include the following elements: land-surface elevation, depth to water table, depth to bedrock, and nature of the material at the base of the boring. These data, along with the site identification information, comprise the tabular portion of the integrated database.

Data from existing drilling projects were collected for a pilot area in southern Rhode Island in a project funded by the University of Rhode Island Transportation Center. Borehole and well data for this project were derived from the RIDOT; the Town of South Kingston, Rhode Island, sewer projects; and the U.S. Geological Survey Groundwater Site Inventory System.

Geographic Information System

Spatial data for the boreholes and wells included in the Access® database are managed in ArcView® GIS. Additional spatial data layers that may be of interest to database users are included in the ArcView project as shape files including bedrock geology, surface outcrops, unconsolidated sediment type (surficial material), soil classification, topographic and orthophotographic base maps, and location of boreholes and groundwater wells. These include data sets from the Rhode Island GIS (RIGIS) and the Department of Geosciences and Rhode Island Geological Survey at the University of Rhode Island (Table 1).

Borehole and well sites were located and digitized on large-scale maps (i.e., <1:5,000 scale) based on information in the associated technical reports. The maps were registered in the Rhode Island State Plane coordinate system (NAD 83), and location coordinates were digitized from site plan maps using ArcView®. Locations generally are accurate to within 1.5 m (5 ft.), subject to the accuracy of the location provided in the original report. Use of global positioning satellite technology for future drilling projects will permit on-going rapid and accurate location of new boreholes.

Interactive capability in ArcView using the standard ArcView interface permits the user to quickly evaluate interrelationships among all variables in the database, thus enhancing data synthesis and the decision-making process. The procedure quickly allows the user to evaluate the completeness of the database and to identify critical areas where additional data are required. For example, by observing the distribution of well and borehole sites in the database, the user is able to observe areas of abundant subsurface information and then focus on regions where more drilling may be desirable. As future data become available, they can be quickly added to the existing database to provide a continually evolving and complete record of the accessible subsurface information. This updating capability is extremely important, because it permits a large volume of critical spatial information to be stored and efficiently accessed from a centralized database. It remedies the common problem of the repeated manual searches through archived materials.

The borehole database can be queried to show the spatial distribution of boreholes that meet specified criteria. For example, useful queries might be the distribution of boreholes and wells that penetrate bedrock at a depth of 10 ft. or less or boreholes that penetrate the water table at shallow depths. The query results are immediately displayed in map view, and the selected records can be saved as a data subset for further analysis.

The spatial data include 34 layers that can be displayed on-screen to show the geographic distribution of diverse data in relation to the borehole data. Such capability permits quick determination of the spatial relationship of transportation corridors to geologic setting, environmentally sensitive areas, areas of cultural importance, and other relevant features, which in turn expedites site evaluation and planning (Shimel et al., 2001).

Web-Based Interface

To ensure accessibility of the borehole data to potential users, a Web-based interface was developed that allows users to access, query, download, or add to the pre-existing database (Murray et al., in press). This interface can be accessed at http://geo.uri.edu/borehole. At present, the Web-based database includes data from the southern Rhode Island study area. Data from the on-going Providence, Rhode Island, study will soon be added. This database is readily expandable to other parts of the state or to other states. The Web-based interface permits access to the borehole tabular data, but it currently does not have the capability to interactively display maps and cross-sections through a GIS.

The major links on the website include the following:

1. *ABOUT BOREHOLES AND THIS DATABASE* (system information),
2. *SEARCH NOW* (report search engine),
3. *LOGIN* (registered user and administrator login),
4. *REGISTER FOR AN ACCOUNT* (new user registration),
5. *CONTACT US* (system contact information),
6. *SUBMIT BOREHOLE REPORT* (report submission from valid users), and
7. *ADMINISTRATIVE OPTIONS* (system management for administrators).

Searching the Database

All users can search and download records from the database using five criteria: town name, quadrangle name, depth to water table, depth to bedrock, and project name. Users have the option of displaying search results either on-screen or downloading them as an Excel® (Microsoft, Redmond, WA) worksheet. Results include borehole information and selected subsurface information. This early version did not provide a complete subsurface lithologic record.

After the system receives a search request from the user with the Display function, a new screen appears that shows the search results, listing all records with hole ID, date drilled, town or city, and project name. The user then can display a single record by selecting a specific record from the list or, by choosing the *Excel Sheet* function, can download all the selected records. The downloaded records can be either saved into a file or opened directly into an Excel worksheet. This function permits users to retrieve tabular records for boreholes of interest.

Submitting New Borehole Data

Registered users can submit new records to the borehole database. This permits continued population of the database with new borehole records as they become available. To submit a borehole report, an authorized user must first log onto the system and then complete the report submission form with relevant data. Data entry is simplified by utilizing drop-down lists for engineering companies, contracting/funding agencies, geotechnical companies, drilling companies, and project names. If the drop-down menu does not include the desired input, the

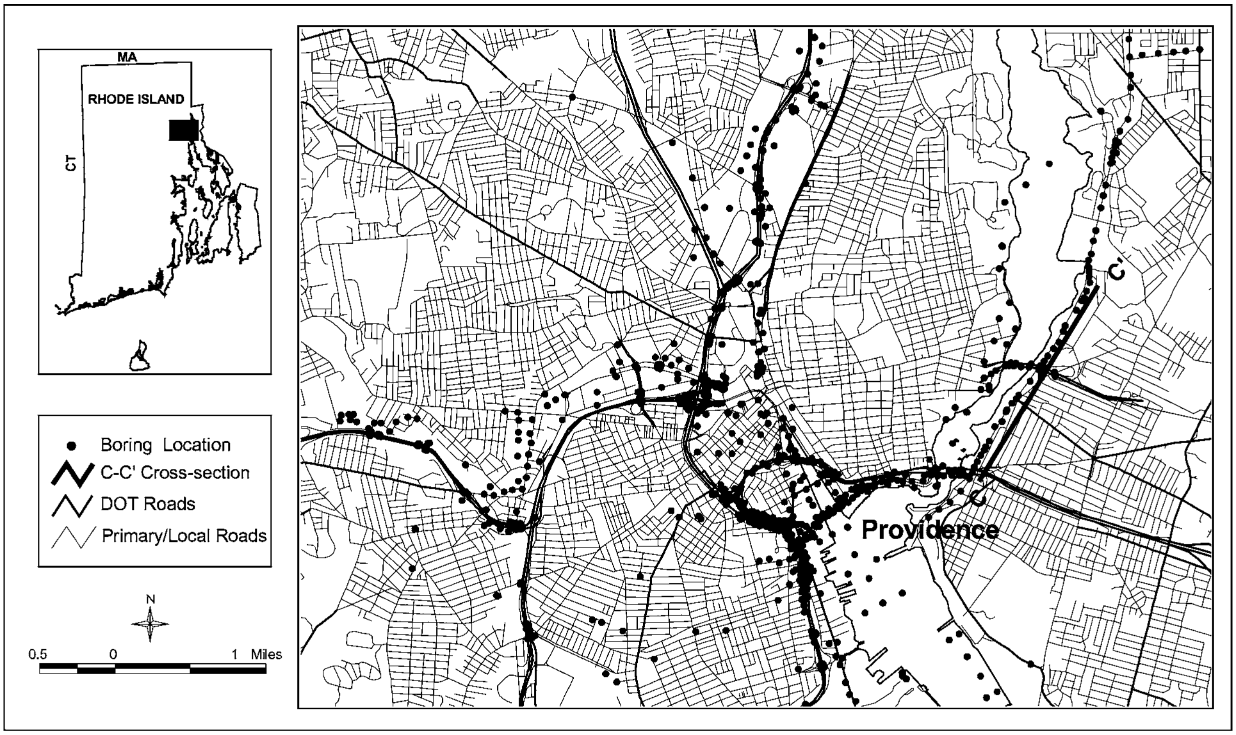

Figure 1. Location of boreholes and wells in the Providence, Rhode Island, digital borehole database.

user can enter a new input at the text field under the drop-down list. To accommodate an image of the original borehole log sheet, the system provides a 'file upload' service. The acceptable image file formats are JPG, TIF, or PDF. Maximum file size is 1 megabyte.

Submitted reports are temporarily stored in a holding table. The newly submitted data are reviewed by the database administrator before final acceptance and incorporation into the database. Access to the *Report Review* screen is reserved for users with administrative privileges. Before accessing the *Report Review* screen, an administrator must select a record from a list of all submitted reports. On the *Report Review* screen, the administrator confirms the details of the report and then submits the confirmed report to the main database. Once submitted, the report is available for general users of the site.

VERSION 2.0

Expanded Database

Through a cooperative project with the RIDOT, a second phase of database development was initiated with the objective of incorporating additional subsurface lithologic and geotechnical data, geologic cross-sections, and scanned images of well logs. To accomplish this, a second pilot area, incorporating the transportation corridors of Providence, was adopted (Figure 1). The resulting database is comprised of three components: spatial data, an expanded tabular relational database, and an image library linked to the GIS. This version improves the utility of the database by providing users with specific information on selected subsurface characteristics critical to geotechnical applications. Access to scanned images of cross-sections and well logs further increases data accessibility, ensuring that users can refer to the original data records used to construct the geologic cross-sections. The RIDOT plans to adopt this database to provide a repository for historical data as well as all data from current and future drilling.

Database Design and Use

An expanded template of borehole attributes was created (Figure 2) that incorporated interval data on selected material properties, including low and/or high blow-count zones and presence or absence of organic soils and artificial fill. The complete subsurface material description record, however, was not incorporated into the data structure.

All attributes from the version 1.0 database were incorporated into version 2.0 to ensure transportability of legacy data from the earlier version. The relational database has a simple architecture, with a single table incorporating all site-specific information and associated look-up tables for common fields (e.g., company name,

Engineering. Co:	Enginr_Co	Report #: *if applicable*	Report_No
Contracting/Funding Agency:	Fund_Agncy	Contract #:	Contrct_No
Geotechnical Co.:	Geotech_Co	Geotech File #: *if applicable*	GeotfileNo
Drilling Company:	Drill_Co	Drilling File #: *if applicable*	DrllfileNo
Project Name: *name*	Proj_Name	Bridge #: *if applicable*	Bridge_No
Hole ID:	Hole_ID	Date Drilled: *DD/MM/YYYY*	Date_Drill
Town:	Town	County:	County
Location X:	X_Coord	Location Y:	Y_Coord
XY Method: GPS digitized other	XY_Method	XY Projection: *state plane NAD 83 preferred*	XY_Proj
Land Surface Elevation (ft):	Altitude	Elevation method: GPS survey estimated altimeter	Alt_Method
Hole Type: boring or well	Hole_Type	Log Type: driller geotechnical geologist	Log_Type
Hole Depth (ft):	Hole_Depth	Scanned log available: yes no	Scan_Log
Depth to Bedrock (ft):	Depth_Bdrk	Visual Description on log: yes no	Visual_Desc
Depth to Water (ft):	DepthWater	Sample type: split spoon auger cuttings core	Samp_Type
Water level Date:	Water_Date	Number of sample intervals:	NumSamples

Subsurface Units:	**Present/Absent**	Top *ft below land surface*	Bottom *ft below land surface*
Artificial Fill:	Artif_Fill	Top_Fill	Bot_Fill
Organic Soils	Organ_Soil	TopOrgSoil	BotOrgSoil
Blow Counts <= 10 *Do not include top of hole*	BlwCnt<10	TopLoBCnt	BotLoBCnt
Blow Counts >= 100 *Do not include bottom of hole*	BlwCnt>100	TopHiCnt	BotHiCnt
Hole ended in: bedrock refusal unconsolidated stratified unknown	Geol_BOH		
Other Data Available:	Other_Data		

For URI/RIDOT use only:

Internal ID: **YYYYMMDD###**	Intrnal_ID
Entered By:	Entered_By
Date Entered:	Date_Enter

Figure 2. Version 2.0 database template (with column attributes in data fields) used to record standardized borehole information.

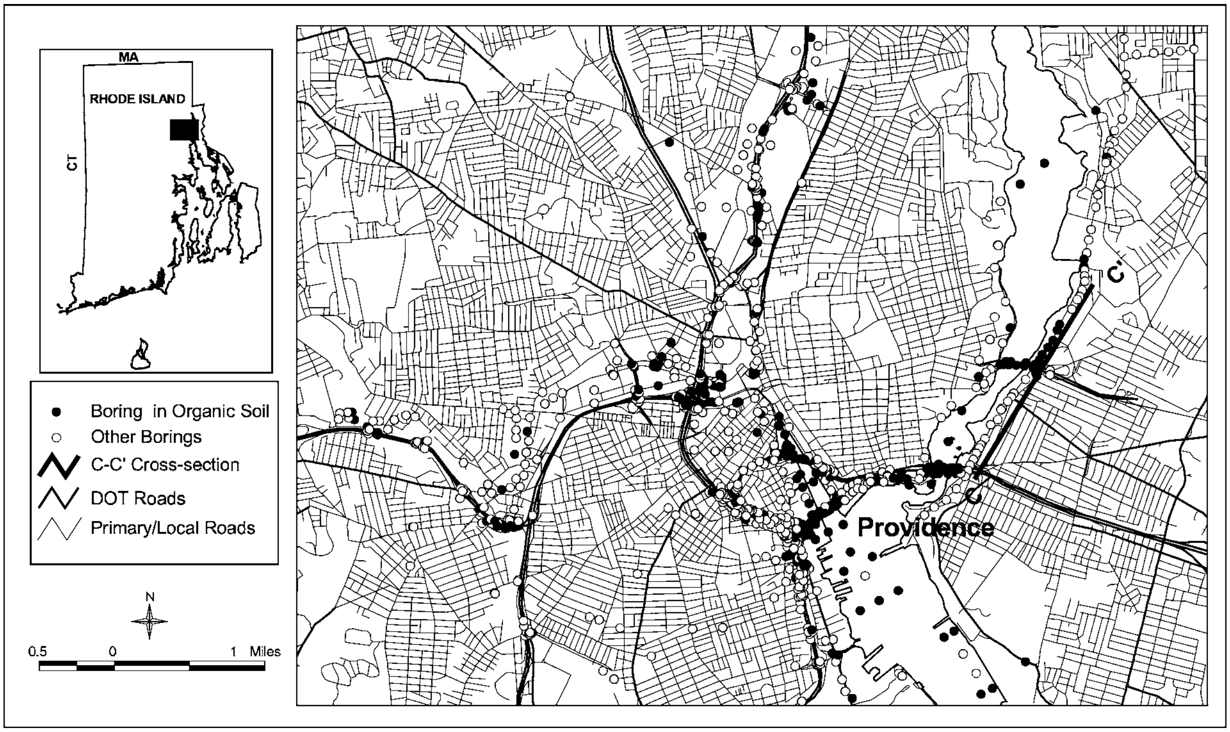

Figure 3. ArcView display showing results of an example query for boreholes that penetrate organic sediments.

project name, etc.). This structure minimizes the need to re-enter redundant information and permits rapid retrieval of all boreholes associated with a given project or engineering company; it also reduces the potential for data-entry errors. Data entry for the revised database can be accomplished through a Web-based interface or an Access application data-entry form.

The borehole database can be queried through ArcView to show the spatial distribution of boreholes that meet specified criteria. Query options include those of version 1.0 as well as the ability to search for boreholes that encounter the material property categories (organic sediment, high/low blow-count zones, and artificial fill) added to version 2.0 and enter complex queries for boreholes that encounter these materials at a specific depth or depth interval. Typical user-defined queries might consist of the distribution of boreholes and wells that penetrate bedrock at a depth of 10 ft. or less or boreholes that encounter organic sediment (Figure 3). The query results are immediately displayed in map view, and the selected records can be saved as a data subset for further analysis.

Virtual Library: Geologic Sections and Scanned Images

Geologic cross-sections, developed from the well log data, were constructed along selected lines in the pilot study area. The geologic sections, showing the subsurface distribution of lithologic units, were developed using RockWorks® version 2002 and stored in the virtual library as JPG images (Figure 4). The images are accessible through ArcView using the hotlink tool on the cross-section line.

The original well logs used for cross-section development were scanned and stored in the virtual library as BMP images. These scanned images are also accessible as hot links, as described above, and allow database users to compare the geologist's interpretation to the original well log descriptions.

VERSION 3.0

GeoInfoDB

Although the database described above provides markedly improved storage and accessibility of borehole data, this structure is limited, however, because it does not permit entry of the complete subsurface lithologic record. The third phase of database development, GeoInfoDB, addresses this weakness through development of a multi-dimensional relational database capable of incorporating a complete subsurface lithologic (visual description) and geotechnical (blow-count) records. This phase also marks the departure from a database geared predominantly toward the geotechnical engineering community to a database capable of meeting the needs of multiple stakeholders (e.g., state governments, town

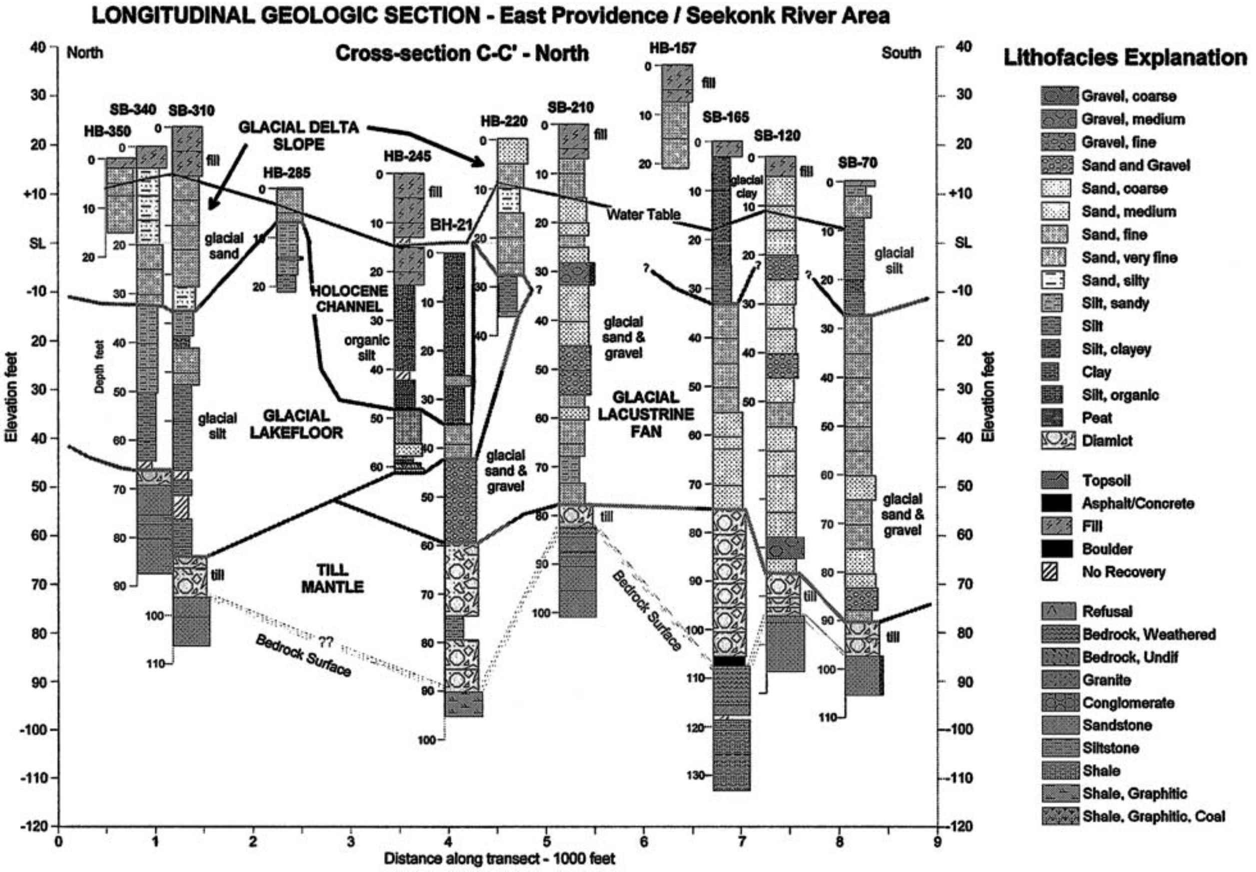

Figure 4. Sample geologic cross-section (C-C′) for Providence, Rhode Island (location of section shown in Figure 1).

planners, and environmental groups) by unifying diverse types of data in a single database.

Database Structure and Characteristics

A relational database is a collection of data items organized as a set of tables from which data can be accessed or queried in different ways without having to reorganize the original data tables. The GeoInfoDB design addresses the following goals: layer-by-layer (multi-value for a single field) data capacity, incorporation of legacy data, data import capability, and scalability to include diverse data as well as future database expansion. This is accomplished in Access through a tiered relational database structure, with related tables for each category and type of data. In our design, we group the data entities in an hierarchical fashion to facilitate top-down dissemination of data. Data are stored in five levels: Level 1 stores information related to the physical location of a data point, level 2 information regarding the types of data related to a data point, level 3 information related to the data sources, level 4 single/multi-valued information for individual data types, and level 5 shared information. At present, the database design includes three different types of data: borehole, water quality, and soil-gas radon. The data type associated with each record determines the data fields that will be populated. Each point location may be associated with multiple records and data types. The resulting modular database therefore is scalable, allowing future development and incorporation of additional data modules. Data access and querying, as well as display and analysis, can be accomplished through Access or GIS applications (e.g., ArcView, ArcInfo®, and ArcIMS®) depending on the user's needs. This will permit querying and display of borehole lithology, retrieval of laboratory data, and access to all borehole related information.

On-Going Work

On-going work on GeoInfoDB includes development of a Web-based user portal with data entry, data query, and spatial data display capability through ArcIMS and an upgrade of the spatial component of the database to make it compatible with ArcInfo version 8.3. The borehole database will be maintained at the RIDOT. Data can be retrieved through Access or ArcView for RIDOT in-house users or through the Web-based interface for external users. External users with Access and ArcView will also be able to download a copy of the integrated spatial database (relational database and associated spatial and virtual libraries) for their use. System requirements include an Intel Pentium II (or compatible) processor, 128 MB RAM, 400 MB hard-drive space, Windows 2000 or XP, Access 2000 or XP, and ArcView version 3.2 (required for graphic display of spatial data).

SUMMARY

We have developed the capacity to organize and store borehole data in an integrated database that provides access to spatial, tabular, and image data. This database marks a significant advancement for the State of Rhode Island, permitting rapid identification of existing boring locations and retrieval of key subsurface data. Adoption of this database as a repository by RIDOT will ensure on-going population of the database with all future drilling records. Development of the Web-based user portal makes the database accessible to a broad audience of potential users, including engineers, environmental scientists, town and state planning officials, and the public. Our results may serve as a model for other agencies attempting to integrate three-dimensional spatial data into an easily accessible and useful repository.

A limitation of this database—the absence of a complete subsurface record (layer-by-layer visual description, blow counts, etc.) and associated layer-specific data (laboratory analyses and geologic/geotechnical interpretations)—is currently being addressed through the development of GeoInfoDB, a modular relational database that provides digital access to the full subsurface record, and an updated Web-based user portal.

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