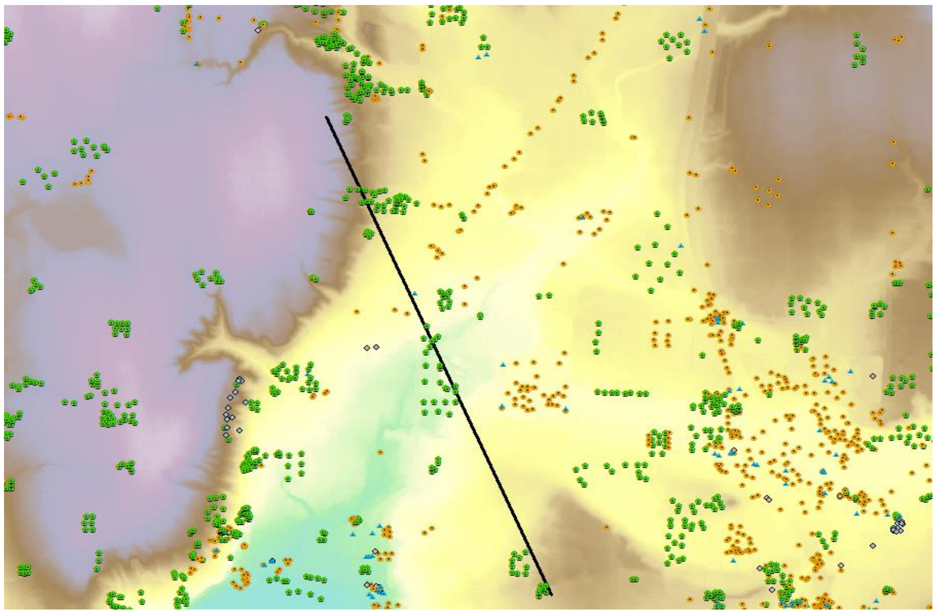

Python-based geoprocessing tools for visualizing subsurface geology

A capstone project report

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University of Washington, Geography 569 GIS Workshop
August 17th, 2018
Report submitted to GeoMapNW

EXECUTIVE SUMMARY

The Pacific Northwest Center for Geologic Mapping Studies (GeoMapNW) is a Seattle-based collaborative research center established by the USGS in 1998. The organization was founded to help create disaster-resilient cities by providing state of the art geologic data to support geologic hazard mitigation projects and inform land use decisions in the Puget Lowland region. A major accomplishment of GeoMapNW was the creation and continued maintenance of a database containing subsurface geologic information compiled primarily from geotechnical boring logs, water well logs, and direct measurements (known collectively as geological explorations). To date, over 100,000 explorations and their associated attributes have been added to this database.

In order to visually display the information contained in this database for the production of geologic maps and related information products, a series of tools were developed in VBA to create cross section views of these explorations and the overlying surface elevation profile. These tools rely on currently outdated and unsupported software and were built to interact with database architecture abandoned by GeoMapNW. Because of this, the organization no longer had the ability to visualize subsurface geology, and commercially available cross section tools could not be used due to prohibitive cost and incompatibility with existing database architecture.

To address this loss of geovisualization ability, GeoMapNW submitted a project proposal to the 2018 University of Washington Masters of GIS for Sustainability Management capstone program to solicit the development of a tool to automate the creation of geologic cross sections. The authors accepted the proposal and began developing several Python-based geoprocessing tools intended for use in ArcMap. These tools borrow heavily from open-source Python scripts written by Evan Thoms of the USGS, though they are extensively modified to address key desired software capabilities identified by GeoMapNW during initial project scoping. Following several weeks of development, the tools were completed and delivered to GeoMapNW in the form of an ArcGIS toolbox (.tbx) with supporting materials including help documentation and relevant layer files used for the application of symbology.

Tool capabilities include returning a 2D cross section view of stick logs of selected GeoMapNW explorations with an overlying surface elevation profile. Each stick log displays major material composition, visualized for each subsurface layer. The user may also specify a vertical and horizontal exaggeration for the output, display the depth of groundwater encountered in each exploration, display the density of each layer, apply symbology as desired, and export the end result to a graphic file format for further editing.

Initial user testing of the tools was successful. Dr. Kathy Troost, Director of GeoMapNW, stated that the tools will be used with near immediacy on a project to map the depth to bedrock in the Seattle area and expects that the tools will allow for the visual identification of vertical offsets in the bedrock that may assist in accurately locating the Seattle Fault.

The following report presents an in-depth explanation of the need for these cross section tools, the processes and methodology involved in their development, and concluding examinations of their technical capabilities with suggestions for further refinement.

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1. BACKGROUND AND PROBLEM STATEMENT

The Pacific Northwest Center for Geologic Mapping Studies (GeoMapNW) is a Seattle-based collaborative research program initiated in 1998. The program created and now maintains a publicly available subsurface database containing geotechnical data for over 100,000 geologic exploration points in the Seattle region. This data is used for increasing knowledge about geologic conditions and hazards in order to inform land use decisions. GeoMapNW submitted a project proposal to the 2018 University of Washington Masters in GIS for Sustainability Management capstone program soliciting the development of a tool to partially automate the creation of geologic cross section maps using GeoMapNW data.

1.1 Background

1.1.1 GeoMapNW

The Puget Sound Lowland is one of the most seismically active areas in the country, and is also highly urbanized. Steep slopes, shallow water tables, and sandy deposits also increase the risk of geologic hazards like landslides and soil liquefaction (Booth et al. 2005). In 1998, GeoMapNW was established when Seattle was selected as one of several cities to participate in a U.S. Geological Survey (USGS) program to help create disaster-resilient cities by providing state of the art geologic data to support geologic hazard mitigation in the region. The program received additional funding from the City of Seattle and King County. The University of Washington's Department Earth and Space Sciences hosts the program on its Seattle campus. The project's goals are to "acquire existing geologic data and create new geologic information; to conduct geologic research and produce new geologic maps; and to support the wide variety of additional research, hazard assessments, and land-use applications of other scientists, organizations, and agencies throughout the region" (Booth et al. 2005).

In the program's initial years, GeoMapNW compiled geotechnical data from geologic explorations using a variety of sources and created a large publicly available database. This database includes geotechnical information about subsurface geology including soil types, subsurface layers, groundwater depth, and material density. These data can be used for applications such as identifying fault locations; informing planning and development decisions; and creating earthquake shaking scenarios, liquefaction, and landslide maps. The initial database contained 35,000 exploration points; the current database has grown to over 100,000 points. Using these data, GeoMapNW produced geologic maps for the region with much more detail and higher quality than previously existing maps. The new maps have with about twice the spatial resolution of previously existing maps. See Figure 1 for an example of old and new maps, showing the enhanced detail in the new version. These maps are used for a variety of purposes and by many users, but generally they provide information about geologic hazards and susceptibility to events such as landslides and earthquakes. Findings from the maps and data include evidence for faults and deformation, landslides, and the existence of organic-rich deposits such as peat and lake deposits.

In 2010, after 12 years operating, the program lost funding. Currently, the program still exists on the University of Washington campus but it has no paid staff. The Washington Department of Natural Resources manages and distributes the data compiled by GeoMapNW. Efforts are being made to refund the program and resume work at full capacity.

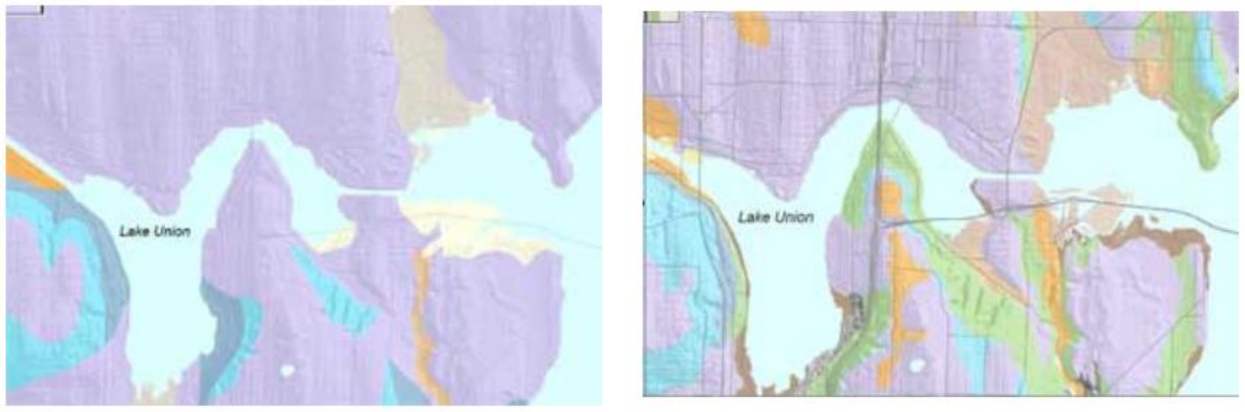


Figure 1. Comparison of detail present in a 1962 geologic map, and 2005 geologic map produced by Troost and others using GeoMapNW data. Image from Booth et al. (2005).

1.1.2 Geologic Cross Sections

A major application of GeoMapNW data is for the creation of geologic cross section maps. Geologic cross sections show the subsurface structure of the earth, viewed as if the earth were sliced open vertically, like a layer cake. Cross sections are used by geologists and engineers to characterize building sites, identify fault locations, and provide other geologic information. Drilling holes into the earth (boreholes or other explorations), observing areas where the layers are naturally exposed, or observing layers that are exposed due to human activity such as road cuts or building excavations provide data that guide the creation of cross sections. Cross sections require interpretation and inference, because not all locations and layers can be visually or otherwise directly observed. Traditionally this interpretation was done manually by geologists, and this is still normal practice. Stick logs (also called borehole logs) showing the vertical distribution of soil characteristics are used to inform the creation of cross-sections. Stick logs along a cross section are displayed, and then geologic layers are interpolated to "link" the subsurface layers displayed on each stick log. Tools also exist that automate this interpolation. However, licenses to these programs may be prohibitively expensive, and some professionals prefer the control afforded by manual interpolation. An example of a geologic cross section with stick logs is provided in Figure 2.

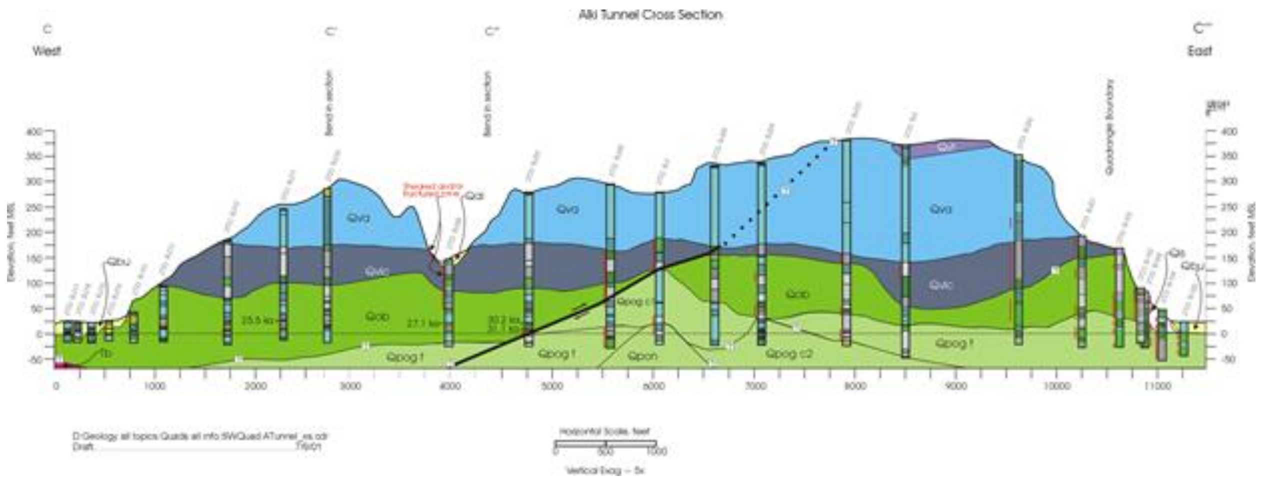


Figure 2. Example geologic cross section showing stick log plots, elevation profile, and interpreted geologic layers and features. Image provided by Kathy Troost, GeoMapNW

1.1.3 GIS Cross-Section and Stick log Tools

For previous versions of the GeoMapNW database, a tool existed to aid in the automation of geologic cross section creation. However, due to updates to ArcGIS software and changes in the database itself (a move from Oracle to Microsoft SQL), the tool is no longer compatible. Without a tool, all work in developing cross sections has to be done manually, which is a cumbersome task. Built-in GIS functions in the ArcMap software have limited functionality, given the 3D nature of the data and thus the inherent challenge of displaying the subsurface data.

Several proprietary programs exist for geologic mapping in a GIS. These programs are not suitable for GeoMapNW or its partners for a variety of reasons. Prohibitive cost is a major factor, as license fees for the software are typically thousands of dollars. Software packages include RockWorks (https://www.rockware.com/product/rockworks/) and Vulcan (https://www.maptek.com/products/vulcan/index.html). Additionally, much of the software is not necessarily compatible with the existing data structure. For example, Aquaveo developed cross section tools for use with ESRI’s Arc Hydro Groundwater data model, and so use of those tools would require a major restructuring of the entire GeoMapNW database http://ahgw.aquaveo.com/Boreholes.pdf).

Some free tools exist, but for various reasons they do not serve the needs of GeoMapNW. Problems such as the large size of the database, incompatibility with the existing data structure, or a less useful output format make them less suited to GeoMapNW’s specific needs. For example, Carrell (2014) developed an ArcGIS toolbox for creating geologic cross sections using Visual Basic for Applications (VBA). This tool is no longer supported in current versions of ArcMap, and the output is not in a format that is most useful for GeoMapNW. Thoms (2005) also developed a VBA tool, which was later redeveloped in Python. This open source tool was a used as a major resource for the current project. It did not meet all the objectives for the current project, but the code for several of the scripts was used as a baseline from which the Stick Log and Elevation Profile tool was written.

1.2 Project Goal and Problem Statement

1.2.1 Project Goal

The goal of the project was to develop and Python-based ArcGIS custom tool for geovisualization of stick logs along a user-selected cross section, showing a vertical plot of soil types, densities, and groundwater locations for each point.

To meet project sponsor specifications, the tool needed to:

- ❑ Be compatible with the existing GeoMapNW data structure.
- ❑ Create a vertical plot (stick log) for a series of geologic exploration points along a cross section line.
- ❑ Allow the user to input a cross section line and selected exploration points.
- ❑ Create a surface elevation profile for the cross section.
- ❑ Display the subsurface layers for each point including major material and material density.
- ❑ Display the groundwater location for each point, if available.
- ❑ Create an editable legend using a borehole lithology key.
- ❑ Allow user specification of vertical and horizontal exaggeration.
- ❑ Create a graphic output that can be edited in a graphics program such as Adobe Illustrator.
- ❑ Include documentation for users.

While most other tools and research focus on creating tools or data models that allow users to work with cross-sections *within* a GIS software program, our focus differs slightly in that the desired output is an editable graphic that will aid with the manual creation of cross sections. The ArcGIS output will be exported to a file format supported by vector graphic editing software, such as Adobe Illustrator. This exported file will be imported into the graphics software and edited to include annotations and other modifications.

Development of the tool will facilitate and enhance the use of GeoMapNW subsurface geology database. Through partial automation of the creation of geologic cross sections, accuracy of maps will increase, as will the ease of data interpretation. By increasing geologic knowledge, the tool will also contribute to improvements in disaster resilience. Project benefits are discussed in further detail in section 3 of this report.

Based on the project goals, the following problem statement was developed:

How can we develop a tool for visualizing geologic data by automating the creation of a surface profile and stick logs along a cross section line, using the GeoMapNW database?

1.2.2 Project objectives

Based on the project goal, project objectives were developed. These are presented in Table 1 in the form of "need to know questions." The need to know questions are the basic questions that needed to be answered in order to successfully develop a tool that will meet project goals. The questions were developed by working backwards, starting with the specifications for outputs the tool ultimately needed to generate, and assessing the information that would be necessary to build each specification into the tool. Of course, in order to answer each question, many other questions ultimately need to be answered first, but the need to know questions form a useful framework for understanding the necessary problem-solving needed to approach the project.

Need to know questions:
What data points should be included in the cross section?
What is the location of each exploration and stick log?
What is the elevation profile along the cross section?
What is the groundwater depth?
What is the density of each layer?
What is the major material of each layer?
What is the depth of each layer?
How will appropriate symbology be applied?
How will the above be displayed visually in a graphic output?

Table 1. Need to know questions.

1.3 This Report

The following sections of this report document the process and results of the toolbox creation. In System Resource Requirements, requirements for data, software, hardware, personnel, and institutional requirements for the project are enumerated. In the Business Case Evaluation, a cost-benefit analysis is presented arguing in favor of tool creation from a fiscal standpoint. In Data Development, the GeoMapNW database structure and the data outputs of the tool are described and discussed. In Workflow Implementation, the methods we undertook to develop the tool are explained, as are technical aspects of script and tool creation. In Results, the final version of the tool and its outputs are presented. Conclusions and Recommendations discusses the usefulness and limitations of the final product, and recommendations for future work. Python scripts, data design tables, tool parameter documentation, and a toolbox instructions document are included as appendices.

2. SYSTEM RESOURCE REQUIREMENTS

This section discusses the necessary system resource requirements both in terms of those necessary for project development, and those necessary for users of the produced tools. Data, software, hardware, personnel, and institutional requirements are discussed.

2.1 Data Resource Requirements

Database design and the information environment are critical considerations when building a custom tool. The existing or theoretical database and data models will influence the functionality, features, interface, and outputs of the tool. In this project, we were tasked with creating a custom tool using data compiled in an existing Microsoft SQL database. Our tool is specifically designed to interface with the current database architecture. Because of this, data resource requirements for our tool are dictated by the existing database structure (feature classes, rasters, relationship classes, domains, etc.), and expected tool processing demands and outputs (geoprocessing steps, and amount and format of output data).

2.1.1 GeoMapNW Existing Database

Due to the prior existence of the relevant database, completing the database design process would constitute a serious duplication of effort. Nevertheless, it is beneficial to understand the stages of developing a conceptual data model for the database design. Database design and creation was a major accomplishment of the early work of the GeoMapNW program. GeoMapNW identified the information products their organization sought to deliver (high quality, high resolution geologic maps of the Puget Lowlands for assessing and identifying seismic risk areas, landslide and liquefaction potential, groundwater resources, and hydrocarbon potential in the urban corridor). They then reviewed existing data sources compared to data requirements and identified key thematic layers and feature classes that would comprise the bulk of the database (geologic explorations taken from public record, topographic and bathymetric data, subsurface layer information, and related tables). Feature classes were detailed to create data models. Subtypes, relationships, and domains were applied as appropriate. The database design is discussed in further detail in section 4 of this report, Data Design.

Because the database design process had been completed prior to our project participation, our project required working within the existing database. The most relevant data design factor is that the exploration points are related to a subsurface layers table in a one to many relationship. For each exploration point, many subsurface layers may exist, each with their own set of attributes (depth, material, density, etc.), some of which are stored in separate related tables. The objective of the tool is to develop a way to display this related data, which in a typical ArcMap session is only accessible by manually clicking on a point with the identify tool to read attributes from the related tables. Clearly, a tool that produces a visualization of this data will be a useful improvement.

2.1.2 GeoMapNW Database Entity-Relationship Diagram

For project development, a subset of the main GeoMapNW database was downloaded to each project member's local drive. The database contains some basemap feature classes unnecessary for tool development or display (streets, lakes, city boundaries, etc.). A simplified enity-relationship diagram is displayed in Figure 3, showing only the feature classes, raster datasets, and tables relevant to our tools. The Data_Points feature class, DEM raster, and

Subsurface_Layers table are required inputs. The Groundwater_WW table is necessary for displaying groundwater depth. The other tables contain additional data related to each exploration data point through a relationship class definition. Primary and foreign keys (EXPLOR_ID field) and attribute fields relevant to the tools are included in the diagram. Many other attributes exist but are omitted here for simplification. Further description of the data can be found in section 4 of this report, Data Design.

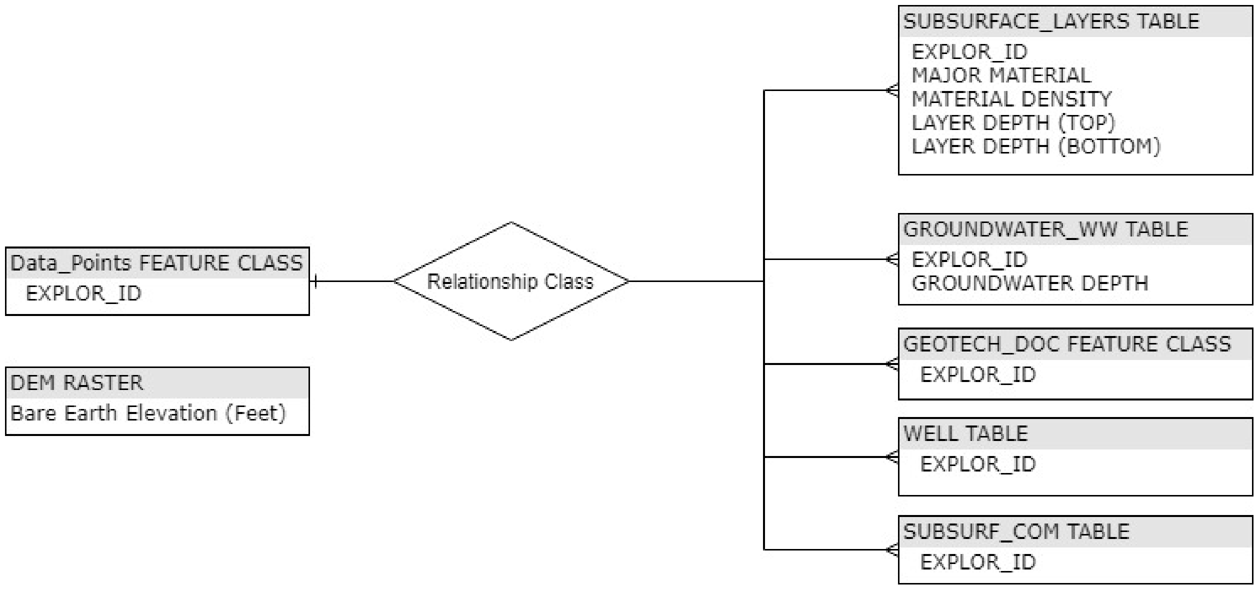


Figure 3. An Entity-Relationship Diagram of the relevant GeoMapNW database elements.

It is useful to examine the relevant input layers and their key attributes as they will be applied by the tool. A DEM raster is input for the display of an elevation profile along the user-provided cross section line, and also determines the starting elevation of each exploration if the elevation is not provided as an attribute. Data points from the ‘Data_Points’ layer are selected by the user as inputs, and a stick log is created for each selected point. Groundwater and subsurface layer tables with relationship classes to the ‘Data_Points’ layer are used to provide the attribute values needed to create stick logs displaying the depth of each subsurface layer, the layer major material type, material density, and groundwater level. A simple visualization of this process is presented in Figure 4. The inputs and operational processes of the tool are discussed in further detail in section 5 of this report, Workflow Implementation.

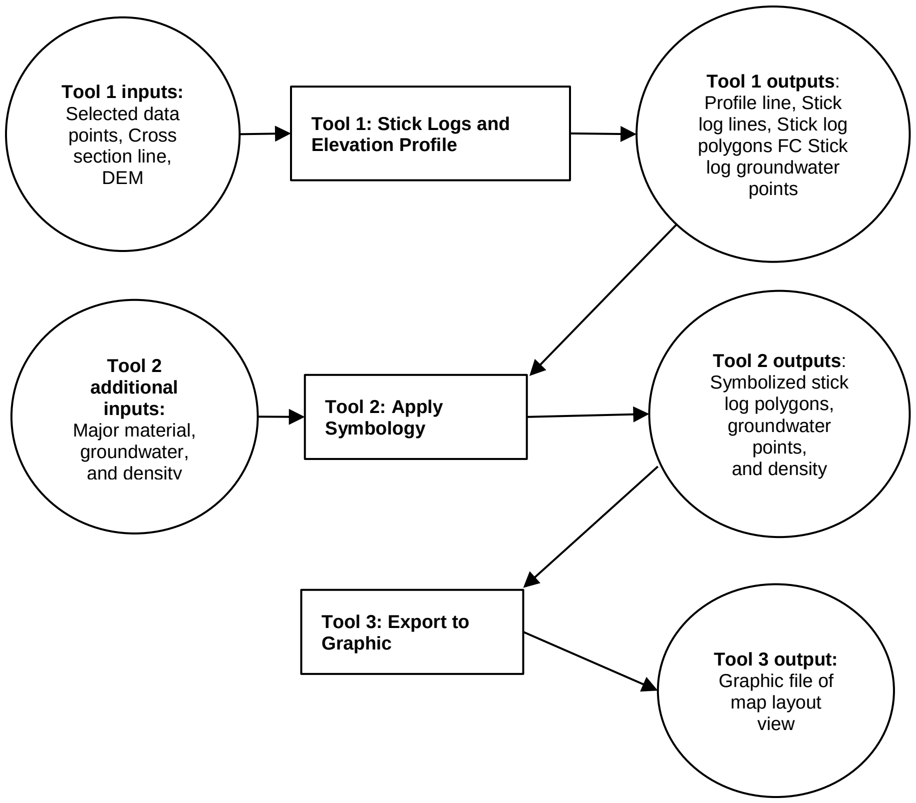

Tool 1 inputs: Selected data points, Cross section line, DEM
Tool 1: Stick Logs and Elevation Profile
Tool 1 outputs: Profile line, Stick log lines, Stick log polygons FC Stick log groundwater points
Tool 2 additional inputs: Major material, groundwater, and densitv
Tool 2: Apply Symbology
Tool 2 outputs: Symbolized stick log polygons, groundwater points, and density
Tool 3: Export to Graphic
Tool 3 output: Graphic file of map layout view

Figure 4. Operations Flow Diagram of basic data inputs and outputs for the three developed tools.

2.2 Software Resource Requirements

2.2.1 Software function capabilities

The scripts were written using Python version 2.7 and the tool was tested with ArcGIS versions 10.2 through 10.5.1. A license for the 3D analyst extension is required for tool operation. The tools call Python (.py) files that are packaged within an ArcGIS toolbox. The Python module is part of an ArcGIS Desktop install, so any ArcMap user with a 3D analyst license should be able to execute the tool without additional software. The custom toolbox, containing three ArcGIS custom script tools, is loaded into ArcToolbox and the tool is executed from ArcMap. An open .mxd file with appropriate input data added to the data frame is necessary for the tool to function (it cannot be run from the command line or from a Python IDE).

The scripts primarily utilize built-in ArcToolbox tools called through the Python Arcpy module, as well as the os, sys, and traceback Python modules. From ArcToolbox, utilized tools include many from the Data Management toolbox, as well as Data Access, Linear Referencing, Analysis, Conversion, Mapping, and 3D Analyst tools. These tools are listed in Table 2.

Toolbox	*Tools/Modules*
Data management	Add Field Calculate Field Make Feature Layer Add Join Copy Features

	List Fields Apply Symbology from Layer Feature to Point Sort
Data Access	Search cursor Update cursor Sort management
Linear Referencing	Create Routes Locate Features Along Routes
Analysis	Buffer
Mapping	Add layer List Data Frames
3D Analyst	Interpolate Shape
Conversion	Export to PDF, AI, JPEG, etc
Python 2.7.13	Arcpy, os, sys, traceback modules

Table 2. Selection of tools and Python modules called in toolbox scripts.

If a tool user wants to edit the graphic file output, rather than working within the ArcMap environment, vector graphics software will be necessary. The ideal software for this task is Adobe Illustrator, as maps can be exported from ArcMap to Adobe Illustrator (.ai), and there is more support for compatibility between programs than for some other software. However, licenses to the Adobe Creative Cloud software are expensive and alternatives exist, for example the open source program Inkscape. At the time of writing an individual Illustrator license was about $20 per month, although educational discounts are available.

2.3 Hardware Resource Requirements

2.3.1 Data input storage requirements

Anticipated data input storage requirements are minimal and depend on the scale of a tool user's project. The sample file geodatabase used for tool development, which includes all raster and feature classes and tabular data required for tool operation, is 553 MB. This geodatabase contains data for the City of Kirkland and represents a similar spatial extent to what would be expected for a typical project. However, the tool may be used for larger-scale applications, which would require additional storage.

Additional storage requirements include a minimum of 4GB of disk space for the ArcMap 10.5.1 installation, which includes the necessary Python installation. Less than 10 MB are required for most Python IDEs, in the case that it is necessary to edit the scripts.

2.3.2 Data processing storage requirements

Requirements for data processing are modest when compared to many GIS processing tasks. Processing will be performed in ArcMap, versions 10.2 or later; at least 4 GB of RAM are recommended for operating the software. The tool was developed primarily in version 10.5.1, on local copies of data for tool development. The tool can be run using any number of input data points, and any length of cross section line. Performance will depend on the capabilities of an individual machine from which it is run, and the number of data points used. Processing time for a smaller run using approximately 20 input points takes between about 30 seconds and several minutes, depending on the computer specifications. For a run using more data points this processing time will increase, but should still not be an unusually heavy processing load compared to other common GIS processes. The required processing should be easily performed by most machines outfitted to operate a GIS.

2.3.3 Data output storage requirements

Data output storage requirements are minimal. The file size of data outputs in graphic format (PDF, JPEG, AI, etc.) depends on the file type, resolution, and quality selected, but typically requires from less than 10 to several hundred KB per output. Additional outputs are generated to a geodatabase as point, line and polygon files, as well as a table. Depending on the number of features, the geodatabase outputs each require several hundred KBs to several MBs of storage. A total maximum of 3 line feature classes, 2 point feature classes, 1 polygon feature class, 1 table, and 1 graphic file are the outputs if all three tools in the toolbox are run. Some of these may be manually deleted by the user, depending on individual needs, further reducing the required storage. The amount of storage capacity required for these outputs is modest compared to what is often produced by typical GIS processes.

2.4 Personnel Resource Requirements

Project roles were defined using the roles described by Huxhold (1992) for guidance. Due to the scope of this project, many of the roles identified by Huxhold do not apply. Only the lead/manager and programmer roles are relevant. For this project, the three team members acted in the role of programmers, and Dr. Kathy Troost was the team leader/manager.

As the program director of GeoMapNW, Dr. Troost provided background context, and technical requirements. Her specifications for tool functionality and design were the basis for tool development. Under her guidance, project members used GIS and programming skills to develop a set of tools that translated the desired specifications into a script and ultimately a user interface than can be used by tool user with minimal GIS experience. GeoMapNW also provided all analyst, database administrator, system administrator, processor, and digitizer roles, although most of these roles were performed in the past as the database was developed.

Team members	***Role***
Jesse Schaefer Martin Weiser Drew Schwitters	Performing the role of programmer. Will create Python scripts to perform the user applications as identified by the project manager. This will require an amount of work equal to that provided by the other group members.

Table 3. Team members and project role. All members assumed the same role.

The three team members all acted in the role of programmer. The decision was made by project team members that each person would perform this role, rather than delegating a lead programmer or otherwise dividing the project components. For some tool development all members independently created scripts, and those scripts were consolidated into a single final version; for others, members worked on different tool portions as time allowed. Constant communication and script sharing prevented duplication of effort. This approach was chosen so that all team members would equally benefit from the learning experience of developing the scripts and building the tools. Synthesis of group work in the form of formal reports and progress reports was also shared equally among group members. Drew Schwitters took on the additional role of in-person team representative for necessary meetings with Dr. Troost, as he was the only team member located in the Seattle area.

2.5 Institutional Resource Requirements

Work was conducted in partnership with the project sponsor Dr. Kathy Troost at GeoMapNW. She was the sole organizational contact, as due to lack of funding she is currently the only representative of GeoMapNW. Dr. Troost provided the group with the data used for tool development, and had access to the necessary hardware, software, and other resource requirements for testing the developed tools. Ultimately, the project delivered a tool that will be used and disseminated by GeoMapNW to their organizational partners and clients. Current partners and clients include the City of Tacoma, the City of Bothell, the City of Seattle, and King County.

3. BUSINESS CASE EVALUATION

A business case evaluation can assist a client in determining whether or not to adopt a project by weighting project costs against project benefits. Known as a cost-benefit analysis, this systematic approach to determining the best option from among known alternatives is commonly used as a defensible methodology for project selection. Before undertaking a project it is important to be confident that the benefits will outweigh the costs; otherwise, the investment is not worthwhile. However, care must be taken to assign proper value to both tangible and intangible costs and benefits, and a thorough and unbiased analysis is often difficult to achieve. With this consideration, the following cost-benefit analysis uses the framework presented by Antenucci (1991) for typifying project benefits and costs associated with the development of a custom geologic cross section toolset by graduate students at the University of Washington. In addition to enumerating project costs and benefits, the analysis will present the two most likely project alternatives to clearly demonstrate the value provided by the adoption of this project.

3.1 Benefits of Commissioning a Student-Developed Geologic Cross Section Tool

The cross section tool development project will provide numerous and diverse benefits, both directly to the GeoMapNW program as well as indirectly through benefits to program partners, other potential users, and even the general public. GeoMapNW's geotechnical data is the most detailed of its kind for the region, and the creation of a tool that increases the ability to access, analyze, and make decisions based on the information gleaned from the data is of significant consequence. Organizations, jurisdictions, and residents will benefit from a bolstering of the ability to apply geographic and geologic information to decision making in the region. Benefits are discussed below, following the structure of Antenucci's five categories of benefit types. These benefit types are summarized in Table 4.

Type 1	Quantifiable efficiencies in current practices, or benefits that reflect improvements to existing practices.
Type 2	Quantifiable expanded capabilities, or benefits that offer added capabilities.
Type 3	Quantifiable unpredictable events, or benefits that result from unpredictable events.
Type 4	Intangible benefits, or benefits that produce intangible advantages.
Type 5	Quantifiable sale of information, or benefits that result from the sale of information services.

Table 4. Benefit categories, from Antenucci (1991), p. 66.

3.1.1 Type 1 Benefits

According to Antenucci's categories, type 1 benefits are "Quantifiable efficiencies in current practices, or benefits that reflect improvements to existing practices." These include the benefits of automation, data handling, and manipulation. These are all key components of the cross section tool, and thus type 1 benefits of this project are numerous. Primarily, the tool should lead to a pronounced increase in work efficiency. According to Dr. Troost, at least 30% of the program's work will include use of the cross section tool. Currently, without the tool, the only way to display geologic cross sections using the GeoMapNW data is by creating them manually. Automating a major part of this process would provide a dramatic increase in the efficiency of map production, as well as improvements to map accuracy. The process for updating existing maps will also be improved, by running the tool on a previously mapped cross section line and applying any new geologic explorations that were not available for the creation of the original map. The type 1 benefits outlined above will exist both as direct efficiencies, or "those that accrue to the organization or unit sponsoring the GIS" as well as indirect efficiencies, or "those that accrue to organizations or individuals who are not sponsors of a GIS" because program partners will also benefit from the increase in efficiency afforded by the tool (Antenucci 1991, p. 66).

3.1.2 Type 2 benefits

Type 2 benefits are "Quantifiable expanded capabilities, or benefits that offer added capabilities." While type 1 benefits are focused on efficiency, type 2 benefits are the result of new capabilities or increased production levels. Aside from manually drawing cross sections, other technological solutions for creating cross sections are unrealistic due to prohibitive cost, steep learning curves, and incompatibility with the existing data structure. Software products like ArcHydro, Rockworks, and CrossView have been evaluated and rejected as solutions. Partner organizations and jurisdictions will for the most part face similar obstacles to utilizing those products. Thus, a custom tool is the best solution for extending the use of the GeoMapNW data. An expansion of those who can utilize GeoMapNW data to include those who would otherwise not have the time, expertise, or resources is a clear benefit of the tool. As with the type 1 benefits, this expansion of capabilities exists directly for GeoMapNW as well as indirectly for program partners and other users.

In addition to utilizing the tool with GeoMapNW data, it can also be applied to other geotechnical datasets. Because of customization available in tool parameters, there is flexibility built in to the tool to allow for use by many users. Other organizations or jurisdictions may already have compatible datasets, or could design compatible databases in order to utilize the tool. The basic scripts could also be modified by someone with intermediate Python skills to make the tool compatible with different data, or to extend its functionality to suit a custom need. Finally, GeoMapNW is hosted by the University of Washington on its Seattle campus. The program director is also a senior lecturer and program coordinator at the university. She plans to utilize the tool in an educational setting with undergraduate and graduate students, further extending the use of the tool and the extent of benefits.

3.1.3 Type 3 Benefits

Type 3 benefits are "Quantifiable unpredictable events, or benefits that result from unpredictable events" (Antenucci 1991, p. 66). A major component of type 3 benefits in this case would be a reduction in damages (including casualties) caused by unpredictable geologic events such as earthquakes or landslides. These events are inevitable in the region, but predicting when and where they occur and the magnitude of damage that will result is challenging and complex, making quantification of benefits difficult. However difficult to quantify, the benefits in this category are real and significant. Improvements in geologic knowledge, understanding, and information sharing can be applied to planning and development decisions. Detailed geologic maps already produced by GeoMapNW have led to the identification of fault lines in the region.

Geologic knowledge can also be applied to understanding landslide susceptibility, and shaking strength and liquefaction potential during an earthquake. Without this kind of baseline information it is not possible to fully prepare and plan for a disaster-resilient community. Well informed decisions such as changes to building codes, zoning, or project approval on an individual site basis can be made only if the information exists and is shared. This tool will help both with developing the knowledge base and distributing the information. Given the occurrence of a geologic event with the potential to cause damage, having buildings and bridges that can withstand seismic events, siting dense developments in lower risk areas, or alerting residents of vulnerabilities can lead to real reduction in damages caused by geologic events.

3.1.4 Type 4 Benefits

Type 4 benefits are “Intangible benefits, or benefits that produce intangible advantages” (Antenucci 1991, p. 66). Antenucci further elaborates that “Although all GIS users enjoy the benefit of improved decision making, improved service to customers and constituents is another potential benefit important to most organizations. The ability to produce an answer or product more quickly, more accurately, in a readily usable form, and with specific content has significant albeit unquantifiable value.” (1991, p. 72). The tool was built to satisfy a need to more quickly and accurately produce content derived from the GeoMapNW data, in a usable and shareable format. In the case of the geologic cross section tool, another intangible benefit is that sharing the tool also has the potential to strengthen relationships between GeoMapNW and its community partners, as well as to lead to the building of relationships with new partners. Additionally, because an estimated 30% of the work performed by GeoMapNW will use this tool, it is highly likely that the tool will replace more repetitive workflows and increase morale by allowing employees to focus on more creative or challenging tasks.

3.1.5 Type 5 Benefits

Type 5 benefits are from the “Quantifiable sale of information, or benefits that result from the sale of information services” (Antenucci 1991, p. 66). GeoMapNW data is publicly available for no cost and it is not anticipated that a charge will be applied for data access in the future. However, this benefit is related to a project’s potential to bring in new revenue. Showcasing a new capability and sharing the tool could help solicit support for the program. GeoMapNW is currently seeking funding to continue operating and expand its capabilities. The tool will be highlighted in funding proposals, and should help to secure new sources of financial support. Funding would be used to hire additional paid staff, which would circle back to producing additional type 1 and 2 benefits. Additionally, GeoMapNW does provide some paid services, and the cross section tool could expand opportunities for revenue producing work. For example, a 2018 project for the city of Kirkland provided maps and other geologic hazard products for use in zoning code updates for hazardous areas. This project was completed for a cost of about $125,000. The added capabilities and efficiencies provided by the tool could lead GeoMapNW to solicit and secure additional paid projects such as this.

3.2 Costs of Commissioning a Student-Developed Geologic Cross Section Tool

Currently, GeoMapNW enjoys low overhead costs due to their affiliation with the UW, relatively low operational costs due to an absence of paid employees, and low capital costs due to free or discounted access to critical software as an educational organization. Costs to GeoMapNW from the development of this geologic cross section tool are manifested primarily as opportunity cost for the students developing the tool. While the costs associated with the student development of the geologic cross section tool therefore appear minimal, certain operating costs of the tool are inherently linked to the operational costs of GeoMapNW. These costs will be examined through the continuing use of the typology presented by Antenucci et al. (1991). The costs will be enumerated as accurately as possible, though a degree of estimation and assumption by the authors will be required in order to present a complete list. Though the tool development itself can be considered a low-cost project, the usefulness of the tool is linked to larger functions performed by GeoMapNW which in turn have larger associated costs. These costs are largely omitted from this analysis, such as costs associated with hosting an online database, as they pertain to both the student development of a cross section tool and all project alternatives.

3.2.1 Operating Costs Specific to Student-Developed Cross Section Tools

The Antenucci cost typology has two major types: capital costs and operational costs. Capital costs include durable goods with multi-year lifespans, and operating costs include personnel and other expenses incurred on a smaller time scale. Though they are anticipated to be minimal, there are some qualitative costs associated with the creation of our geologic cross section tool. Chief among these is the operating cost manifested as opportunity cost incurred by the three student developers in performing the programming and testing of the tool. We estimate that each person spends an average of 15 hours per week on tool development (exclusive of hours spent on other course requirements and papers). At this rate, across the 8 weeks of actual programming, our group performed a cumulative total of around 360 hours of work. The average annual salary of a GIS analyst in the greater Seattle Area was approximately $60,000 as of May of 2018 according to Glassdoor.com, before bonus and benefit additions. This represents an hourly rate of $29 per hour, meaning that if the students were to have performed this work for a paying client instead of as a capstone project they could have earned a shared total of around $10,500. However, this is not necessarily representative of the costs to GeoMapNW, who would have likely hired a consulting firm at a much higher hourly or project-based rate. Dr. Troost estimates that this project would have cost around $200 per hour if granted to a contracting agency (either by a programming or GIS-based consulting firm), meaning that a similar input of work hours would have resulted in a $72,000 project cost to GeoMapNW. In all likelihood this cost would be reduced if the consulting agency had staff experienced with programming, as their time necessary to complete the project would be less. This could feasibly be represented by a single contractor charging $200/hr for 20 hours of work each week during the nine week duration of the quarter, which would cost the organization $18,000. Based on these estimates and costs associated with similar projects, a project cost in the low to mid five figures would certainly not be unreasonable to assume. Fortunately, the operating costs are in this case are incurred during the duration of a single academic quarter. Further operational costs related to the cross section tool are minimal and include future script adjustments for compatibility changes across GIS software versions.

3.2.2 Capital Costs Specific to Student-Developed Cross Section Tools

Capital costs associated with tool development are primarily manifested by software needs. In addition to the operational cost of the programming, tool testing requires access to ArcGIS (version 10.2 or newer with an advanced user license), and the 3D Analyst extension (currently estimated at a cost of $4,800 for an annual subscription for an independent worker). These costs can be considered capital costs as they represent single large purposes of long-lasting equipment.

Fortunately, this access is available at no cost to GeoMapNW and the student developers with the UW Educational Site License. While it is possible to create a tool that performs a similar task outside of the ESRI ecosystem by using alternative GIS software such as the free and open-sourced Quantum GIS (QGIS) and the Geospatial Data Abstraction Library (GDAL) as an alternative to the Arcpy Python site package, the amount of market saturation enjoyed by ESRI means that a tool developed specifically for use in ArcGIS using Arcpy will be usable by the maximum possible number of project partners with the most ease. Due to this consideration, access to this ESRI software is a critical for both tool development and use and should be considered as part of the project cost in both the development and use phases of the tool. Because of the dependency on ESRI for the tool function, it should also be noted that ongoing periodic maintenance will be required for the tool to remain operational. This tool creation project was necessitated in the first place by the obsolescence of an older tool that performed the same tasks in ArcView, a discontinued and unsupported program. This tool was written in VBA, which is no longer compatible by default with ArcGIS software. Custom configurations or conversion to an ArcMap add-in would allow for theoretical compatibility, though this process is technically demanding and not viable for many GeoMapNW clients and project partners. As the prebuilt tools are changed with subsequent versions of ArcGIS, certain Arcpy functions and commands may no longer work as intended with each software release, and user testing and occasional script editing will be necessary at a minimum of once per release. Further, with the end of support for ArcMap coming within the next decade, there will be an eventual need for the script to be re-configured for use in ArcGIS Pro or an equivalent program when it is no longer feasible for organizations to rely on applications like ArcMap. This work could reasonably be expected to be performed by student assistants, costing them an investment of time and effort.

<u>3.3 Benefit-Cost Analysis: Cost savings vs. Alternative solutions</u>

GeoMapNW is a highly atypical organization. As a grant-funded, collaborative research center hosted by the University of Washington, they do not incur the same operating or capital costs incurred by private equivalents. At the same time, many information products produced by the organization are available free of charge, with the exception of occasional contracted special assignments. Because of this, many traditional cost-benefit analyses are confounded by the task of determining exactly how to calculate the true costs and benefits associated with their operation. How can you value enhanced emergency preparedness in a community informed by high-resolution geologic mapping? How do you measure the cost of time spent applying and searching for grants? How do license subscriptions, overhead, IT, and related services provided by the University of Washington fit into the GeoMapNW budget? This challenge is compounded by the current status of GeoMapNW as an organization: since 2011 the center has been unofficially closed, with Kathy Troost acting as the sole unpaid staff member and director. Most activities that the center would perform themselves with associated costs (such as hosting an online database) have been shifted to partners like the Washington State Department of Natural resources.

However, Dr. Troost has stated that GeoMapNW requires approximately $500,000 in annual funding to function at maximum capacity. Fully staffed, this would include three full-time geologist positions and five part-time student positions. In our meetings, Dr. Troost mentioned that she is currently completing a proposal for funding and seeking additional grant money to re-open the center and hire paid employees. This tool is expected to feature prominently in both the applications for funding and in future work performed by the center, with approximately 30% of all work involving use of the tool. Because of this, and the relative uselessness of estimating cost savings for an organization that is incurring no costs, the following cost-benefit analysis relies on the assumption the GeoMapNW is able to reopen and operate with full staffing. Most benefits and cost savings presented by the tool are represented by Antenucci's Type 1 benefits: they are quantifiable efficiencies in current practices. Dr. Troost was unable to inform us how much time this tool will save, though if we assume that 30% of all work hours are to be made more efficient through automation we can liken the tool to an employee that is performing a repetitive task. Assuming 3 full time and 5 part time staff members, this increase in efficiency is very roughly equal to the addition of a full-time employee without salary or benefits. Aside from Type 1 benefits, there are cost savings inherent in using student developers over professional tool developers, which have been discussed in prior sections. Type 2 benefits in the form of expanded and additional capabilities include the ability to use the tool as a means for achieving grant eligibility. This benefit is again somewhat difficult to estimate, as grant eligibility does not necessarily mean that the grant will be won. An additional type 2 benefit is the expansion of the use GeoMapNW data to other organizations made possible by the tool. Although it is difficult to predict exactly how many users outside of GeoMapNW will utilize the tool, Dr. Troost has stated that numerous partners are interested in the tool. For estimation, it could be assumed that across all partners, the efficiencies and expanded capabilities afforded by tool use would equate to the annual work of a single full-time GIS Analyst with a salary of $60,000.

Table 5 below presents a summary of the cost savings presented in this section. Dollar amounts calculated for workflow automation, grant awards, and client attraction all assume that the tool will be used continuously throughout the year at a relatively even rate, and therefore divide a total assumed cost savings or benefit by a 52 week year. For example, Dr. Troost stated that the tool will feature in a proposal for funding that will allow for the addition of paid staff if accepted. Assuming that one full time geologist and one part-time student will be hired, this proposal will bring in at least $78,000 (approximately $60,000 to cover a geologist salary and $18,000 for a part-time student employee). This means the tool will create a benefit of $1,494 on a weekly basis. Table 6 presents a summary of the costs associated with the purchase of alternative specialized software (RockWorks by RockWare) to replace development of a custom tool, and costs associated with the use of a private contractor to develop a custom tool. Not included in this table are the costs associated with reconfiguring the data present in the GeoMapNW database to be compatible with RockWare, which is one reason for not choosing that option despite the relatively low weekly cost representing a license fee at a weekly rate. These cumulative costs for each alternative to the student-developed cross section tool are presented graphically alongside cumulative benefits to using the student-developed tool are shown below in Figure 5.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Total
Workflow Automation	460	460	460	460	460	460	460	460	460	4,140
Grant Awards	1,494	1,494	1,494	1,494	1,494	1,494	1,494	1,494	1,494	13,446
Client Attraction	2,404	2,404	2,404	2,404	2,404	2,404	2,404	2,404	2,404	21,636
Type 3 Benefits (N/A on this time scale)	-	-	-	-	-	-	-	-	-	-
Student vs. Contractor tool development	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	36,000
Weekly Cost Savings Total	8,358	8,358	8,358	8,358	8,358	8,358	8,358	8,358	8,358	75,222
Cumulative Total Cost Savings	8,358	16,716	25,074	33,432	41,790	50,148	58,506	66,864	75,222	-

Table 5. Estimated cost savings over a nine week period with the geologic cross section tool (assuming full operating capacity with 3 geologists and 5 student assistants). All values are in dollar amounts.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Total
RockWorks Software	58	58	58	58	58	58	58	58	58	519
Cumulative RockWorks Software Costs	58	115	173	231	288	346	404	462	519	-
Contractor Tool Development	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	36,000
Contractor Cumulative Costs	4,000	8,000	12,000	16,000	20,000	24,000	28,000	32,000	36,000	-

Table 6. Estimated expenditures over a nine week period using RockWorks proprietary software and estimated cost for a contractor to develop the geologic cross section tool. All values are in dollar amounts.

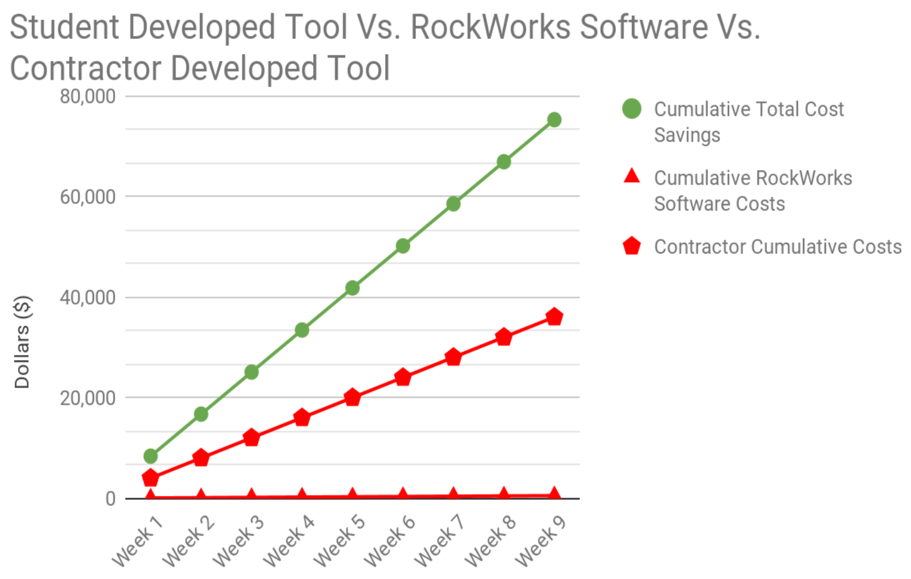


Figure 5. Total cost savings vs. cost of alternative solutions. See row 7 from table 1 for cumulative total cost savings input amounts and rows 2 and 4 from table 2 for RockWorks software and contractor cumulative costs input amounts.

<u>3.4 Benefit-Cost Analysis Conclusions</u>

The development of a custom tool used for partially automating the creation of geologic cross sections would provide numerous and significant benefits to GeoMapNW. Particularly Type 1 (efficiencies in current practices) and Type 2 (extended or additional benefits) benefit types can be quantified and used as persuasive arguments for tool development in a cost benefit analysis. Type 3 benefits (benefits related to unpredictable events) are also a significant factor and one that should be presented in an argument in favor of developing the tool, although these are harder to quantify and not applicable given the 9 week time scale that was considered in the cost-benefit analysis presented here.

Due to the current semi-operational nature of GeoMapNW, the low cost of student tool development, minimal training requirements for tool proficiency, and a minimal time investment on behalf of GeoMapNW to commision the tool, the cost-saving benefits of this GIS project clearly outweigh more expensive alternatives, such as the purchase of specialized software or hiring a contractor to develop the tool. Of the three available scenarios, the construction of a custom tool is the only one that presents cumulative benefits as opposed to cumulative costs. Due to the nature of custom tool creation, this project will also deliver a product that will not require extensive database reconfiguration to ensure compatibility.

4. DATA DEVELOPMENT

This project is focused on creating a geologic cross section tool to interact with existing data, schemas, and data models. At project launch, Dr. Troost provided a well organized and extensive geologic file geodatabase containing all data necessary for tool development. The objective of the geologic cross section tool was to have the toolbox interact with other geologic file geodatabases that may have a different file structure than GeoMapNW but will have a similar database design based on join tables and feature classes joined through primary and foreign keys. To begin development for the cross section tool design, Dr. Troost provided the authors with a subset of the primary GeoMapNW database, complete with all feature classes, relationships, tables, and rasters. This database was delivered to the City of Kirkland in 2018 in an effort to assist them in revising Zoning Code 85 (Critical Areas: Geologically Hazardous Areas) for public safety purposes in order to be in compliance with the Growth Management Act. GeoMapNW's database design was well thought out and organized, as its intended purpose is to be used by a variety of public and private organizations. The database is used for site suitability studies, seismic hazard assessment, groundwater infiltration studies, and planning hazard mitigation strategies. The work GeoMapNW has done with the design of their database is exceptionally detailed. The amount time and effort spent by GeoMapNW staff, project partners, and students from the University of Washington to compile and integrate geotechnical and geological engineering reports from over 100,000 borehole permit applications into the GeoMapNW database represents an incredible investment of effort.

4.1 Data Acquisition

The ESRI file geodatabase was shared by Dr. Troost to us via DropBox and a Team Google Drive we had set up for the project. Data acquisition was very straightforward, as the authors simply download the data file and made a local copy on their personal computers for faster processing. On the other hand, GeoMapNW is continuously adding more geologic data to their database. Since GeoMapNW has opened by 2010 they had approximately 60,000 exploration points from the Seattle area. Now they have integrated over 100,000 explorations into the database.

In order for our tool to work with GeoMapNW's database, the authors had conducted research to possibly find past methods and solutions that would automate geologic cross sections. As said in section 1.1.3, we found proprietary software that was too expensive and unrealistic, and we also found VBA scripts that are no longer compatible with the current version of ArcGIS. We decided our tool needed to be written with Python's Arcpy module. Of the scripts we did find, our main script heavily relies on Evan Thoms of the USGS geologic cross section tool created in 2005. Thoms script is a beta version written with the Python Arcpy module. We streamlined Thoms' script to work with GeoMapNW database.

4.2 Data Quality Issues

We did not encounter any data quality issues, due to receiving a functioning database that had all the data requirements in order for our tool to work. We did not have to perform any post processing of data. The unique ID field found in the feature classes and tables provided enough detail in order to join attribute tables. There were no issues with GeoMapNW database apart from possibly how data from the geotechnical reports they receive is processed and input. From what we know, staff and students manually process the reports and integrate the data into their database. This process is time consuming and can be prone to errors, although there are extensive quality assurance (QA) procedures in place to mitigate human error. This process could be automated by scraping pertinent information that will be included in the database.

Included in the data package we received from Dr. Troost, was a master ReadMEfile, *GeoMapNW Kirkland Geologic and Geological Hazards Maps and Products 2018 Master ReadME file.* In this file, we found explanations of data gaps that exist. Residential neighborhoods, as an example is difficult to gather subsurface data from due to sound nuisance that the drilling process would create. However, for our project this is not a concern. We did find one issue with database design that would allow our tool function better. It would be helpful if the tables were created as feature layers, as this would eliminate several steps in the scripting process.

4.3 Future Data Preparation

The nature of our project involves the automation of data manipulation. We did not have to manually alter the data provided, as the tool will perform these processes for the user. The user will be responsible for providing minimal inputs and data, such as creating a cross section line and specifying tool parameters including buffer distance from the cross section line for the selection of explorations to be visualized. Our tool will perform three broad categories of tasks involving the display of data. We have been assigned to 1) create an elevation profile in a cross section view from an input line or selection of explorations, 2) create stick logs for each exploration occurring along the input line or selected explorations, and 3) display additional indicators, such as the groundwater depth and the density of the layers shown in the stick logs. Each of these tasks requires additional data preparation as described below. Most preparation will occur during the execution of our tool.

1) Elevation Profile Display

Input data must include a DEM and a transect line (or selection of explorations through which a best fit transect will be generated). The transect line elevation values will be interpolated from the DEM surface with the 'Interpolate Shape' tool. It will then be added to a new feature class with an unknown spatial reference so that it can be displayed correctly in profile in a 2D setting.

2) Sticklog Display

Our tool requires turning geologic exploration locations and layer information into a 2D cross sectional view of the layers selected near a transect line. In working to visualize a layer profile of a borehole or similar exploration, it is beneficial to have a feature class or table that has a discrete feature or row for each layer. Unfortunately, the data provided only offers the XY location of the exploration in a point feature class. A layer table containing layer depth, composition, density, and other Z information is joined to this feature class by a common exploration ID field (EXPLOR_ID). In order to display each layer as a feature in ArcMap or ArcPro, we have decided to create a line feature class, with the line length being proportional to the layer depth, and the line location originating at the borehole location and extending downward. More details of how this function works is in the results section 6.1.1.

3) Indicator display

Because indicator depth is known, displaying properties such as density and water table depth is relatively simple. Interpolation of depth was used again, and linear referencing, route creation, and/or cartographic buffers were be applied.

All data preparation should occur concurrent with tool use, and the data outputs will be minimal. Feature classes created through intermediate processes are deleted or stored locally for reference.

4.4 Shared Group Challenges

GeoMapNW has done an exceedingly thorough job in data collection. Not once did we need to find additional data not provided by the database, unless the originating geotechnical document did not include values. An example of this is the exploration elevation field (EXPLOR_ELEV), for which approximately half of the explorations have a value of 0 and an elevation source that is null. This is because the height of the exploration was not recorded in the original geotechnical document or supporting materials. Because the height was recorded as 0 and not as null, it is difficult to tell which explorations truly originate at sea level and which have no actual elevation record. To address this, our tool is able to interpolate heights for the exploration based on an area DEM, although this is not always an accurate method and means that a cross section may display stick logs for explorations that do and do not have initial elevations. Explorations without elevations then appear to always begin on the DEM surface, even if they began in a local depression or outcropping or terrain that was altered before or after the creation of the DEM. Geologists using the tool will be made aware of this fact.

4.5 Database Schema Specifications

The following section will describe the database schema that we received from Dr. Troost. In Table 7 is a list of rasters, tables, and feature classes that is required for the tool to work properly. The full schema table GeoMapNW has compiled can be found in Appendix A, Table 10. In the file geodatabase, we have a variety of raster layers, vector data (points, lines, and polygons) and tables. Third-party databases that will be using the geologic cross section tool will need to have a similar database structure for the tool to work correctly. For example, a unique ID field will need to be made across all feature classes and tables in order to for the tool to function properly.

Field Name	***Source***	***Spatial Object Type***	***Description***
Rasters			
Kirk_Lidar	GeoMapNW - Kathy Troost	Raster	DEM
Feature Classes			
Data_Points	GeoMapNW - Kathy Troost	Point	Surficial geology data
CrossSection	User	Line	Create lines for cross sections
Tables			

GROUNDWATER_WW	GeoMapNW - Kathy Troost	Table	Groundwater data from exploration, and well logs table
SUBSURF_LAYER	GeoMapNW - Kathy Troost	Table	Subsurface layer descriptions table
Tools			
Sticklog&Groundwater& Profile	Script created by project group	Script tool	Tool to create elevation profile, sticklogs, and groundwater
Symbology	Script created by project group	Script tool	Applies major material, density, and groundwater symbology
Export2Graphic	Script created by project group	Script tool	Export to graphic output

Table 7. Database Schema Specifications. Required rasters, feature classes, tables, and tools that is required for the geologic cross section tool to function using GeoMapNW database schema.

4.6 Description of Attribute Table Information

Attribute table information as described in Table 8 illustrates the work GeoMapNW has put into compiling geologic records from boreholes, and other exploration records. For documentation and metadata, GeoMapNW provided us with the *GeoMapNW Kirkland Geologic and Geological Hazards Maps and Products 2018 Master ReadME file*. This file provided detailed information about the attribute tables and the fields to be used in order for us to progress with our geologic cross section tool development. The full attribute table information can be seen in Appendix A, Table 11.

Field Name	***Description***	***Data Type***	***Length***
EXPLOR_ID	Exploration ID	Long	10
EXPLOR_DEPTH	Exploration Depth	String	10
EXPLOELEV	Exploration Elevation from report	String	10
EXPLOELEVD	Exploration Elevation from DEM	Date	8
EXPLOR_ID	Exploration ID	Long	10
GROUNDWATER_DEPTH	Depth to groundwater	Float	8
EXPLOR_ID	Exploration ID	Long	10
LAYERTOPDE	Layer Top Depth	Float	8
LAYERBOTDE	Layer Bottom Depth	Float	8
DENSITYRAN	Density Is Range?	Short	5
MATDENSITY	Material Density	String	10

MATMAJOR	Major Material Type	String	10

Table 8. Attribute Table Specifications for DATA_POINT feature class and associated tables that are used in the geologic cross section tool.

4.7 Content Metadata Descriptions

The table below is a data data dictionary containing descriptions of each dataset necessary for tool operation. The full data directory can be seen in Appendix A, Table 12. Data quality considers components of accuracy, resolution, consistency, and lineage across location, theme and time, as described by Paradis and Beard (1994). Data lineage is described in detail in Section 1 of this document. Information for the dictionary came from the *GeoMapNW Kirkland Geologic and Geological Hazards Maps and Products 2018 Master ReadME file*, data properties as viewed in ArcCatalog, and metadata included with each data set. Because the tool was developed for GeoMapNW, and GeoMapNW also created the data and desires a tool that will work with the existing data and data structure, it can be assumed that in the context of GeoMapNW's use of the tool, the data is suitable. Although future improvements in accuracy, detail of attributes, or coverage of exploration points across the region may be improved, the goal of the current project is to create a tool for use with the existing data. Future improvements in data quality may, however, lead to more accurate interpolations drawn from the data.

File Name	***Description***	***Quality****
Kirk_Lidar	Bare earth DEM	2016 Lidar; 3 feet resolution
Data_Points	Compilations of exposures and explorations from subsurface investigations and observations at field sites in City of Kirkland. This is the primary feature class that will be used with the tool. Associated tables (SUBSURF_LAYER, SUBSURF_COM, BLOW_COUNT_WW, GROUNDWATER_WW) should be used with this feature class for information of subsurface layers and other details for each point location.	Compiled by GeoMapNW 2010 and 2016-17 from outside sources and validity/quality of original data is not guaranteed. Location accuracy is included as an attribute field.
Kirk_Lakes	Lakes in Kirkland polygon feature class.	For general mapping purposes only.
GROUNDWATER_WW	Groundwater data from multiple sources including monitoring wells installed in subsurface explorations, and water well logs. Includes depth to groundwater, how depth was measured, and observation date. May reflect seasonal groundwater occurrence. should be joined to Data_Points layer using "exploration_id" field.	Data compiled by GeoMapNW 2010 and 2016-2017
SUBSURF_LAYER	Subsurface layer descriptions table; should be joined to Data_Points layer using "exploration_id" field.	Data compiled by GeoMapNW 2010 and 2016-2017
Sticklog&Groundwater&Profile	Script to plot elevation profile, borehole stick logs and groundwater in a cross-sectional view	This script heavily relies on Evan Thoms of the USGS beta version.

Symbology	Script to apply symbology to major material, material density, and groundwater	Script created by project group
Export2Graphic	Export current extent to graphic file	Script created by project group

Table 9. Metadata descriptions for rasters, feature classes, tables and tools.

5. WORKFLOW IMPLEMENTATION

In order to provide a suitable deliverable to GeoMapNW at the culmination of the academic quarter, a workflow processing plan was developed to guide both technical objectives and project deadlines. This plan was primarily informed by the critical tool functions identified during project scoping, and was used as a guide throughout the processes of tool development, troubleshooting, user-testing, and delivery. The following section details the process involved in the creation of the workflow processing plan and the resulting actual workflow used to create the geologic cross section tool.

5.1 Determination of Deliverables

The format of the final cross section tool deliverable was discussed during a preliminary project scoping meeting with Dr. Troost on 26 June, 2018. During that meeting it was explained that GeoMapNW had developed a set of tools between 1999 and 2002 in Visual Basic for Applications (VBA) for displaying down-hole geologic data in ESRI's ArcView 3.x versions. An example output from these tools is shown below in Figure 6. Due to the replacement of ArcView with ArcGIS in 2000, these tools were quickly made obsolete. Additionally, prepackaged support for the VBA programming language was discontinued with ArcGIS 10.x releases, requiring VBA tools to be migrated to VB.NET or directly to compatible ArcGIS add-ins. This conversion process was quickly decided to be both difficult and less useful than existing alternatives. It was ultimately decided that the best practice would be to create a new Python-based tool by writing Python script that could be executed from a script tool or tools housed in a shareable ArcGIS toolbox. This script could be easily customized by users with basic Python familiarity to ensure compatibility with new versions of ArcGIS and for eventual migration to ArcGIS Pro.

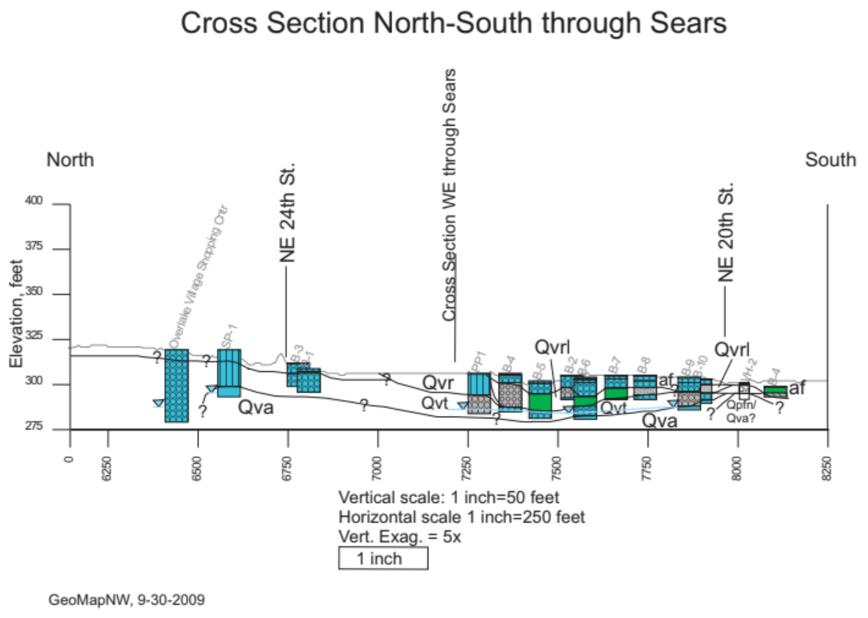


Figure 6. Output from a VBA tool developed for GeoMapNW displaying a 2D cross section including elevation profile and geologic exploration layer composition.

Critical software capabilities were also identified by Dr. Troost during the scoping meeting. A selection of outputs from the VBA tools were provided and used as a rough approximation of the functionality that our tool should provide. At minimum, the tool should provide a 2D cross section view of a surface profile and subsurface geologic layers drawn from an input cross section line and a selection of geologic explorations from the GeoMapNW database, with appropriate symbology applied to the layers so that material class and density are apparent. Additionally, the tool should indicate groundwater depth when encountered and allow the user customizable vertical and horizontal exaggeration and the ability to export the cross section to an image file. These identified capabilities were distilled into a series of need-to-know questions that could be addressed by our script and tool, including:

- ❏ What data points should be included in the cross section?
- ❏ What is the elevation profile along the cross section line?
- ❏ What is the location of each exploration and stick log relative to the cross section line?
- ❏ What is the major material of each subsurface layer?
- ❏ What is the density of each layer?
- ❏ What is the depth of each layer?
- ❏ What is the groundwater depth for each exploration?
- ❏ How will appropriate symbology be applied?
- ❏ How will the above be displayed visually in a graphic output?

Knowing the format of the final deliverable and focusing on key software capabilities identified with these questions allowed for the creation of a workflow processing plan that included target dates for the completion of scripts, a timeline for the creation of the final tool delivery, and plans for user testing, implementation, and reporting.

5.2 Refining the Workflow Processing Plan

Following the identification of both deliverables and deadlines, further discussion of technical limitations and considerations to the eventual user interface yielded a framework for the division of software capabilities across multiple tools. It was decided that a main script would be written for a tool to create an elevation profile, stick logs, and additional information requested by GeoMapNW in a 2D cross section view. A second script would be written to apply symbology and labels, and a third script would be written to export the current map view to an image file for further processing. These tools would be packaged in an ArcToolbox integrated application (.tbx) and constitute the primary deliverable to GeoMapNW. Secondary deliverables would include tool help (both supporting documentation and in-line help from an HTML file or a compiled .chm help file), symbology layers necessary for applying symbology to stick log material type, density, and groundwater location, and the three scripts with developer commentary used for tool creation. With deliverable requirements, capabilities, formats, and organization determined, preliminary research was conducted to examine possible workflows.

Initial research regarding existing commercially-available cross section tools quickly confirmed the problems that Dr. Troost mentioned regarding their suitability for her work and underscored the need for the development of a custom tool. Most available software require licenses with expensive pricing, and nearly all would require an alteration or additions to the GeoMapNW exploration database schema. Further, a proprietary tool would not allow for data or tool sharing among the many partners that assist or are assisted by GeoMapNW. Due to financial and staff availability considerations, these concerns quickly invalidated the use of existing software. Our research turned to free and open source software, the existence and functionality of which is extremely limited. However, one promising software package consisting of a geoprocessing tools for working with geologic cross sections in ArcGIS was found on GitHub. These tool and scripts had been authored relatively recently, with most files updated between 2013 and 2016. The author of these tools, Evan Thoms, is an employee of the USGS and explicitly states that his software is in the public domain because it contains materials that originated with the USGS. An example dataset included with the software contained data obtained from GeoMapNW, and with some testing and minor code alteration these tools were found to be compatible with current versions of ArcGIS. It was determined that, with some modification, these tools and scripts would be able to form the basis of our deliverable to GeoMapNW. The tools provided the ability for a user to generate elevation profiles and line stick logs in a 2D cross section view, though the selection method, customizations, tool assumptions, and outputs would require alteration for our purposes. Figure 7 demonstrates the outputs of these tools. With an understanding of existing software capabilities and operational methodology, sufficient information was gathered to allow for the creation of a workflow processing plan. This plan was altered somewhat from inception to realization, and the final actual workflow implementation is explained below.

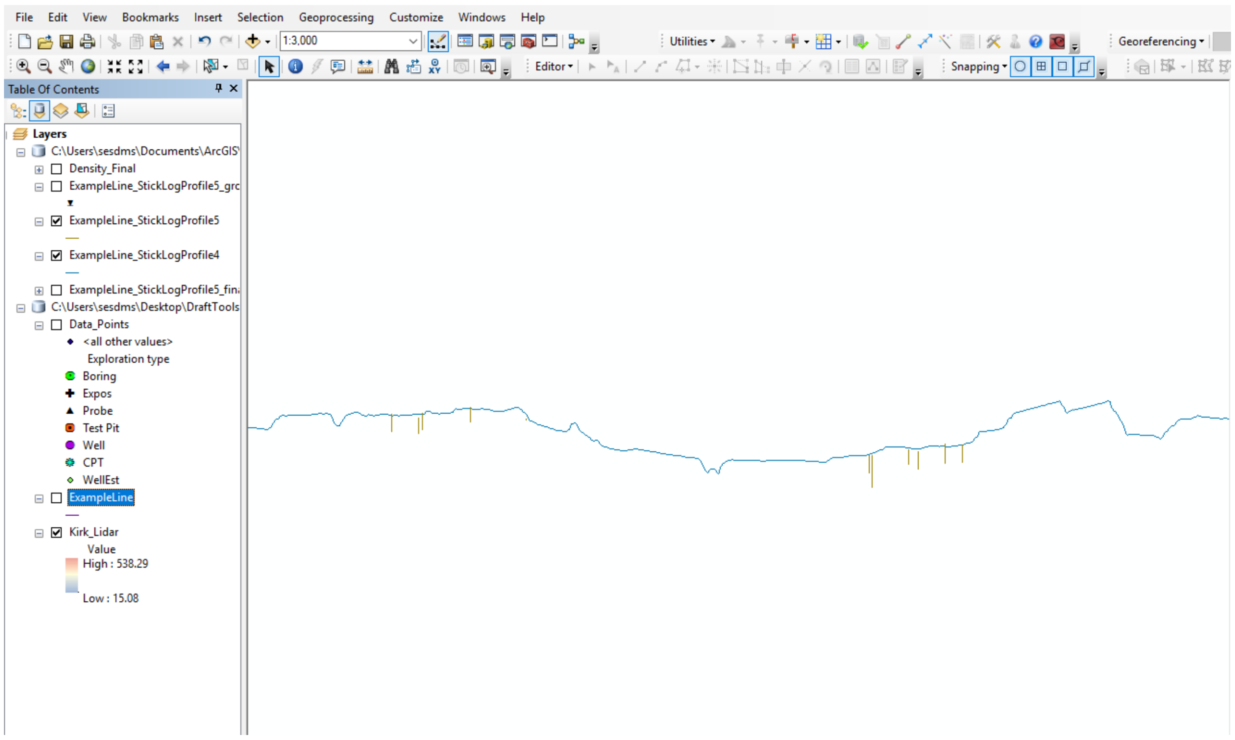

File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
1:3,000
Utilities
Georeferencing
Editor
Snapping
Table Of Contents
Layers
C:\Users\sesdms\Documents\ArcGIS\
Density_Final
ExampleLine_StickLogProfile5_grc
ExampleLine_StickLogProfile5
ExampleLine_StickLogProfile4
ExampleLine_StickLogProfile5_fin
C:\Users\sesdms\Desktop\DraftTools
Data_Points
<all other values>
Exploration type
Boring
Expos
Probe
Test Pit
Well
CPT
WellEst
ExampleLine
Kirk_Lidar
Value
High : 538.29
Low : 15.08

Figure 7. Outputs from Evan Thoms' geoprocessing tools for use with geologic cross sections in 10.x versions of ArcGIS.

<u>5.3 Actual Workflow Implementation</u>

General workflow primarily involved writing Python scripts. Each of the three required tools had a separate script, and all three group members assumed the role of programmer to assist with writing code for each script. Operations flow diagrams were created in early project stages to assist with conceptual understanding of script operation. These diagrams are presented in the following sections to represent both how each script was written and how the script works by the calling of specific functions and operations. Our scripting relied heavily on the Arcpy Python site package, which benefits from being native to Python with access to numerous modules developed for various GIS niche uses, code completion, and a variety of available functions and classes. Operations flow diagrams are demonstrated below for each script written.

5.3.1 Stick Log and Elevation Profile Tool Operation Flow

The script to generate a 2D cross section view of stick logs, elevation profile, and groundwater depth is the largest and most complex script, with 645 lines of code (including notation). This script began as two separate scripts posted by Evan Thoms which were originally intended to generate a surface profile from a cross section line and stick logs within a buffer distance from a provided cross section line. These scripts were joined, common variables were identified, and some extraneous functionality was removed. After a working script was obtained, modifications to the original script were added to include the ability to:

- ❏ Select specific explorations to include in the output instead of relying on a buffer distance from the line for finer control over the eventual 2D cross section output
- ❏ To allow for the user to specify the starting exploration elevation (the Y value from which the exploration extends downward) as a field or to be interpolated from an accompanying DEM
- ❏ To specify a horizontal exaggeration for the final output (in addition to included vertical exaggeration)
- ❏ To create a point feature class representing groundwater location (depth), when encountered in an exploration
- ❏ To buffer and order the stick log line outputs to better visually represent the outputs as geologic layers appropriately located

The script is broken into several sections. It begins by importing necessary modules. Lines 24-325 provide definitions for functions that are called for execution later in the script. Lines 332 to 395 define the parameters. The workspace is then set, and the main body of the script begins at line 410. First, the ‘addAndCalc’ function is called, which adds a field (ORIG_FID) with an rkey value to the cross section line that will undergo transformations that may overwrite the OID value. The input line is then interpolated using the ‘arcpy.InterpolateShape_3d’ function, and a zLines feature class is created. This is a near exact copy of the input line, but with an rkey field and z value field added. M values are added to the zLines layer using the ‘arcpy.CreateRoutes_lr’ function, which creates accumulated measures by using the geometric length of the input features and writing m values to a zmLines feature class. Measures are assigned according to the coordinate priority specified by the user. Attributes from the original line input and the zmLines layer are joined by using the ‘transferAtts’ function, which performs a join based on the calculated rKey field and creates a new zmAtts feature class. Next, a new feature class, zmProfiles, is created with an unknown spatial reference and the zmAtts feature class is appended to it before calling the ‘plan2side’ function. This function updates the existing geometry of the feature layer line and essentially changes the line from a 2D map (plane) view to a 2D cross section (side) view by creating an array that transforms existing x and y values into z and m values, where z values are obtained by interpolating the cross section line with the arcpy.InterpolateShape_3d function and m values are measured distances from the beginning of the cross section line to the exploration location (see Figure 8 for an illustration of this process). Within this function, a drawing order is specified for the cross section line to determine where the m values are drawn from and the horizontal and vertical exaggerations are applied as a multiplier, if applicable. As the end result, this feature class is copied and provided in a feature class as named by the user in a location specified by the user. This feature class is the cross section line profile. Calculated rKey fields are deleted from the input line, and several intermediate geoprocessing results are deleted. This process is shown in Figure 9.

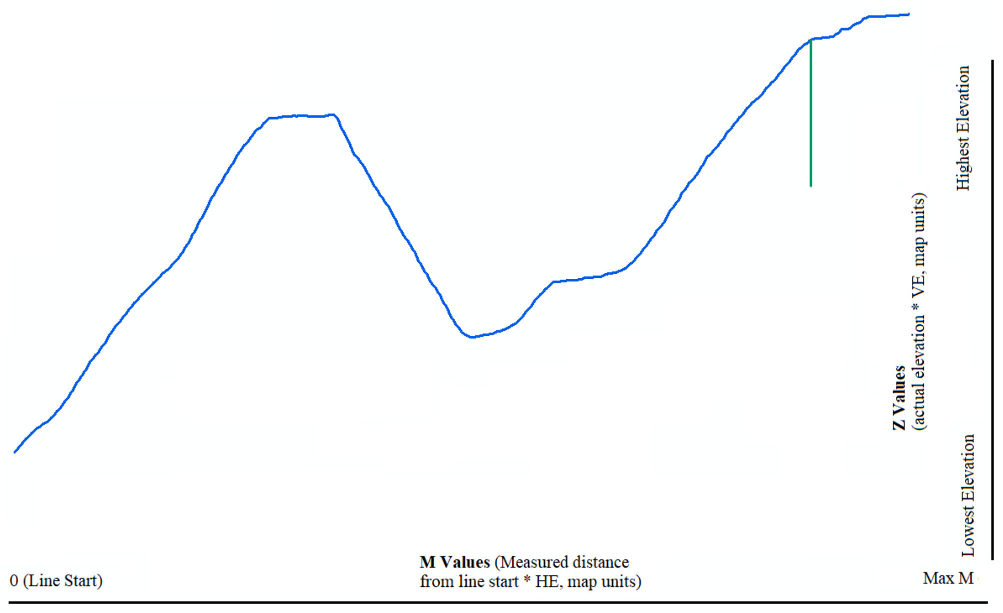
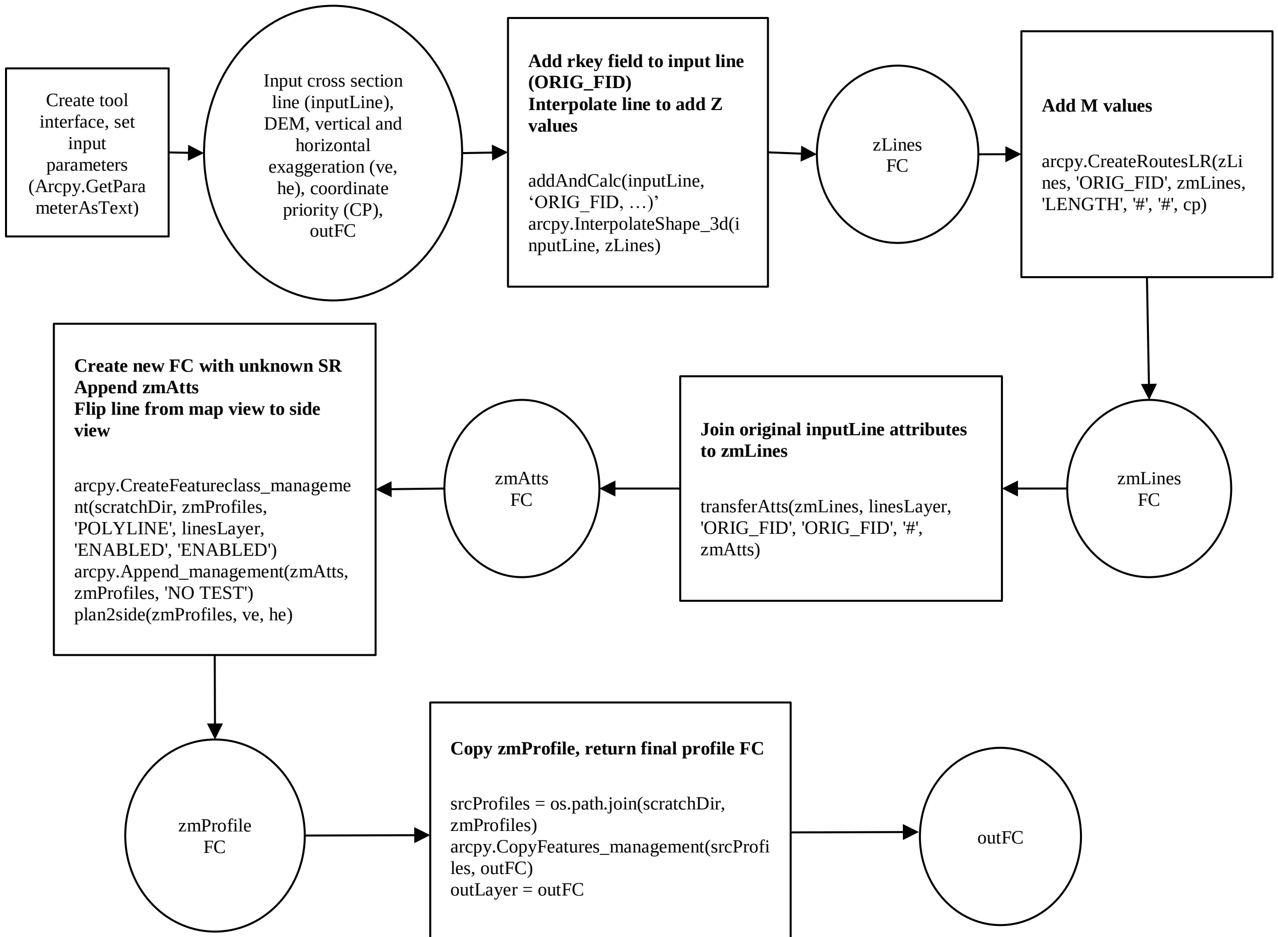

Highest Elevation
Z Values
(actual elevation * VE, map units)
Lowest Elevation
0 (Line Start)
M Values (Measured distance from line start * HE, map units)
Max M

Figure 8. A surface profile and stick log with an unknown spatial reference drawn using M and Z values obtained from route measurement and elevation interpolation described in section 5.3.1.

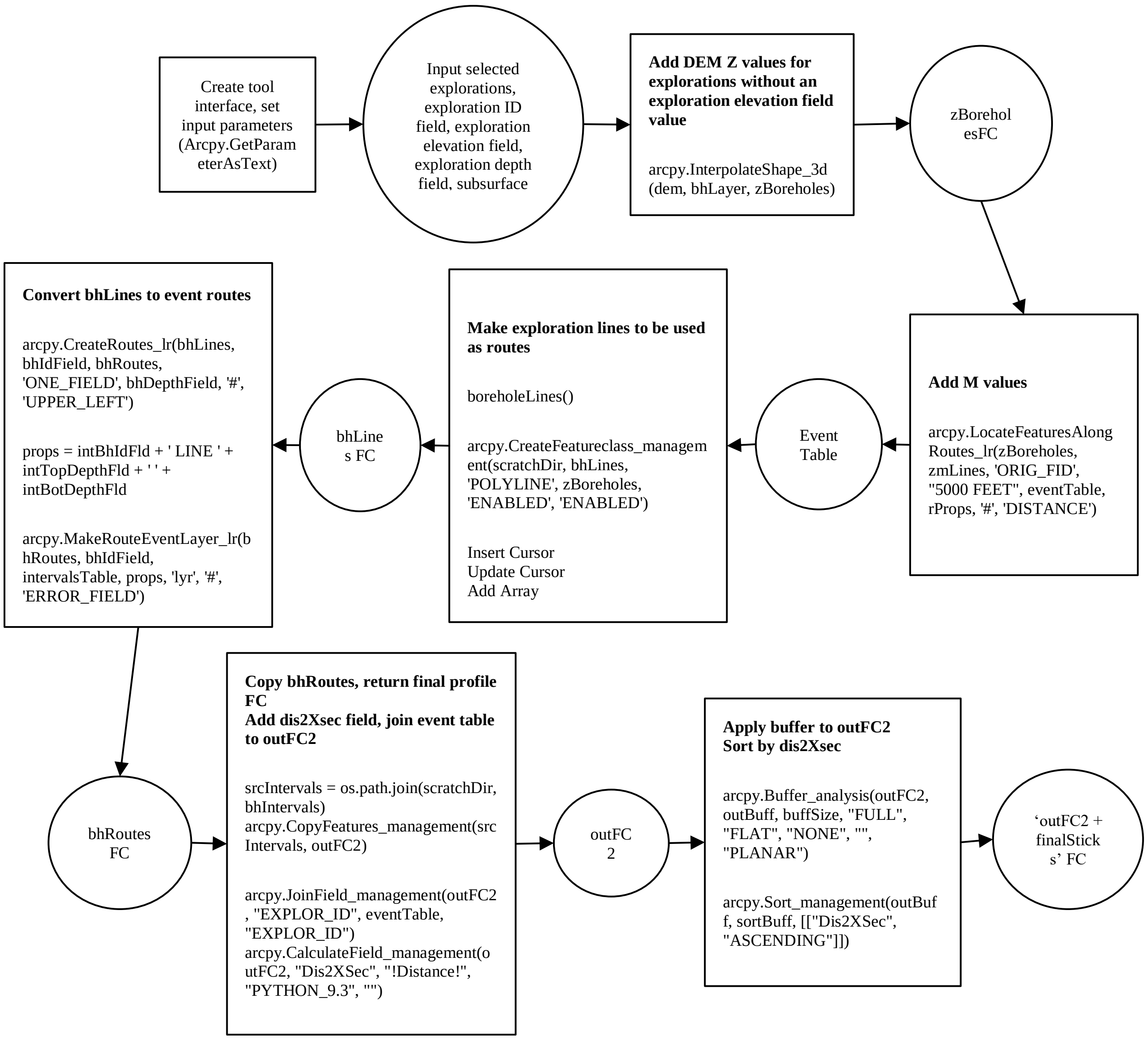
After creating a surface elevation profile, the next code block creates stick logs from selected explorations. First, selected explorations are interpolated to obtain a starting elevation if an exploration elevation field is not specified or the field value is null using the 'arcpy.InterpolateShape_3d function'. The resulting zBoreholes feature class contains explorations that are located along the zmLines feature class from the previous surface profile code block using the 'arcpy.LocateFeaturesAlongRoutes_lr' function. This function yields an event table containing route IDs, route location data, and other information created during the generation of z and m values for various feature classes in the creation of the surface profile feature class. Exploration lines are then created by calling the boreholeLines function, which first creates a new bhLines feature class and then opens a search cursor on the event table and an insert cursor in bhLines. For each row in the event table, which contains a row for each exploration that will be included in the bhLines feature class, the beginning y coordinates for the points are set according to the borehole elevation or interpolated elevation multiplied by the applicable vertical exaggeration. Ending y coordinates are calculated by applying the same multiplier to the exploration depth. The x coordinates are calculated using the m values for the location from the zmLine feature class, multiplied by the appropriate horizontal exaggeration.

These points are added to an array, and the features are added to the bhLines feature class with the insert cursor. The resulting lines from the bhLines feature class are measured and assigned m values using the ‘arcpy.CreateRoutes_lr function’, resulting in a new bhRoutes feature class. Using an input subsurface layer table with top and bottom depth fields, the ‘arcpy.MakeRouteEventLayer_lr’ function is used to place exploration layers along the exploration routes in a new feature class, bhIntervals. A new field is added to bhIntervals and the distance from the cross section line to the exploration is populated in the field for later use in ordering the placement of the stick logs. The feature class is then copied and renamed as specified by the user and written to the location specified by the user. A buffer is applied and a sort operation is performed to yield the final stick log feature class that is ready for the application of symbology. The process for creating the output stick logs is shown below in Figure 10.



Create tool interface, set input parameters (Arcpy.GetParameterAsText)
Input cross section line (inputLine), DEM, vertical and horizontal exaggeration (ve, he), coordinate priority (CP), outFC
Add rkey field to input line (ORIG_FID)
Interpolate line to add Z values
addAndCalc(inputLine, ‘ORIG_FID, …)’
arcpy.InterpolateShape_3d(inputLine, zLines)
zLines FC
Add M values
arcpy.CreateRoutesLR(zLines, 'ORIG_FID', zmLines, 'LENGTH', '#', '#', cp)
zmLines FC
Join original inputLine attributes to zmLines
transferAtts(zmLines, linesLayer, 'ORIG_FID', 'ORIG_FID', '#', zmAtts)
zmAtts FC
Create new FC with unknown SR
Append zmAtts
Flip line from map view to side view
arcpy.CreateFeatureclass_management(scratchDir, zmProfiles, 'POLYLINE', linesLayer, 'ENABLED', 'ENABLED')
arcpy.Append_management(zmAtts, zmProfiles, 'NO TEST')
plan2side(zmProfiles, ve, he)
zmProfile FC
Copy zmProfile, return final profile FC
srcProfiles = os.path.join(scratchDir, zmProfiles)
arcpy.CopyFeatures_management(srcProfiles, outFC)
outLayer = outFC
outFC

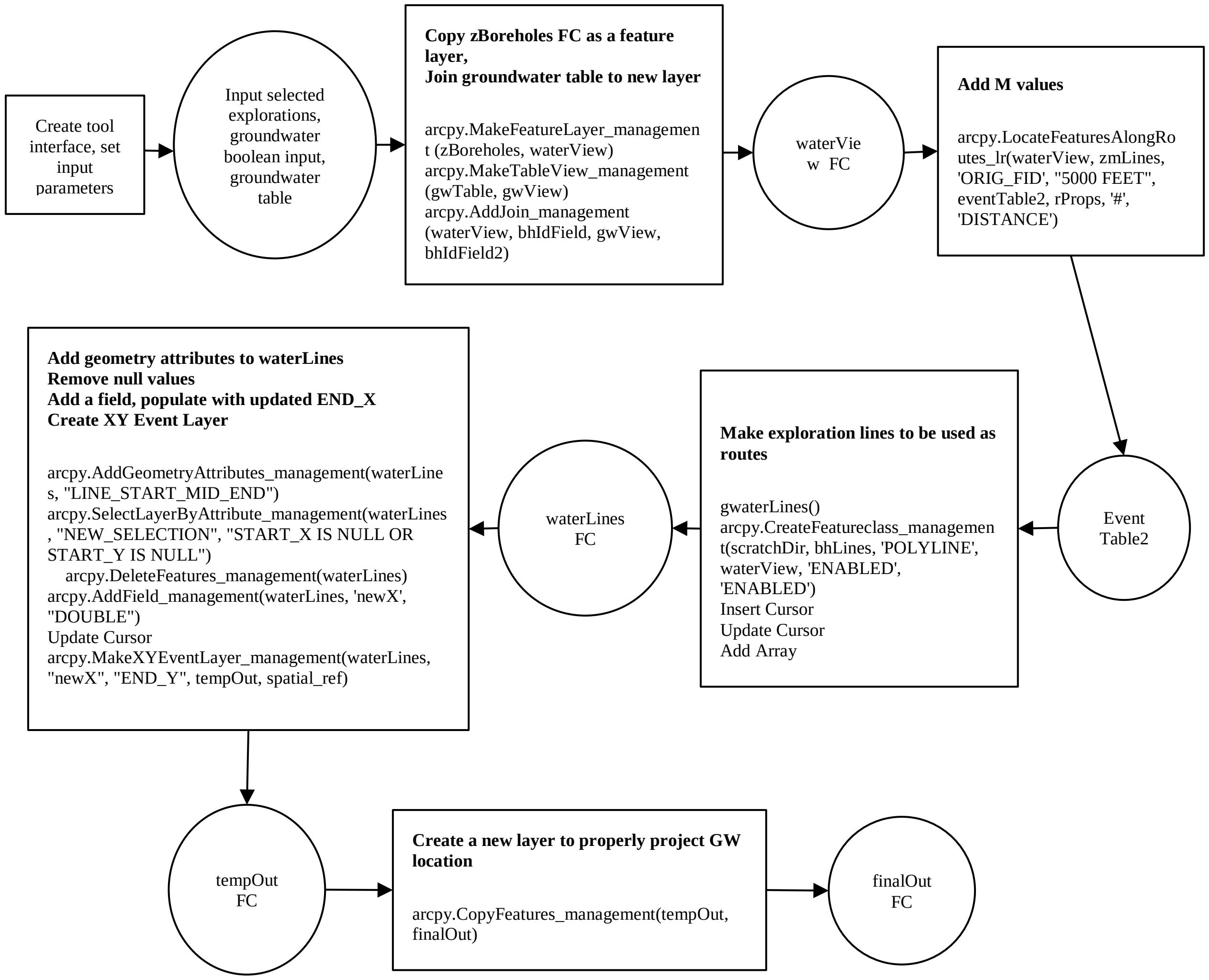
Figure 9. Operations flow diagram demonstrating the code block from the stick log and elevation profile script used to create a 2D cross section view of the elevation profile of an input cross section line.



Create tool interface, set input parameters (Arcpy.GetParamaterAsText)
Input selected explorations, exploration ID field, exploration elevation field, exploration depth field, subsurface
Add DEM Z values for explorations without an exploration elevation field value
arcpy.InterpolateShape_3d (dem, bhLayer, zBoreholes)
zBoreholesFC
Add M values
arcpy.LocateFeaturesAlongRoutes_lr(zBoreholes, zmLines, 'ORIG_FID', "5000 FEET", eventTable, rProps, '#', 'DISTANCE')
Event Table
Make exploration lines to be used as routes
boreholeLines()
arcpy.CreateFeatureclass_management(scratchDir, bhLines, 'POLYLINE', zBoreholes, 'ENABLED', 'ENABLED')
Insert Cursor
Update Cursor
Add Array
bhLines FC
Convert bhLines to event routes
arcpy.CreateRoutes_lr(bhLines, bhIdField, bhRoutes, 'ONE_FIELD', bhDepthField, '#', 'UPPER_LEFT')
props = intBhIdFld + ' LINE ' + intTopDepthFld + ' ' + intBotDepthFld
arcpy.MakeRouteEventLayer_lr(bhRoutes, bhIdField, intervalsTable, props, 'lyr', '#', 'ERROR_FIELD')
bhRoutes FC
Copy bhRoutes, return final profile FC
Add dis2Xsec field, join event table to outFC2
srcIntervals = os.path.join(scratchDir, bhIntervals)
arcpy.CopyFeatures_management(srcIntervals, outFC2)
arcpy.JoinField_management(outFC2, "EXPLOR_ID", eventTable, "EXPLOR_ID")
arcpy.CalculateField_management(outFC2, "Dis2XSec", "!Distance!", "PYTHON_9.3", "")
outFC2
Apply buffer to outFC2
Sort by dis2Xsec
arcpy.Buffer_analysis(outFC2, outBuff, buffSize, "FULL", "FLAT", "NONE", "", "PLANAR")
arcpy.Sort_management(outBuff, sortBuff, [["Dis2XSec", "ASCENDING"]])
'outFC2 + finalSticks' FC

Figure 10. Operations flow diagram demonstrating the code block from the stick log and elevation profile script used to create a 2D cross section view of the stick logs from selected explorations.

After these operations are performed, lines 558-623 allow for the user to optionally create point features that represent the groundwater location for each exploration, if encountered. This code block first checks a boolean input; if true, the zBoreholes feature class is copied as a new feature layer and joined to a table view of a provided groundwater table. An event table and gwaterLines function is called that is a nearly identical copy of the borholeLines function, though the ending y value is determined by the input groundwater depth field instead of the exploration depth field. The resulting waterLines feature class is a line that begins at the exploration elevation and ends at the groundwater depth. Geometry attributes are added to this line with the 'arcpy.AddGeometryAttributes_management' function, and the END_X field is updated using an update cursor so that the eventual point will appear to the left of the stick log buffer instead of inside the buffer polygon. An XY event layer is created using the ‘arcpy.MakeXYEventLayer_management’ function, resulting in a final feature class with the specified outname and ‘_groundwater’. This process is shown below in Figure 11.



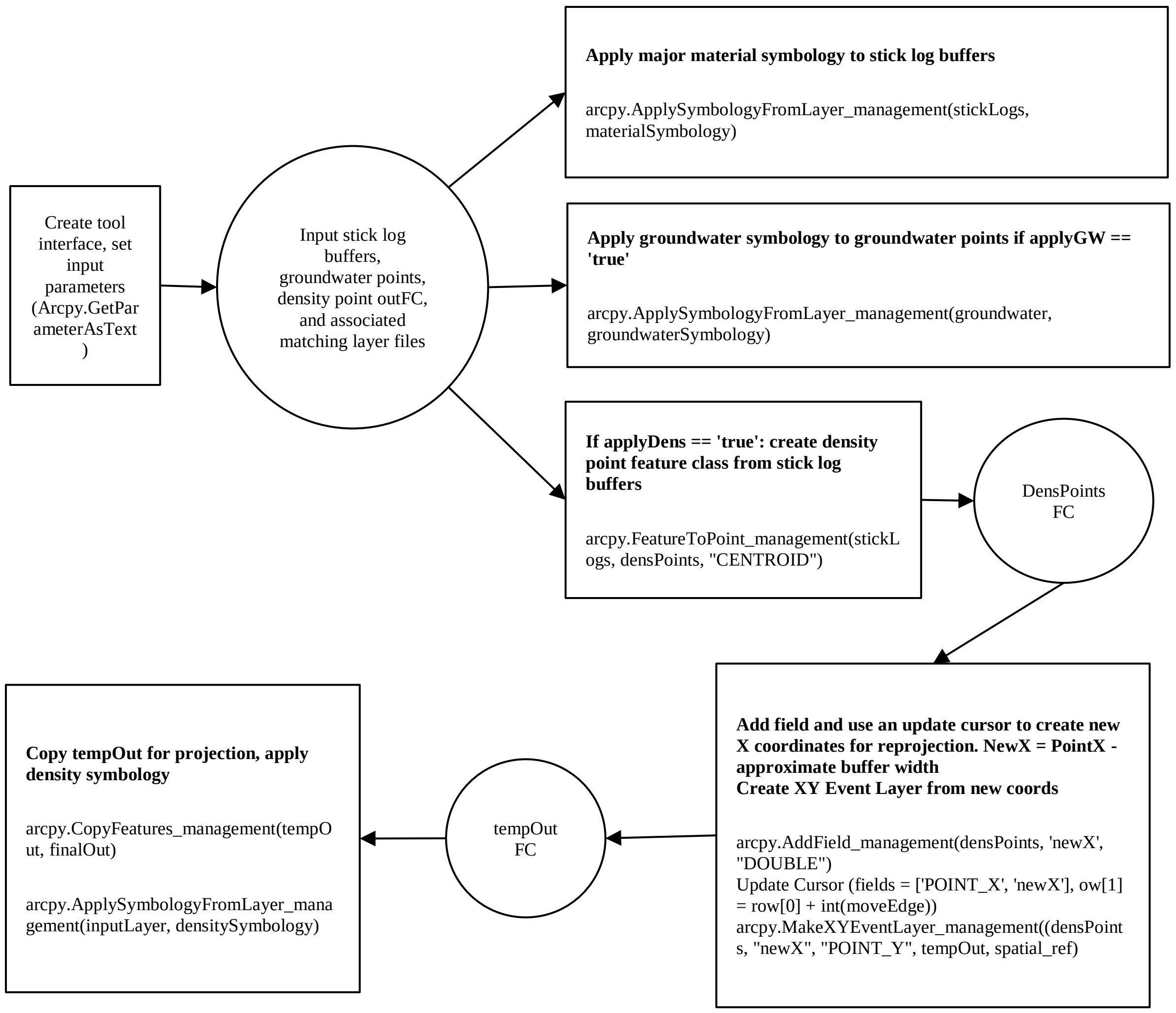
Create tool interface, set input parameters
Input selected explorations, groundwater boolean input, groundwater table
Copy zBoreholes FC as a feature layer,
Join groundwater table to new layer
arcpy.MakeFeatureLayer_management (zBoreholes, waterView)
arcpy.MakeTableView_management (gwTable, gwView)
arcpy.AddJoin_management (waterView, bhIdField, gwView, bhIdField2)
waterView FC
Add M values
arcpy.LocateFeaturesAlongRoutes_lr(waterView, zmLines, 'ORIG_FID', "5000 FEET", eventTable2, rProps, '#', 'DISTANCE')
Event Table2
Make exploration lines to be used as routes
gwaterLines()
arcpy.CreateFeatureclass_management(scratchDir, bhLines, 'POLYLINE', waterView, 'ENABLED', 'ENABLED')
Insert Cursor
Update Cursor
Add Array
waterLines FC
Add geometry attributes to waterLines
Remove null values
Add a field, populate with updated END_X
Create XY Event Layer
arcpy.AddGeometryAttributes_management(waterLines, "LINE_START_MID_END")
arcpy.SelectLayerByAttribute_management(waterLines, "NEW_SELECTION", "START_X IS NULL OR START_Y IS NULL")
arcpy.DeleteFeatures_management(waterLines)
arcpy.AddField_management(waterLines, 'newX', "DOUBLE")
Update Cursor
arcpy.MakeXYEventLayer_management(waterLines, "newX", "END_Y", tempOut, spatial_ref)
tempOut FC
Create a new layer to properly project GW location
arcpy.CopyFeatures_management(tempOut, finalOut)
finalOut FC

Figure 11. Operations flow diagram demonstrating the code block from the stick log and elevation profile script used to create a point feature class for the location of groundwater for selected explorations.

With all major tool outputs accounted for, the script proceeds to delete the many intermediate outputs from geoprocessing results. Though this could be avoided by writing to the in-memory workspace, certain intermediate outputs can be used for other applications and a user is able to keep those which they deem useful by simply hashing out the delete functions for the feature class they would like to keep in the final lines of code.

5.3.2 Symbology Tool Operation Flow

The symbology tool is powered by a relatively compact script, with 102 lines of code. This script primarily applies symbology to map layers from pre-packaged layer files included in the final zipped folder using the ‘arcpy.ApplySymbologyFromLayer_management’ function. However, the task of symbolizing density concurrent with major material type did result in the need for some geoprocessing operations, as it was decided that the best way for creating text-based density labels was to apply a symbology layer with custom marker symbols, due to the fact that the labeling functions in ArcPy are limited and that our density labels would need to reference two fields to obtain both the density type and density range for each layer. This necessitated the creation of a point feature class from the buffer polygon of each layer, adjusting the X coordinates of the points, and reprojecting the points using the new coordinates so that the label would appear to the side of the layer buffer polygon and not within it. Due to the possibility of a user not needing to display density symbology at certain scales, a boolean parameter allows the user to specify whether or not to execute the code related to this task. Similarly, applying groundwater symbology is also optional. An operations flow diagram representing the processes involved in the symbology script is shown below in Figure 12.



Create tool interface, set input parameters (Arcpy.GetParameterAsText)
Input stick log buffers, groundwater points, density point outFC, and associated matching layer files
Apply major material symbology to stick log buffers
arcpy.ApplySymbologyFromLayer_management(stickLogs, materialSymbology)
Apply groundwater symbology to groundwater points if applyGW == 'true'
arcpy.ApplySymbologyFromLayer_management(groundwater, groundwaterSymbology)
If applyDens == 'true': create density point feature class from stick log buffers
arcpy.FeatureToPoint_management(stickLogs, densPoints, "CENTROID")
DensPoints FC
Add field and use an update cursor to create new X coordinates for reprojection. NewX = PointX - approximate buffer width
Create XY Event Layer from new coords
arcpy.AddField_management(densPoints, 'newX', "DOUBLE")
Update Cursor (fields = ['POINT_X', 'newX'], ow[1] = row[0] + int(moveEdge))
arcpy.MakeXYEventLayer_management((densPoints, "newX", "POINT_Y", tempOut, spatial_ref)
tempOut FC
Copy tempOut for projection, apply density symbology
arcpy.CopyFeatures_management(tempOut, finalOut)
arcpy.ApplySymbologyFromLayer_management(inputLayer, densitySymbology)

Figure 12. Operations flow diagram for the symbology script used to apply material symbology and optional groundwater and density symbology to outputs from the stick log and elevation profile script.

5.3.3 Export to Graphic Tool Operation Flow

Our final script is used to export the current visible extent of an open .mxd file to a graphic format specified by the user for further use in a graphic editor downstream. The user is able to enter a series of parameters to determine the file format, resolution (DPI), quality (when applicable to the file format), and the output location. The script uses a series of if and elif statements to determine the selected format, then applies other relevant parameters and exports the map view extent using the 'arcpy.mapping.ExportToX' function. An operations flow diagram representing the processes involved in the export to graphic script is shown below in Figure 13.

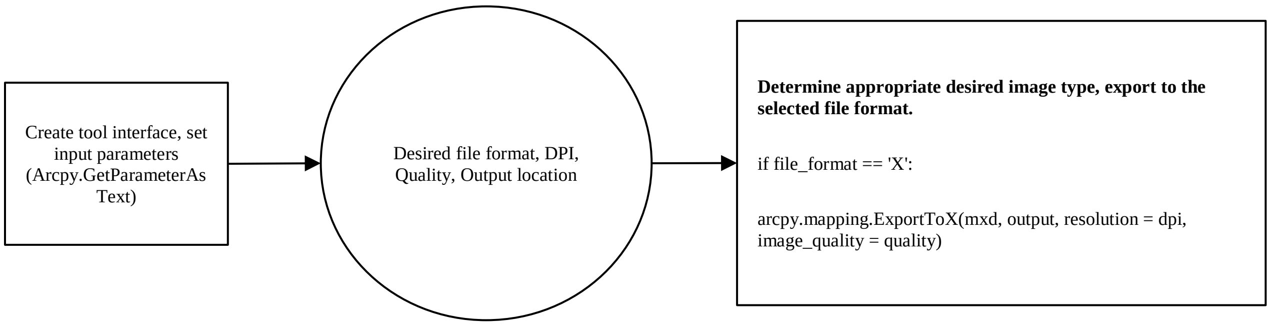
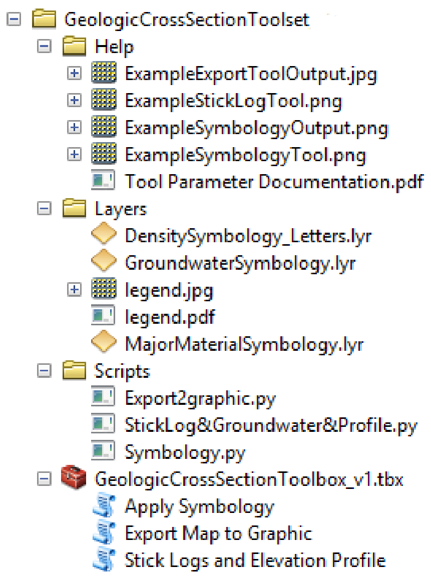

Create tool interface, set input parameters (Arcpy.GetParameterAsText)
Desired file format, DPI, Quality, Output location
Determine appropriate desired image type, export to the selected file format.
if file_format == 'X':
arcpy.mapping.ExportToX(mxd, output, resolution = dpi, image_quality = quality)

Figure 13. Operations flow diagram for the export to graphic script used to export the current map view to a graphic with selectable file format, resolution, quality, and output path parameters.

<u>5.4 Concluding the Workflow Implementation</u>

Following the completion of all scripts, the corresponding geoprocessing tools created during testing were updated to reference the completed scripts, and tool documentation including help files were completed. A zipped folder of approximately 1.5MB was created containing the geologic cross section toolbox with the three tools and subfolders for our scripts (Figure 14), layer files, and help documentation. This folder was delivered to Dr. Troost for user testing, and work began on the creation of the final project report.



```
GeologicCrossSectionToolset
  Help
    ExampleExportToolOutput.jpg
    ExampleStickLogTool.png
    ExampleSymbologyOutput.png
    ExampleSymbologyTool.png
    Tool Parameter Documentation.pdf
  Layers
    DensitySymbology_Letters.lyr
    GroundwaterSymbology.lyr
    legend.jpg
    legend.pdf
    MajorMaterialSymbology.lyr
  Scripts
    Export2graphic.py
    StickLog&Groundwater&Profile.py
    Symbology.py
  GeologicCrossSectionToolbox_v1.tbx
    Apply Symbology
    Export Map to Graphic
    Stick Logs and Elevation Profile
```

Figure 14. Contents of the final deliverable sent to GeoMapNW viewed in ArcCatalog.

6. RESULTS

6.1 Tool Results

The primary results of concern are the geoprocessing outputs generated by the geologic cross section tools. The following section presents results from our tools as they appear as outputs from running the tools in ArcMap 10.5.1. Further testing in ArcMap 10.4.1 was conducted and determined that outputs between these software versions were equivalent. The completed scripts used by the cross section tools can be found in Appendix B.

6.1.1 Stick log and Surface Profile Tool Outputs

This tool successfully addressed several of the requested software capabilities identified during project scoping. The user is able to manually select which geologic explorations will be included in the tool output. The elevation profile of the cross section line is delivered from an input line, and both horizontal and vertical exaggeration can be applied. The coordinate priority, or drawing order, of this line can be specified by the user. The location of each exploration and associated stick log relative to the cross section line is accurately depicted. The depth of each layer is represented, and the location of encountered groundwater is plotted. The starting elevation for selected exploration stick logs can be specified by using a field or by interpolation from an input DEM. Finally, the user can specify the buffer width applied to the stick log lines that will be used downstream for symbolizing material type for each subsurface layer. Due to the complexity of the script, 17 required input parameters and 3 optional input parameters are necessary to provide before running the tool. A typical selection process for explorations and cross section lines will include manually selecting those elements from an open map document with necessary data loaded, which is shown in Figure 15. The tool interface, with example parameters specified, is shown below in Figure 16.

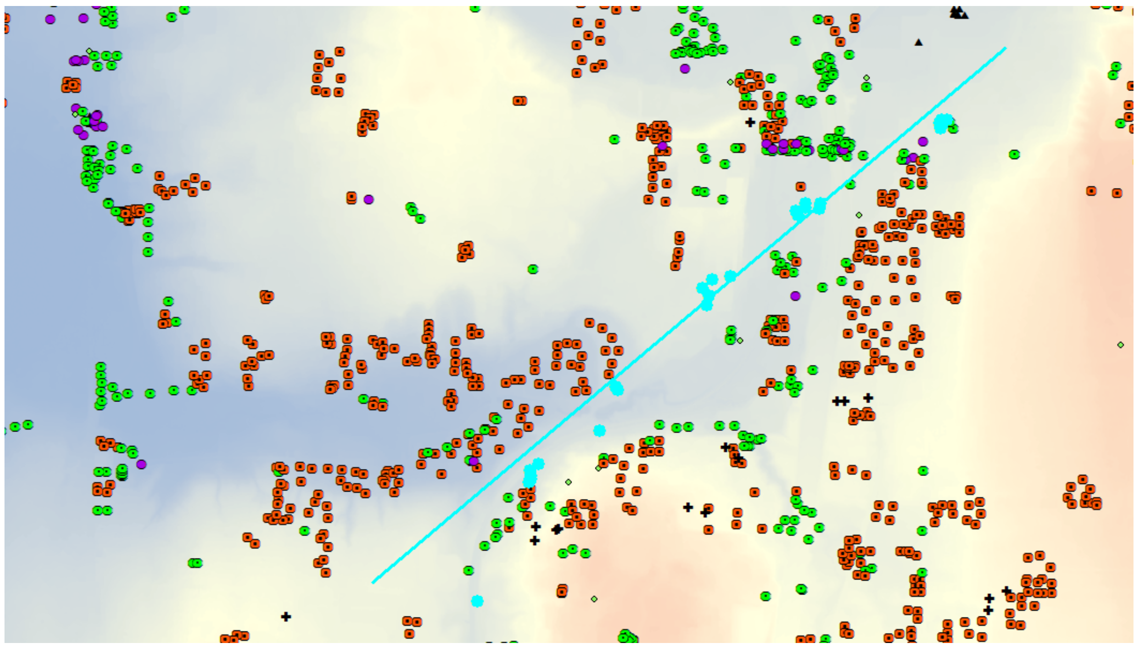
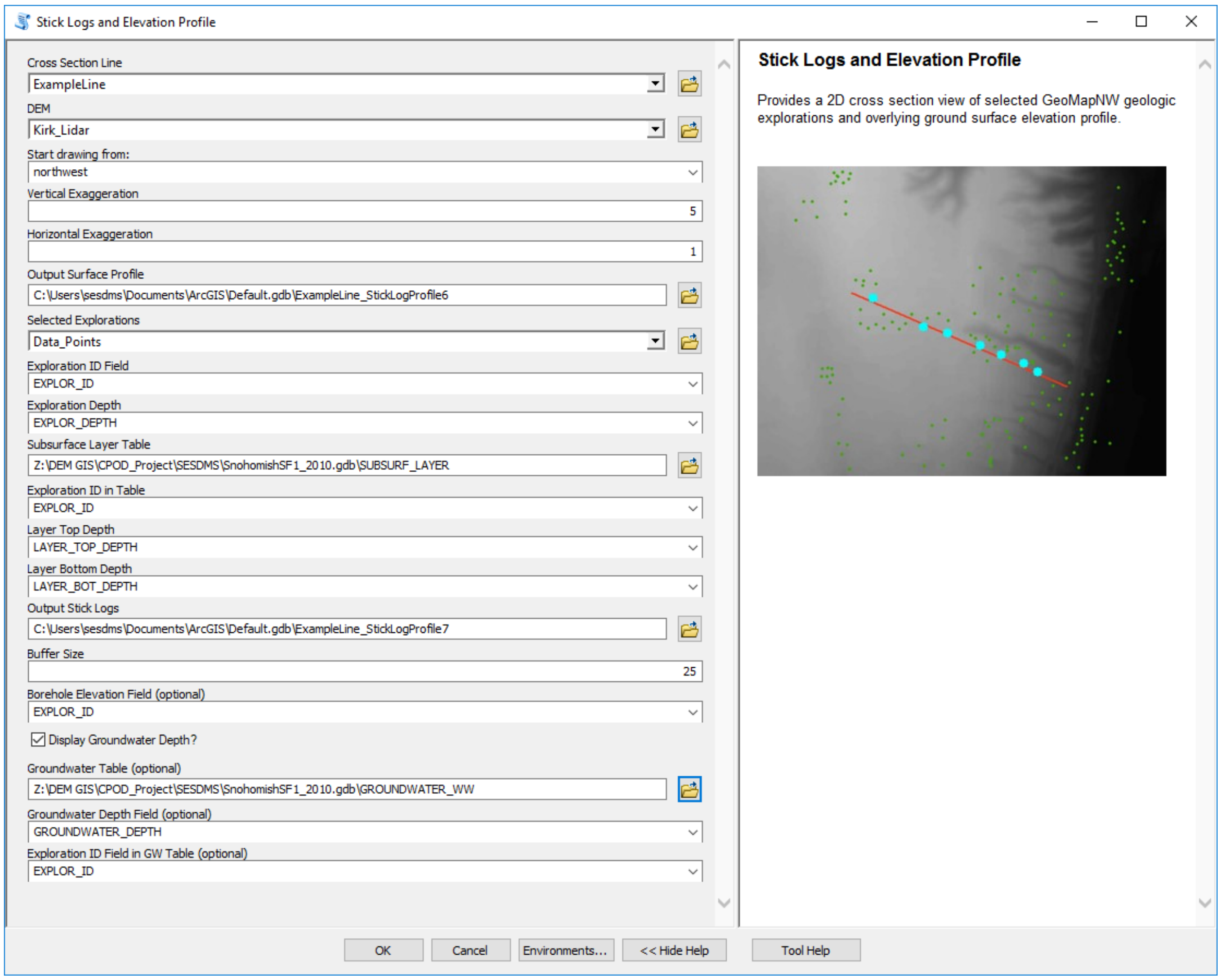


Figure 15. A map containing a selected cross section line, a DEM, and a selection of GeoMapNW geologic explorations symbolized by exploration type (boring, test pit, CPT, etc). Once a selection has been made, the Stick Log and Elevation Profile tool may be run.



Stick Logs and Elevation Profile

Cross Section Line: ExampleLine
DEM: Kirk_Lidar
Start drawing from: northwest
Vertical Exaggeration: 5
Horizontal Exaggeration: 1
Output Surface Profile: C:\Users\sesdms\Documents\ArcGIS\Default.gdb\ExampleLine_StickLogProfile6
Selected Explorations: Data_Points
Exploration ID Field: EXPLOR_ID
Exploration Depth: EXPLOR_DEPTH
Subsurface Layer Table: Z:\DEM GIS\CPOD_Project\SESDMS\SnohomishSF1_2010.gdb\SUBSURF_LAYER
Exploration ID in Table: EXPLOR_ID
Layer Top Depth: LAYER_TOP_DEPTH
Layer Bottom Depth: LAYER_BOT_DEPTH
Output Stick Logs: C:\Users\sesdms\Documents\ArcGIS\Default.gdb\ExampleLine_StickLogProfile7
Buffer Size: 25
Borehole Elevation Field (optional): EXPLOR_ID
☑ Display Groundwater Depth?
Groundwater Table (optional): Z:\DEM GIS\CPOD_Project\SESDMS\SnohomishSF1_2010.gdb\GROUNDWATER_WW
Groundwater Depth Field (optional): GROUNDWATER_DEPTH
Exploration ID Field in GW Table (optional): EXPLOR_ID

Stick Logs and Elevation Profile

Provides a 2D cross section view of selected GeoMapNW geologic explorations and overlying ground surface elevation profile.

Figure 16. The user interface for the Stick Log and Elevation Profile tool.

Running this tool results in three mandatory and one optional feature classes that are added by the script to the data frame. This process is manually forced by the script in the event that the geoprocessing settings of the user are not configured to automatically do so. These feature classes include the elevation profile of the input cross section line (referenced as ‘outFC’ by the script, and named by the user in the ‘Output Surface Profile’ parameter), output stick log route lines (referenced as outFC2 by the script and named by the user in the ‘Output Stick Logs’ parameter), the sorted stick log buffers for selected explorations (named as ‘outFC2 + ‘_finalSticks), and an optional point feature class indicating groundwater depth (named as ‘outFC2 + ‘_groundWater). Running the tool with the example inputs above yielded the resulting feature classes shown in Figure 17. An example of the tool functionality and flexibility is shown in Figure 18, which demonstrates two results generated from the same selection of explorations and profile line with different vertical and horizontal exaggeration and coordinate priorities specified.

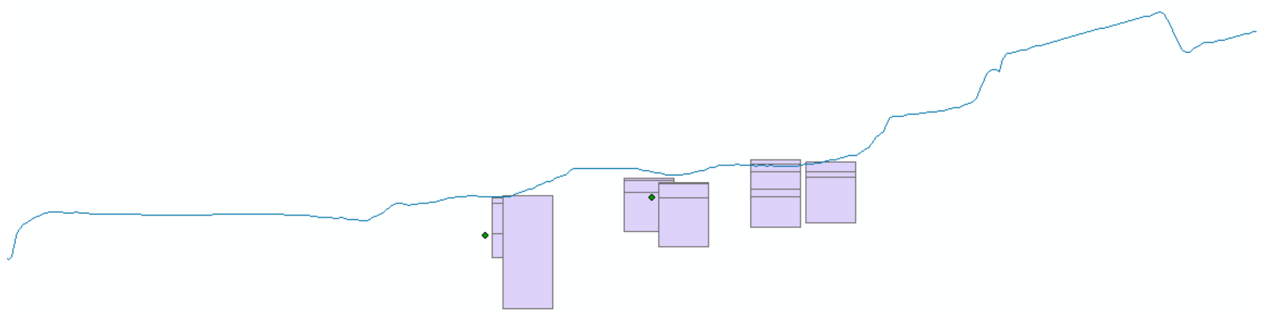


Figure 17. Geoprocessing results from the Stick Log and Elevation Profile tool. Feature classes include the surface profile line, the sorted stick log buffer, stick log route lines (hidden behind the buffer), and the groundwater location points (encountered in only two of the selected explorations).

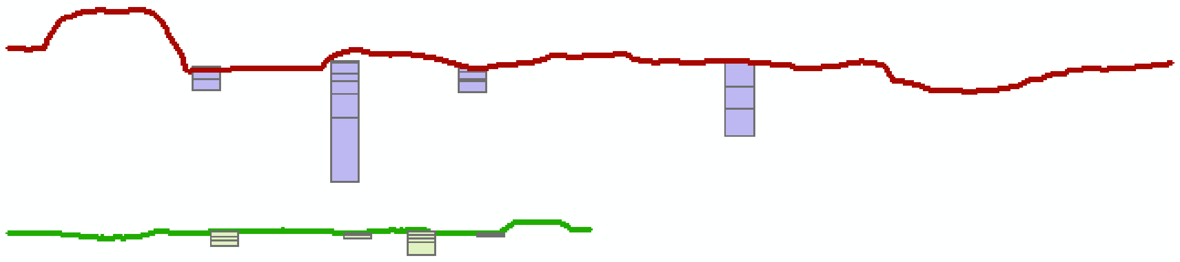


Figure 18. Geoprocessing results from running the Stick Log and Elevation Profile tool with an identical cross section line and selected explorations. The top result was run with 5x vertical exaggeration and 2x horizontal exaggeration, with the line drawn from the northwest. The bottom result was run with 1x vertical and horizontal exaggeration with the line drawn from the northeast.

Processing time takes approximately 0.5-4 minutes for tool execution, depending on available RAM and the size of the cross section line and number of selected explorations. On a multi-core machine with 16GB of RAM the tool was able to generate a stick log and elevation profile with groundwater indicators for all explorations along a cross section line transecting the entire City of Kirkland, WA (approximately 5 miles) in 4 minutes and 30 seconds (Figure 19). Average selections of a dozen explorations or fewer take significantly less time.

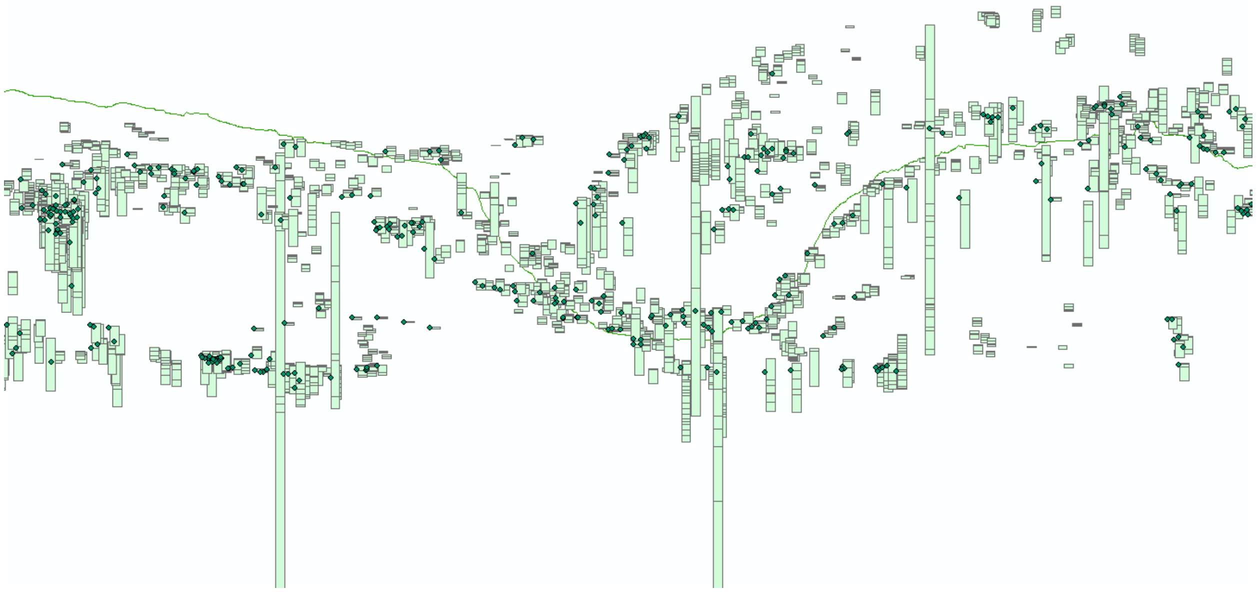
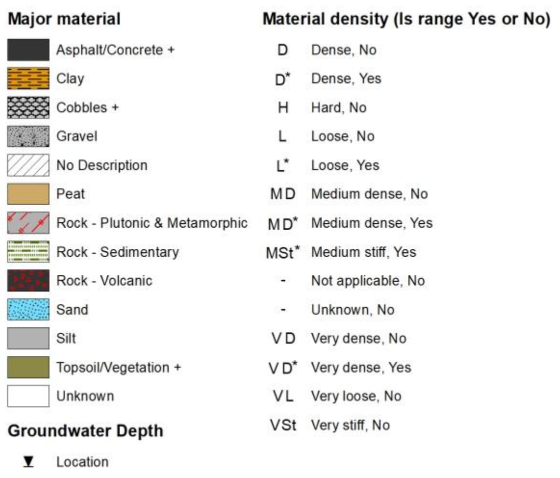


Figure 19. Output from the Stick Log and Elevation Profile Tool with 6x vertical exaggeration for a transect line crossing the entire City of Kirkland including stick logs for all GeoMapNW explorations within city limits. Stick logs appearing significantly above or below the cross section line are located far enough away from the cross section line that significant elevation changes may have occurred.

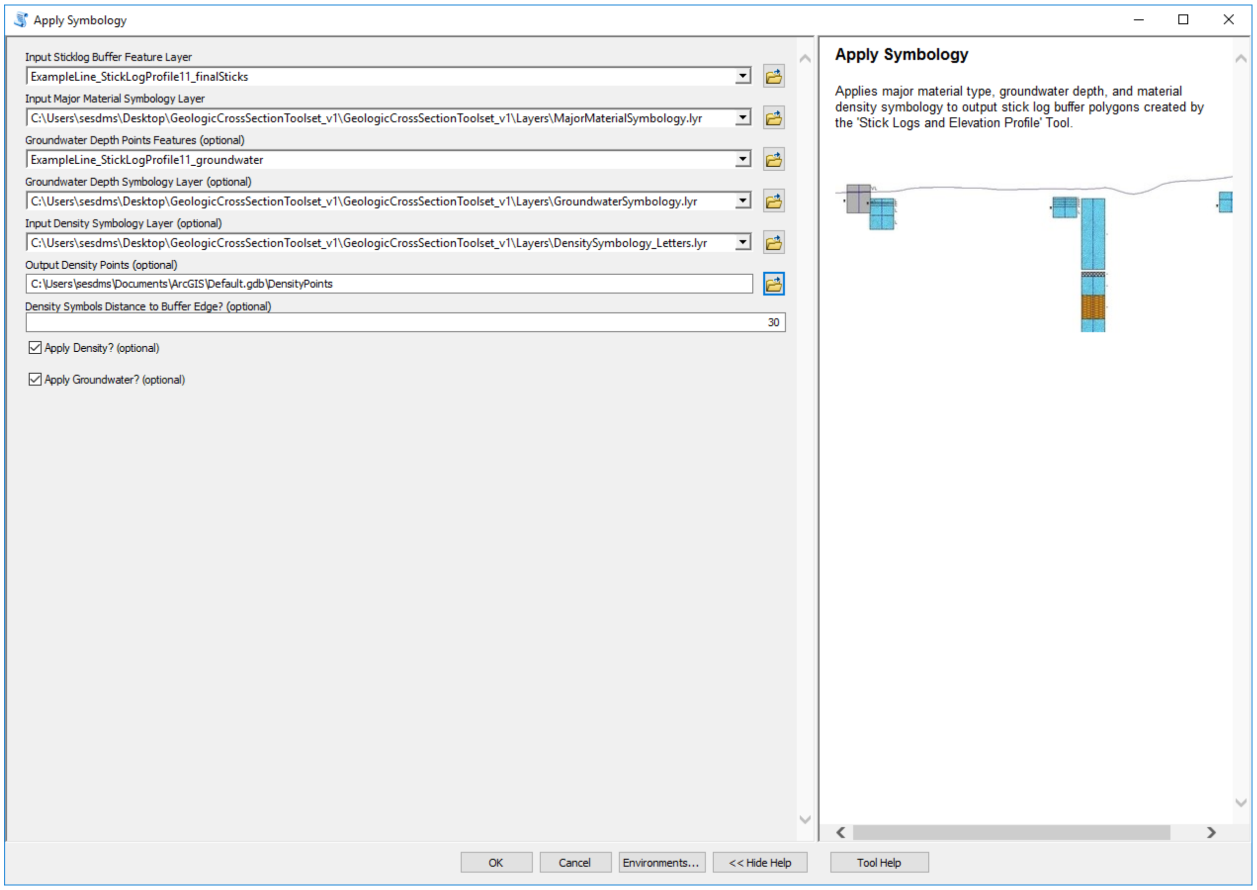
6.1.2 Apply Symbology Tool Outputs

The Apply Symbology tool successfully addressed several remaining requested software capabilities identified during project scoping. After running the tool, the user is able to clearly discern the major material type (sand, gravel, clay, etc) for each subsurface layer. A legend is provided in the tool package in addition to being automatically generated in the map document Table of Contents (Figure 20). Through the user interface the user is able to specify a stick log feature class to apply symbology to, a major material type layer file from which symbology is applied, a groundwater point feature class to apply symbology to, a groundwater depth layer file from which symbology is applied, a material density point feature class location, a material density layer file from which symbology is applied, the offset of the density labels (in map units), and whether or not to display groundwater depth and/or material density for each layer when information is available. An example of the tool UI with filled parameters is shown in Figure 21. Processing time takes approximately 0.1-1 minute for tool execution, depending on available RAM and the size of the cross section line and number of selected explorations. Choosing to display density symbology is the longest operation to process since it involves running geoprocessing tools and generating a new feature class.



Major material		Material density (Is range Yes or No)	
⬛	Asphalt/Concrete +	D	Dense, No
🟧	Clay	D*	Dense, Yes
▩	Cobbles +	H	Hard, No
▒	Gravel	L	Loose, No
▨	No Description	L*	Loose, Yes
🟫	Peat	MD	Medium dense, No
🟥	Rock - Plutonic & Metamorphic	MD*	Medium dense, Yes
🟩	Rock - Sedimentary	MSt*	Medium stiff, Yes
⬛	Rock - Volcanic	-	Not applicable, No
🟦	Sand	-	Unknown, No
⬜	Silt	VD	Very dense, No
🟫	Topsoil/Vegetation +	VD*	Very dense, Yes
⬜	Unknown	VL	Very loose, No
Groundwater Depth		VSt	Very stiff, No
▼	Location		

Figure 20. A legend included in the geologic cross section toolbox providing a key for major material, density, and groundwater symbols used by the Apply Symbology tool.



Apply Symbology

Input Sticklog Buffer Feature Layer
ExampleLine_StickLogProfile11_finalSticks

Input Major Material Symbology Layer
C:\Users\sesdms\Desktop\GeologicCrossSectionToolset_v1\GeologicCrossSectionToolset_v1\Layers\MajorMaterialSymbology.lyr

Groundwater Depth Points Features (optional)
ExampleLine_StickLogProfile11_groundwater

Groundwater Depth Symbology Layer (optional)
C:\Users\sesdms\Desktop\GeologicCrossSectionToolset_v1\GeologicCrossSectionToolset_v1\Layers\GroundwaterSymbology.lyr

Input Density Symbology Layer (optional)
C:\Users\sesdms\Desktop\GeologicCrossSectionToolset_v1\GeologicCrossSectionToolset_v1\Layers\DensitySymbology_Letters.lyr

Output Density Points (optional)
C:\Users\sesdms\Documents\ArcGIS\Default.gdb\DensityPoints

Density Symbols Distance to Buffer Edge? (optional)
30

☑ Apply Density? (optional)

☑ Apply Groundwater? (optional)

Apply Symbology

Applies major material type, groundwater depth, and material density symbology to output stick log buffer polygons created by the 'Stick Logs and Elevation Profile' Tool.

Figure 21. The user interface for the Apply Symbology Tool with example parameters provided.

Despite early challenges with displaying multiple levels of symbology simultaneously, the tool output provides a clear representation of all three symbolized layers. Major material class type is symbolized by the fill of the stick log buffer polygons. Density is displayed by applying symbol levels to a point feature class that is generated and moved to the right edge of the layer buffer as described in the workflow implementation section 5.3.2. Density symbology indicates both the consistency and hardness of the layer and whether or not the density exists as a range for the layer (such as in the event that the layer is both dense and loose across instances of the same material type in a layer). Groundwater symbology is simply applied as a symbol to a point representing the depth of the groundwater, displayed to the left of the stick log buffer. The groundwater and density indicators are appropriate for use with small selections of explorations, but can be overwhelming with a large selection. For this reason, groundwater and density symbology are optional parameters. The Apply Symbology tool generates only one optional feature class, which are the points that are used to apply density symbology to for each layer. An example of the tool output is shown in Figure 22.

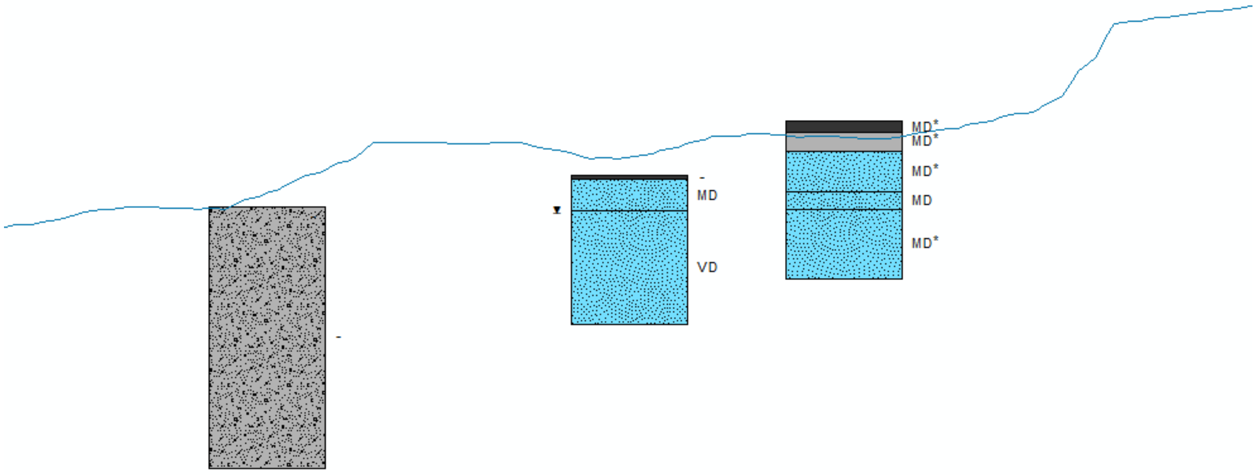
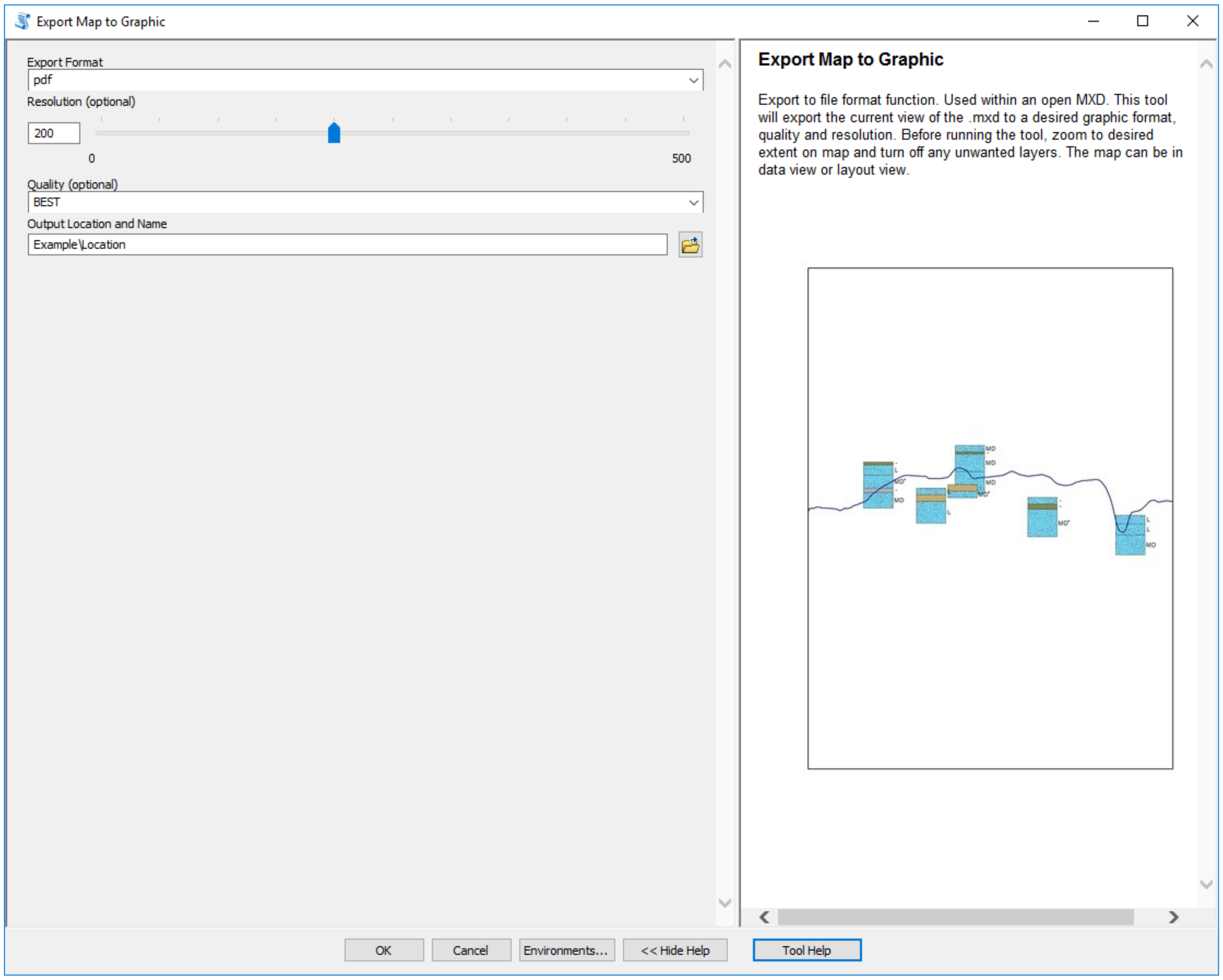


Figure 22. Results from the Stick Log and Elevation Profile tool after running the Apply Symbology tool. Density symbols appear to the right of the stick log buffer ('-' indicates no available data), and groundwater indicators appear to the left (present in the middle stick log only).

6.1.3 Export to Graphic Tool Outputs

The Export to Graphic tool successfully addressed our remaining requested software capability identified during project scoping, namely providing the tool output in a graphic file format specified by the user. The tool supports export to PDF, JPEG, AI, TIFF, or SVG files. The user is able to specify resolution from 0 to 499 DPI (defaulting at 200), and image quality for PDF, AI, and SVG files. Finally, the user is able to specify an output location for the resulting image file. The tool interface is shown in Figure 23, and an example output is shown in Figure 24. The tool takes several seconds to run, with slightly increased processing times for highest quality images.


Export Map to Graphic

Export Format
pdf
Resolution (optional)
200
0 500
Quality (optional)
BEST
Output Location and Name
Example\Location

Export Map to Graphic

Export to file format function. Used within an open MXD. This tool will export the current view of the .mxd to a desired graphic format, quality and resolution. Before running the tool, zoom to desired extent on map and turn off any unwanted layers. The map can be in data view or layout view.

Figure 23. The user interface for the Apply Symbology Tool with example parameters provided.

6.2 User Testing Results and GeoMapNW Use Viability

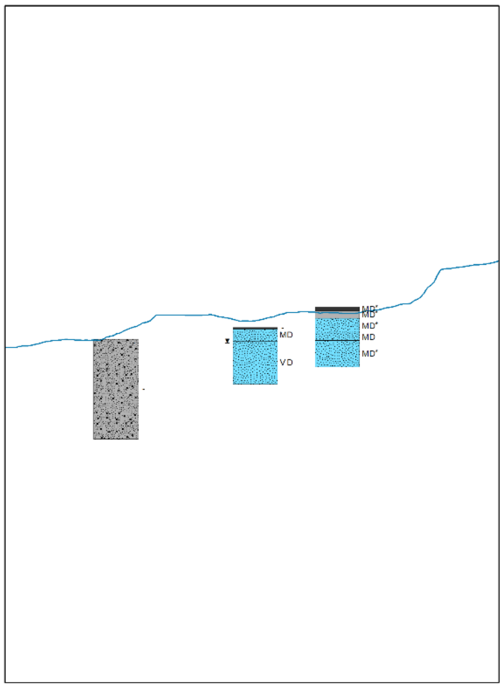


Figure 24. Example output from the Export to Graphic tool.

Initial user testing was performed remotely. A zipped folder containing the toolbox and supporting files was sent via email to Dr. Troost on July 27, 2018, who began field testing under normal working conditions shortly after. Team members attempted to provide support by phone while the tools were tested. These trials were unsuccessful, and due to the remote nature of our troubleshooting we were unable to accurately diagnose the problem. Likely sources of error included Dr. Troost directly accessing the GeoMapNW database (all of our developer testing had been conducted on local copies of data) and the inclusion of spaces in her file paths. Further instructions to address these possible sources of error were sent via email. After encountering further errors, an in-person meeting was scheduled for user testing on August 8, 2018.

During this meeting a new version of the toolbox and final deliverable with expanded help documentation and several bug fixes was tested. The testing was extremely successful, with all tools performing as expected using both local copies of the data and a live connection with the GeoMapNW database. Figure 25 presents a result from this testing demonstrating the database connection in the ArcMap table of contents. Testing lasted for approximately three hours, during which time a robust set of input configurations were attempted. Minor setbacks occurred (such as difficulty applying exploration ID labels to the output stick log lines), though it was concluded by all parties that work practice alterations (IE manual labeling of stick logs) would provide an easier solution than further tool refinement. Dr. Troost estimates that these tools require a similar amount of time to prepare for use as the previous VBA tool, but that actual processing time is faster. Because the tools were able to perform with data both stored locally and from online sources, provide improvement over previous software options, and meet all client needs identified in project scoping and most needs requested during development, it was determined that these tools will be a valuable asset for GeoMapNW. With the loss of functionality from the older VBA tools several years ago, the ability to visualize this comprehensive geologic database had been lost. The delivery of these tools has restored that ability.

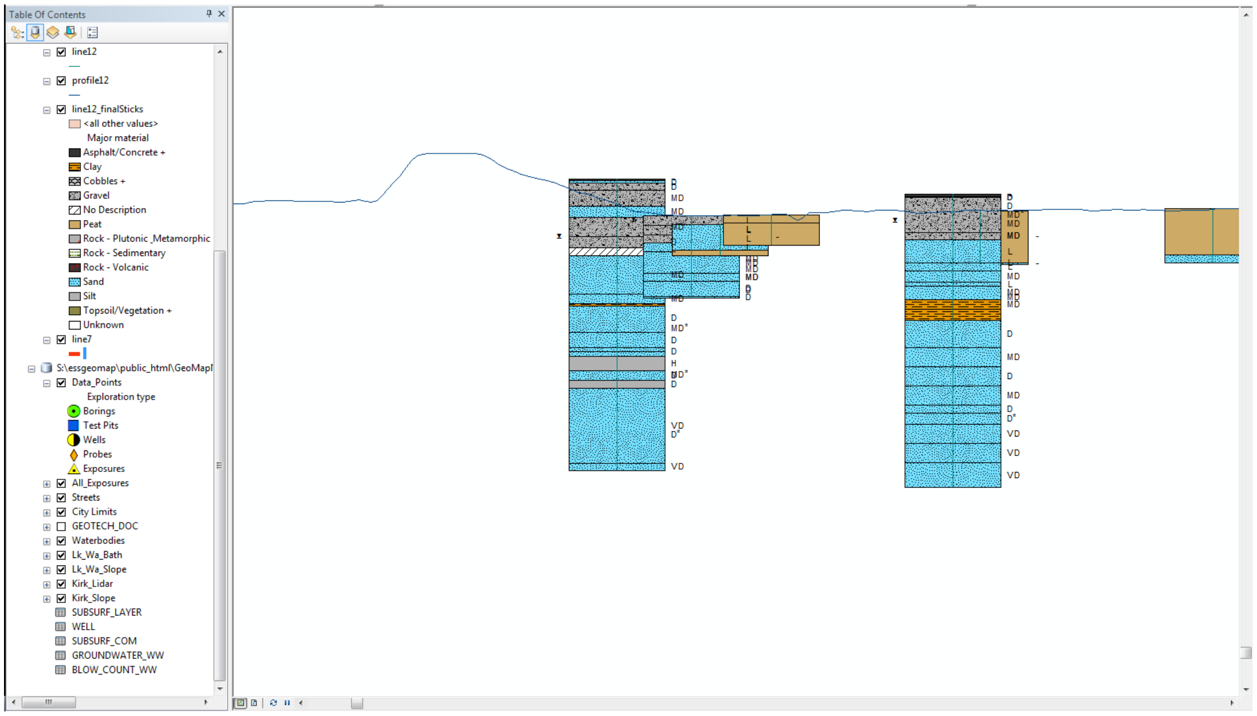


Figure 25. Final results from user testing with Dr. Troost at GeoMapNW using a connection to the online exploration database on August 8, 2018. Results displayed are the product of the Elevation Profile and Stick Log tool and Apply Symbology tool.

At the conclusion of this meeting it was decided that all remaining deliverable requests from GeoMapNW could be met with a revised help document. It was agreed that the authors would provide a more detailed guide, with help and troubleshooting added to address common issues encountered while testing the tool. The authors were also excited to hear that GeoMapNW would be using the tools almost immediately to begin a project involving detailed mapping of the Seattle Fault. The tools will be used for visualizing the depth of bedrock in Seattle and the Puget Sound, with visible offsets in the bedrock expected to be encountered by the tools at the approximate fault location. Further, Dr. Troost stated an intent to use the tools for educational purposes in a geological engineering course to visualize subsurface layers around and under buildings such as SafeCo Field in Seattle.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions Regarding Tool Suitability and Client Adoption

After providing and testing the final tool deliverable, it was determined by GeoMapNW that the cross section tools would be put to use by the organization with near immediacy. Despite this successful trial and adoption decision, it will likely be some time before the tools can be sufficiently field tested to assess the true full suitability for client needs, due to low staffing. Long-term cumulative benefits from the automation of creating cross section profiles from these tools will only be realized after sustained use that may not occur in the immediate future. However, smaller realized benefits will occur in the very near future with commencement of the Seattle Fault location project, which will be made significantly easier with these tools. The authors remain optimistic about initial tool testing results and are excited to see such immediate adoption and use of the tools.

Similarly, it is likely that the tools will not be immediately shared with GeoMapNW clients or partners until they have been deemed suitable and fully adopted for use by GeoMapNW. This lag time before full deployment should hopefully not be complicated by tool compatibility between partner organizations. The tool was intentionally developed for use with current versions of ArcMap and using a programming language fully supported by ESRI. If modifications became necessary (e.g. modifying the tool for use in ArcGIS Pro) these should be achievable by another student group or by GeoMapNW staff with basic to intermediate programming skills.

7.2 Conclusions Regarding Tool Capabilities Relating to Need-To-Know Questions

One method for determining tool success is to assess how the tools are able to answer the need-to-know questions developed in project scoping and presented in section 1.2.1. These questions are revisited in the subsections below, with tool actualized capabilities related to the relevant question.

7.2.1 What data points should be included in the cross section?

By using the included select tools and interfaces in ArcGIS, tool users are able to manually select the explorations they would like to see presented as stick logs in the tool output. This affords the user complete control over inclusions and exclusions, and provides the client with with the method of selection they originally requested. Early versions of the tool relied on the selection method built into the cross section toolbox from Evan Thoms, which selected all explorations within a user-supplied buffer distance from the input cross section line. The refinement of the selection process present in this tool presents significant utility for GeoMapNW and is a major success for the tool.

7.2.2 What is the elevation profile along the cross section line?

This tool successfully delivers the elevation profile for an input cross section line. Further, this elevation profile can be drawn starting from the northwest, northeast, southwest, or southeast through a user-supplied coordinate priority assignment. Vertical and horizontal exaggeration can also be supplied in integer intervals which will apply to both the surface profile and stick log outputs. This functionality uses the methodology present in the scripts written by Evan Thoms, with the exception of horizontal exaggeration, which was an addition by the student developers. Despite being delivered as an output with undefined spatial reference, points within the array representing the profile contain accurate Z values, in map units. These may be queried to provide surface elevations at selected locations. With these capabilities, the tool successfully addresses all client needs related to delivering an elevation profile from a cross section line.

7.2.3 What is the location of each exploration and stick log relative to the cross section line?

By using event data and linear referencing, explorations and their associated output stick logs are able to be placed accurately along the elevation profile returned from the input cross section line. Due to possible horizontal exaggeration of the line and undefined spatial reference of the tool output, this is a relative location dependent on coordinate priority, cross section line characteristics, and other user specifications. This method of determining location was provided in scripts written by Evan Thoms. Student modifications to the scripts added the ability for stick logs to be sorted by their perpendicular distance from the cross section line, which allows the tool to display the relative distance from the cross section line to each stick log when stick logs overlap. This provides rudimentary 3D capabilities to an otherwise 2D output. Aside from stick log overlap priority placement, no means for determining the relative distance from the stick log to the elevation profile exist. However, this need was not identified by the client during project scoping. Current outputs satisfy all client requests and represent another successful technical capability of the tool.

7.2.4 What is the major material of each subsurface layer?

Through application of a buffer to the output stick log lines generated by the tool, a rectangular polygon of customizable size is added to the map view at the location of each subsurface layer. By using the Apply Symbology tool, these polygons can be used to quickly differentiate between the major material of each layer. An included legend with the final deliverable and a generated table of contents legend in ArcMap provide a key for interpreting the symbology. This method for representing major material types for each layer satisfies client requests, though it requires running two tools: one to generate stick logs and one to apply symbology. This process could have been streamlined into one tool, though by using a second tool for symbology application a user is able to provide their own symbology layer file if desired and the overall complexity of the stick log tool is reduced. This tool capability is another success and relies entirely on original scripting provided by the student developers.

7.2.5 What is the density of each layer?

Density for each subsurface layer is applied again through the application of symbology. The Apply Symbology tool creates points from the center of each stick log polygon which are shifted to the polygon edge and labeled according to both density and whether or not the density ranges throughout the layer. Several draft scripts experimented with applying density symbology as a stick log polygon border, with thicker borders representing denser layers. Attempts were also made to label density with a graphic line indicator similar to original outputs from the GeoMapNW VB tool, though this method was also abandoned in favor of the more successful method presented here. This tool capability again is derived from original student development and represents a successful completion of client requests.

7.2.6 What is the depth of each layer?

Layer depths are generated by locating the points along the exploration route that correspond to the layer top depth and layer bottom depth, which are field inputs provided by the user. The location of these points are altered appropriately by the provided vertical exaggeration and used to generate stick log line segments that begin at the layer top and extend down to the layer bottom.

7.2.7 What is the groundwater depth for each exploration?

The groundwater depth for each exploration point can be optionally displayed as a marker symbol located at the groundwater depth location along the side of each stick log where the data is available. The groundwater points are created within the "Profile and Stick Logs" tool, and symbology can be applied from within the "Symbology" tool. To create the markers, the script follows similar steps to those used to create the stick log lines. Using linear referencing, lines are placed along the cross section line, and the length (depth) of each line is determined by the groundwater depth value, found in a joined table of groundwater attributes. Each line is converted into a single point located at the end (bottom) of the line, and this point is then shifted to be displayed at the edge of the stick log polygon.

7.2.8 How will appropriate symbology be applied?

Symbology is applied through a separate tool called "Symbology." This tool applies a user-provided symbology definition stored in a layer file to the tool outputs. The tool symbolizes each subsurface layer by major material class, and also optionally displays the density of each layer and the groundwater depth observed at each point. Symbology layer files for major material, density, and groundwater are included in a folder within the packaged tool. As necessary, users can use the Symbology tool to apply layer files other than those provided with the tool package, or manually alter the symbologies.

7.2.9 How will the above be displayed visually in a graphic output?

The final symbolized tool outputs can be exported to a graphic file format using the "Export to Graphic" tool included in the toolbox. This tool is designed to provide a simplified workflow for the export process, with minimal parameters. The user first manually pans and zooms to the extent of the map desired for export, or alternatively creates a layout view of the desired portion of the map. Layers within the export extent that the user does not wish to be included in export must be removed or turned off. Upon opening the Export to Graphic tool, the user selects the desired export file format and sets parameters for resolution and quality, and then the current map extent is exported. If further customization of export options are required than those provided by the tool, the map can be manually exported using the built-in ArcMap export function found in the File menu.

7.3 Recommendations for Further Development

This project achieved its goal of developing a set of tools that met the specifications requested in the original project scope, and also included additional useful functions identified by the authors and the project sponsor during the course of tool development. Nevertheless, opportunities to enhance functionality, improve the presentation of outputs, and simplify the workflow for tool operation have been identified. Some of these recommendations were identified during the tool development process, but given the short time period for project completion the authors were unable to include them in the final product. Others were identified as enhancements outside the scope of the current project that could expand its capabilities if undertaken in the future. Recommendations for further development are discussed below.

7.3.1 Output scale

Profile line, stick log, groundwater and density feature classes generated by the toolbox have no spatial reference and are assigned an “unknown” coordinate system. With an unknown coordinate system, the map units and hence the scale are unknown. A scale bar or some other indicator of scale is typically considered a necessary element in any professional map. In this particular case a scale would be useful to provide references such as the length of the cross section, the depth of subsurface layers, and the changes in elevation across the profile. Assuming that the data frame is assigned the same coordinate system as a relevant input features, the map units will be set to this coordinate system. This means that with vertical and horizontal exaggeration values set to “1,” adding a scale bar to the map would provide an accurate reference scale. However, if the data frame is set to an unknown or other coordinate system, or if vertical or horizontal exaggerations are a value other than one, a scale bar would be inaccurate. In this case, a less traditional method for representing map scale would need to be developed. Adding dynamic text displaying the total length of the cross section line, or providing a “reference” stick log with static, labeled layer depths are two ideas for including some information on the output relating to scale.

7.3.2 Profile line and stick log drawing direction

The “Start drawing from” parameter in the Stick Logs and Elevation Profile script allows users to specify the “coordinate priority,” or the quadrant from which to start drawing. This parameter identifies which end of the line is considered the “start” for the profile line and stick log display. Knowing the starting direction is critical for accurately interpreting the results. If an output is created and then shared, it might be falsely assumed that the drawing direction is from the west because maps commonly display west on the left hand side. Displaying the drawing direction on the output would be useful and would reduce errors resulting from misinterpretation of the line direction. In its current configuration, the tool output does not provide a visual indication of the chosen drawing direction, nor have the authors identified a simple way to manually add this information. Creating a function within the tool that would add a drawing direction indicator to the map would be a useful improvement.

7.3.3 Outputs with no spatial reference to separate data frame

Profile line and stick log outputs have no spatial reference, and thus appear on the map in an arbitrary location, separate from the input cross section line and data points. It would be useful to have the tool automatically add these outputs to a new data frame. This would enable adding some additional mapping automation using the arcpy.mapping module (for example, automatically panning and zooming to the extent of the outputs when the tool executes). Additionally, a separate data frame would simplify the process of creating a map layout that displays both the plane view cross section line and exploration points as well as the cross section view profile line and stick log outputs.

7.3.4 Include template .mxd file to facilitate tool use

Related to the recommendations for a separate data frame for tool outputs discussed above, a template .mxd file could be included with the packaged toolbox to facilitate tool use. This would be especially helpful for users with limited GIS skills, and additionally would allow for expanding use of the arcpy.mapping module within the script, because the creation of new objects is not supported within the mapping module (for example, neither creating a new .mxd nor adding a new data frame is a supported function). A template .mxd could contain multiple data frames, and a default map layout including a legend and page size and orientation properties. A template could also incorporate some of the other recommendations discussed in this section, such as objects to hold scale and drawing direction indicators.

7.3.5 Automate labeling of the stick logs

One client request that we were unable to accommodate was the automation of stick log labeling. Because the desired label positioning requires use of the Maplex labeling engine, and because saving and sharing label properties is not well supported within current versions of ArcMap, we were unable to automate label creation. Tool documentation includes instructions for manually adding labels with the desired position and orientation, but ideally this would be included as an automated tool feature. It is possible that as support for labeling functionality increases within the ArcGIS platform, a labeling function could be added to the symbology script. Alternatively, different methods for labeling automation could be explored, if manually labeling proves too cumbersome.

7.3.6 Delete extraneous results and improve tool efficiency

Running the three tools with all optional outputs included currently results in a total of eight outputs (6 feature classes, 1 table, and 1 graphic file). At least one of these outputs has been identified as extraneous, however an unidentified bug in the script prevents the feature class from being deleted automatically. It would be ideal to remove this extra data from the final results. Additionally, as the client further assesses tool suitability, some of the other outputs may be identified as unnecessary; the script could easily be modified to delete those outputs.

A related improvement would be to have the intermediate results stored in the in-memory workspace, rather than written to the output location and then deleted. This would improve tool performance and reduce the processing and storage requirements for the user. The process of modifying the script to store intermediate results in-memory should be fairly simple.

7.3.7 Optional 3D output for use in ArcScene

The current tool produces results suitable for display in a 2D environment. Future development could add functionality for converting these results into a format suitable for viewing in a 3D environment, such as ArcScene. In addition to the more “realistic” view provided in a 3D environment, having 3D results would be beneficial because the coordinate system could be defined and results could be displayed in a spatially accurate location along with a contextualizing basemap. This would be possible because within the 3D environment, visualization of Z-values is an inherent capability. In a 2D environment it is not, and thus for the outputs of this tool Z values are stored as X-coordinates within the features, essentially “overwriting” a feature’s actual location.

7.3.8 Development for ArcGIS Pro

It is expected that ESRI will discontinue support for its ArcGIS Desktop products in 2024, by which point Desktop users should be migrated to the ArcGIS Pro environment. In anticipation of this event, it would be ideal to develop the toolbox for use in ArcGIS Pro. Creating a tool for use with ArcGIS Pro would also provide additional benefits. Projects within the Pro environment are packaged such that a multiple layout templates can be created for a single map. Also, 2D views as well as a 3D views (“Scenes”) can be created within the same project. Other benefits may exist or be added as the capabilities of Pro are extended by ESRI. For example, additional support for the automation of feature labeling may be added to Pro but not to Desktop software.

Overall, the project can be considered successful. A set of ArcGIS custom tools was developed that achieved all the primary capabilities identified in project scoping, within the necessary timeline. Nevertheless, there still exist many opportunities for refining the tool and expanding its functionality.

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9. TECHNICAL APPENDICES

Appendix A: Data Design Tables

Table 10. Schema Specifications

Field Name	**Source**	**Spatial Object Type**	**Description**
Rasters			
Kirk_Lidar	GeoMapNW - Kathy Troost	Raster	DEM
Kirk_Slope	GeoMapNW - Kathy Troost	Raster	DEM
Lk_Wa_Bath	GeoMapNW - Kathy Troost	Raster	Bathymetry
Lk_Wa_Slope	GeoMapNW - Kathy Troost	Raster	DEM
Feature Classes			
All_Exposures	GeoMapNW - Kathy Troost	Point	Borehole data
Data_Points	GeoMapNW - Kathy Troost	Point	Surficial geology data
CityLimits	GeoMapNW - Kathy Troost	PolyLine	Kirkland study area
kirk_streets	GeoMapNW - Kathy Troost	Line	Kirkland streets
CrossSection	Self	Line	Create lines for cross sections
GEOTECH_DOC	GeoMapNW - Kathy Troost	Polygon	Geotechnical reports from contractors
Kirk_Lakes	GeoMapNW - Kathy Troost	Polygon	Lakes in Kirkland
Tables			
BLOW_COUNT_WW	GeoMapNW - Kathy Troost	Table	Subsurface geology ID table
GROUNDWATER_WW	GeoMapNW - Kathy Troost	Table	Groundwater data from exploration, and well logs table
SUBSURF_COM	GeoMapNW - Kathy Troost	Table	Subsurface geology comments on exploration logs table
SUBSURF_LAYER	GeoMapNW - Kathy Troost	Table	Subsurface layer descriptions table

WELL	GeoMapNW - Kathy Troost	Table	Monitoring well data from exploration logs table
Tools			
Sticklog&Groundwater&Profile	Script created by project group	Toolbox	Tool to create elevation profile, sticklogs, and groundwater
Symbology	Script created by project group	Toolbox	Applies major material, density, and groundwater symbology
Export2Graphic	Script created by project group	Toolbox	Export to graphic output

Table 11. Attribute Table Specifications

Field Name	Description	Data Type	Length
EXPOSID	Exposure ID	String	40
EXPOSNAME	Exposure Name	String	40
EXPOSTYPE	Exposure Type	String	40
EXPOSADD	Exposure Address	String	40
LOCATCONF	Location Confidence	String	40
EXPOSELEV	Exposure Elevation	Float	8
ELEVSOURCE	Elevation Source	String	40
DATUMNAME	Datum Name	String	40
OBSERVER	Observer	String	40
EXPOSDATE	Exposure Date (yyyymmdd format)	Date	8
EXPLOR_ID	Exploration ID	Long	10

DOCID	Document ID	Long	10
EXPLONAME	Exploration Name	String	50
EXPLOTYPE	Exploration Type	String	10
NORTHING	Northing, State Plane North	Float	8
EASTING	Easting, State Plane North	Float	8
LOCATCONF	Location Confidence	String	10
EXPLODEPTH	Exploration Depth	String	10
EXPLOELEV	Exploration Elevation from report	String	10
EXPLOELEVD	Exploration Elevation from DEM	Date	8
ELEVSOURCE	Elevation Source	String	10
DATUMNAME	Datum Name	String	10
AUTHORNAME	Author Name	Short	5
EXPLODATE	Exploration Date (yyyymmdd format)	Short	5
BORINGMETH	Boring Method	Date	8
CONTRACTOR	Contractor Name	String	10
ID	Identification	Double	
MAINT_MAIN	Maintenance	Double	
PERIMETER	Kirkland Perimeter	Double	
ACRES	Acres	Double	
HECTARES	Hectares	Double	

AREA_	Area in feet	Double	
FULL_STRNAME	Full Street Name	String	38
STREETID	Street ID	Long	10
SEGMENTID	Segment ID	Long	10
NAME	Lake name	String	40
In_Kirk_	Lake in Kirkland?	String	50
DOCID	Document ID	Long	10
DOCTYPE	Document Type	String	10
SOURCENAME	Source Name	String	10
AUTHORNAME	Author Name	String	10
DOCNAME	Document Name	String	100
DOCDATE	Document Date (yyyymmdd format)	Date	8
PROJTYPE	Project Type	String	10
PROJADD	Project Address	String	100
LOCALID1	Local Identifier/Number 1	String	50
LOCALID2	Local Identifier/Number 2	String	50
HASNEWDATA	Has New Data?	Short	5
NEWDATAINC	New Data Incomplete?	Short	5
HASOLDDATA	Has Old Data?	Short	5
HAS_PROFILE	Has Profile?	Short	5

HAS_SLIDE	Has Slide?	Short	5
EXPLOR_ID	Exploration ID	Long	10
SUBSURF_LAYER_ID	Subsurface Layer ID	Long	10
BLOW_COUNTS_DEPTH	Starting Depth of Sample	Float	8
BLOW_COUNTS	Sample Has Blow Counts	Short	5
SPT	Standard Penetration Test?	Short	5
BLOW_COUNTS_1ST_6	Blows per 1st 6 inches	Short	5
BLOW_COUNTS_2ND_6	Blows per 2nd 6 inches	Short	5
BLOW_COUNTS_3RD_6	Blows per 3rd 6 inches	Short	5
BLOW_COUNTS_4TH_6	Blows per 4th 6 inches	Short	5
REFUSAL	Blows before sample refused	Short	5
PENETRATION	Total Penetration at Refusal	Short	5
SAMPLE_TYPE	Sample Type	String	10
SAMPLE_D_IN	Sampler Diameter (inches)	Float	8
ID_OD	Inside or Outside diameter?	Short	5
HAMMER_TYPE	Hammer Type	String	10
DROP_IN	Hammer drop height	Short	5
EXPLOR_ID	Exploration ID	Long	10
DOC_ID	Document ID	Long	10
EXPLOR_NAME	Exploration Name	String	50

GW_ENCOUNTERED	Groundwater encountered?	Short	5
GROUNDWATER_DEPTH	Depth to groundwater	Float	8
EXPLOR_DEPTH	Depth of exploration	Float	8
FLOWING	Flowing water?	Short	5
HEIGHT	Height of water flow	Float	8
DATE	Observation date	Date	8
DATA_SOURCE	Data source type	String	10
OBSERVATION_TYPE	Groundwater observation type	String	10
GROUNDWATER_DEPTHS	Number of observations	Short	5
GROUNDWATER_DEPTH_TYPE	Which observation logged?	String	10
COMID	Comment ID	Long	10
EXPLOR_ID	Exploration ID	Long	10
COMNUM	Comment Number	Short	5
COMDEPTH	Comment Depth	Float	8
COMDESC	Comment Description	String	400
LAYERID	Layer ID	Long	10
EXPLOR_ID	Exploration ID	Long	10
LAYERNUM	Layer Number	Short	5
LAYERTYPE	Layer Type	String	10
LAYERTOPDE	Layer Top Depth	Float	8

LAYERBOTDE	Layer Bottom Depth	Float	8
LAYERDESC	Layer Description	String	500
DENSITYRAN	Density Is Range?	Short	5
MATDENSITY	Material Density	String	10
MINORGRAV	Material Is Gravelly?	Short	5
MINORSAND	Material Is Sandy?	Short	5
MINORSILT	Material Is Silty?	Short	5
MINORCLAY	Material Is Clayey?	Short	5
MATMAJOR	Major Material Type	String	10
ORGANICS	Material Has/Is Organic(s)?	Short	5
DEBRIS	Material Has Debris?	Short	5
MATUSCS	USCS on Log	String	10
MATLOGUNIT	Geologic Unit on Log	String	50
WELLID	Well ID	Long	10
EXPLOR_ID	Exploration ID	Long	10
WELL_NAME	Well Name	String	50
WELL_DEPTH	Well Depth	Float	8
WELL_DIAME	Well Diameter	Float	8
SCREEN_TOP	Depth of Screen (top)	Float	8
SCREEN_BOT	Depth of Screen (bottom)	Float	8

SCREEN_GEO	Geology at Screen	String	10
NUM_READIN	Number of Readings	Short	5
LAST_READI	Last Reading Date	Date	8
LAST_REA_1	Last Reading	Float	8
WELL_TESTI	Well Testing	Short	5
WATER_LEVE	Water Level Type	String	10

Table 12. Metadata Descriptions

File Name	**Description**	**Quality**
Kirk_Lidar	Bare earth DEM for City of Kirkland	2016 Lidar; 3 feet resolution
Lk_Wa_Bath	Bathymetry data for the bottom of Lake Washington, clipped 2000 feet from shoreline	Data produced by NOAA, unknown date. Cell size 28.25 feet.
Lk_Wa_Slope	Slope DEM derived from Lk_Wa_Bath	See Lk_Wa_Bath
All_Exposures	Compilation of exposures and their attributes, from geologic field mapping efforts in the City of Kirkland. Exposures include roadcuts, landslide scarps, riverbanks, excavations, etc.	Compiled by GeoMapNW 2010 and 2016-17 from outside sources and validity/quality of original data is not guaranteed. Location accuracy is included as an attribute field.
Data_Points	Compilations of exposures and explorations from subsurface investigations and observations at field sites in City of Kirkland. Associated table, SUBSURF_LAYER should be used with this feature class for information of subsurface layers for each point location.	Compiled by GeoMapNW 2010 and 2016-17 from outside sources and validity/quality of original data is not guaranteed. Location accuracy is included as an attribute field.
Expo_Points	Surficial geology data	
GEOTECH_DOC	Spatial information (polygons) and attributes about geotechnical reports; spatial index of documents.	Data compiled by GeoMapNW 2010 and 2016-2017
BLOW_COUNT_WW	Blow count data compiled from borehole logs. Includes depth of sample, blows per 6 inches, and details about samplers and	Data compiled by GeoMapNW 2010 and 2016-2017

	hammers.	
GROUNDWATER_WW	Groundwater data from multiple sources including monitoring wells installed in subsurface explorations, and water well logs. Includes depth to groundwater, how depth was measured, and observation date. May reflect seasonal groundwater occurance.	Data compiled by GeoMapNW 2010 and 2016-2017
SUBSURF_COM	Subsurface geology comments on exploration logs table; should be joined to Explorations layer using "exploration_id" field.	Data compiled by GeoMapNW 2010 and 2016-2017
SUBSURF_LAYER	Subsurface layer descriptions table	Data compiled by GeoMapNW 2010 and 2016-2017
WELL	Monitoring well data from exploration logs. Table can be joined to other layers using "exploration_id" field.	Data compiled by GeoMapNW 2010 and 2016-2017
borehole	Script to plot borehole stick logs in a cross-sectional view	Beta version of script; limited documentation.
sufaceprofile	Tool script to create one or more surface profiles from an ArcMap line layer in a cross sectional view shapefile. Requires a line layer and a DEM in the same coordinate system.	Can not check for schema lock; limited documentation.

Appendix B.: Python Scripts

1. Stick Log and Profile Line

```python
'''''
Description: This script uses a cross section transect line and a bare earth DEM raster to create an elevation profile line,
and then displays geologic along the transect as 2D vertical stick log plots. The user can specify the vertical exaggeration
of the profile and sticklogs. The output features do not have a spatial reference.

Requirements: ArcMap, 3D analyst extension, GeoMapNW database or other geotechnical explorations data
Credits: The script relies heavily on code from Evan Thoms' open-source Cross-Section Tools 10.2 Surface Profile script.
Authors: Jesse Schaefer, Drew Schwitters, Martin Weiser; University of Washington MGIS GEOG569 Capstone project

Notes: The tool must be run from ArcMap with an open .mxd (not from Python window or ArcCatalog).
'''

##################################################################################################
# IMPORT IMPORT IMPORT
##################################################################################################

# Import modules
import arcpy, os, sys, traceback

##################################################################################################
# DEFINITIONS DEFINITIONS DEFINITIONS
##################################################################################################

def getCPValue(quadrant):
    cpDict = {'northwest':'UPPER_LEFT', 'southwest':'LOWER_LEFT', 'northeast':'UPPER_RIGHT', 'southeast':'LOWER_RIGHT'}

    return cpDict[quadrant]

##################

def addAndCalc(layer, field, calc):
    #adds a field to a table (layer) of name (field), and calcs a value
    #created as means to add an rkey value to line layers that consist
    #of OID values
    try:
        #add a key field if it doesn't already exist
        if len(arcpy.ListFields(layer, field)) ==0:
            arcpy.AddField_management(layer, field, 'LONG')

    #calculate the id value over to the new value so we always have it in the table
    #as it goes through it's various transformations, some of which will re-write
    #the id field.
        arcpy.CalculateField_management(layer, field, calc)

    except:
        tb = sys.exc_info()[2]
        tbinfo = traceback.format_tb(tb)[0]
        pymsg = tbinfo + '\n' + str(sys.exc_type)+ ': ' + str(sys.exc_value)
        arcpy.AddError(pymsg)
        raise SystemError
    finally:
        arcpy.RefreshCatalog

##################

def addZ(ZptLayer):
    #adds the z value to the table so that it is in the event table when we locate
    #points along the line route
    try:
        arcpy.DeleteField_management(ZptLayers, 'DEM_Z')
    except:
        pass

    try:
        arcpy.AddField_management(ZptLayer, 'DEM_Z', 'DOUBLE')
        rows = arcpy.UpdateCursor(ZptLayer)
        for row in rows:
            # create the geometry object
            feat = row.Shape
            pnt = feat.getPart(0)
            # set the value
            row.setValue('DEM_Z', pnt.Z)
            # update the row
            rows.updateRow(row)

    except:
        tb = sys.exc_info()[2]
        tbinfo = traceback.format_tb(tb)[0]
        pymsg = tbinfo + '\n' + str(sys.exc_type)+ ': ' + str(sys.exc_value)
        arcpy.AddError(pymsg)
        raise SystemError


##################################


def transferAtts(inFC, joinTable, parentKey, childKey, fInfo, outName):
    try:
        #transfers attributes from a table to a fc: OIDs must match!
        #get the attributes through a join which only works on a feature layer
        lName = 'lay'
        layer = arcpy.MakeFeatureLayer_management(inFC, lName)[0]

        #before the join, set the QualifiedFieldNames environment setting so that
        #we don't see the source table name as a prefix in the field names
        arcpy.env.qualifiedFieldNames = False

        #make the join based on key field
        arcpy.AddJoin_management(lName, parentKey, joinTable, childKey)

        #copy features out to the output name
        arcpy.CopyFeatures_management(lName, outName)

    except:
        tb = sys.exc_info()[2]
        tbinfo = traceback.format_tb(tb)[0]
        pymsg = tbinfo + '\n' + str(sys.exc_type)+ ': ' + str(sys.exc_value)
        arcpy.AddError(pymsg)

####################################

def plan2side(ZMlines, ve, he):
    #flip map view lines to cross section view without creating a copy
    #this function updates the existing geometry
    arcpy.AddMessage('Flipping ' + ZMlines + ' from map view to  cross section view')
    try:
        rows = arcpy.UpdateCursor(ZMlines)
        n = 0
        for row in rows:
            # Create the geometry object
            feat = row.shape
            new_Feat_Shape = arcpy.Array()
            a = 0
            while a < feat.partCount:
                # Get each part of the geometry)
                array = feat.getPart(a)
                newarray = arcpy.Array()

                # otherwise get the first point in the array of points
                pnt = array.next()

                while pnt:
                    pnt.X = float(pnt.M) * float(he)
                    pnt.Y = float(pnt.Z) * float(ve)

                    #Add the modified point into the new array
                    newarray.add(pnt)
                    pnt = array.next()

                #Put the new array into the new feature  shape
                new_Feat_Shape.add(newarray)
                a = a + 1

            #Update the row object's shape
            row.shape = new_Feat_Shape

            #Update the feature's information in the workspace using the cursor
            rows.updateRow(row)
    except:
        tb = sys.exc_info()[2]
        tbinfo = traceback.format_tb(tb)[0]
        pymsg = tbinfo + '\n' + str(sys.exc_type)+ ': ' + str(sys.exc_value)
        arcpy.AddError(pymsg)
        raise SystemError

def boreholeLines():
    #creates 2d cross section view sticklogs that show the depth of each borehole
    try:
        # create an empty output featureclass with the fields of the event table
        arcpy.CreateFeatureclass_management(scratchDir, bhLines, 'POLYLINE', zBoreholes, 'ENABLED'
, 'ENABLED')

        # open search cursor on the event table
        tRows = arcpy.SearchCursor(eventTable)

        # open insert cursor on the output layer
        cur = arcpy.InsertCursor(bhLines)

        # create point and array objects
        pnt1 = arcpy.CreateObject('Point')
        pnt2 = arcpy.CreateObject('Point')
        array = arcpy.CreateObject('Array')

        #get a list of fields in the template table that does not include OBJECTID or FID or SHAPE
        #anything else? add it to xf! ("excluded fields")
        xf = ('shape', 'objectid', 'fid', 'shape_length')
        lf = arcpy.ListFields(zBoreholes)
        names = []
        for f in lf:
            if not f.name.lower() in xf:
                names.append(f.name)
                #we also want the 'DISTANCE' value, calculated when the event table is built
                #to be saved to this fc so it's needs to be in this list
                names.append('distance')

        # enter while loop for each row in events table
        for tRow in tRows:
            # set the point's X and Y coordinates
            # set Y depending on whether the user wants to use the elevation of the
            # borehole from the DEM or from a value in the collar z field
            try:
                if bhElev == 0:
                    pnt1.Y = float(bhElev) * float(ve)
                else:
                    pnt1.Y = float(tRow.getValue(zField)) * float(ve)
            except:
                arcpy.AddMessage('No collar elevation available for borehole ' + str(tRow.getValue(bhIdField)))
                arcpy.AddMessage('Using a value of 10000 for collar elevation')
                pnt1.Y = 10000

            pnt1.X = tRow.RouteM * float(he)
            pnt2.X = pnt1.X

            #if there is no value in bhDepthField, subtract 5000 from the top
            #elevation as a way of flagging this point
            try:
                pnt2.Y = pnt1.Y - (float(tRow.getValue(bhDepthField) * float(ve)))
            except:
                arcpy.AddMessage('    No borehole depth available for borehole ' + str(tRow.getValue(bhIdField)))
                arcpy.AddMessage('      Using a value of 5000 for borehole depth.')
                pnt2.Y = pnt1.Y - 5000

            # add points to array
            array.add(pnt1)
            array.add(pnt2)

            # set array to the new feature's shape
            row = cur.newRow()
            row.shape = array

            # copy over the other attributes
            for name in names:
                #try to write the value, but maybe the field can't be found or the value can't be set
                #for some reason. Don't want the whole thing to blow up
                try:
                    row.setValue(name, tRow.getValue(name))
                except:
                    #if it can't be written, forget about it
                    pass

            # insert the feature
            cur.insertRow(row)

            #cleanup
            array.removeAll()

    except:
        pass


###############################

def gwaterLines():
    #creates 2d cross section view sticklogs that show the depth of each borehole
    try:
        # create an empty output featureclass with the fields of the event table
        arcpy.CreateFeatureclass_management(scratchDir, waterLines, 'POLYLINE', zBoreholes, 'ENABLED', 'ENABLED')

        # open search cursor on the event table
        tRows = arcpy.SearchCursor(eventTable2)

        # open insert cursor on the output layer
        cur = arcpy.InsertCursor(waterLines)

        # create point and array objects
        pnt1 = arcpy.CreateObject('Point')
        pnt2 = arcpy.CreateObject('Point')
        array = arcpy.CreateObject('Array')

        #get a list of fields in the template table that does not include OBJECTID or FID or SHAPE

        #anything else? add it to xf! ("excluded fields")
        xf = ('shape', 'objectid', 'fid', 'shape_length')
        lf = arcpy.ListFields(zBoreholes)
        names = []
        for f in lf:
            if not f.name.lower() in xf:
                names.append(f.name)
                #we also want the 'DISTANCE' value, calculated when the event table is built
                #to be saved to this fc so it's needs to be in this list
                names.append('distance')

        # enter while loop for each row in events table
        for tRow in tRows:
            # set the point's X and Y coordinates
            # set Y depending on whether the user wants to use the elevation of the
            # borehole from the DEM or from a value in the collar z field
            try:
                if bhElev == 0:
                    pnt1.Y = float(bhElev) * float(ve)
                else:
                    pnt1.Y = float(tRow.getValue(zField)) * float(ve)
            except:
                arcpy.AddMessage('No collar elevation available for borehole ' + str(tRow.getValue(bhIdField)))
                arcpy.AddMessage('Using a value of 10000 for collar elevation')
                pnt1.Y = 10000

            pnt1.X = tRow.RouteM * float(he)
            pnt2.X = pnt1.X

            #if there is no value in bhDepthField, subtract 5000 from the top
            #elevation as a way of flagging this point
            try:
                if gwDepthField > 0:
                    pnt2.Y = pnt1.Y - (float(tRow.getValue(gwDepthField) * float(ve))) #changes bottom Y value to groundwater depth times ve.
                else:
                    pnt2.Y =  float(bhElev) * float(ve)
            except:
                arcpy.AddMessage('    No groundwater depth available for borehole ' + str(tRow.getValue(bhIdField)))
                pnt2.Y = 0

            # add points to array
            array.add(pnt1)
            array.add(pnt2)

            # set array to the new feature's shape
            row = cur.newRow()
            row.shape = array

            # copy over the other attributes
            for name in names:
                #try to write the value, but maybe the field can't be found or the value can't be set
                #for some reason. Don't want the whole thing to blow up
                try:
                    row.setValue(name, tRow.getValue(name))
                except:
                    #if it can't be written, forget about it
                    pass

            # insert the feature
            cur.insertRow(row)

            #cleanup
            array.removeAll()

    except:
        pass

###############################################################################################
# PARMETERS PARAMETERS PARAMETERS
################################################################################################


arcpy.env.overwriteOutput = True

# Cross-section layer
linesLayer = arcpy.GetParameterAsText(0)

# elevation raster layer
dem = arcpy.GetParameterAsText(1)

#coordinate priority - corner from which the measuring will begin
cp = getCPValue(arcpy.GetParameterAsText(2))

# vertical exaggeration (for both borehole lines and profile line)
ve = arcpy.GetParameterAsText(3)

```

```
#horizontal exaggeration (he)
he = arcpy.GetParameterAsText(4)

# stick log output feature class
outFC = arcpy.GetParameterAsText(5)
outName = os.path.splitext(os.path.basename(outFC))[0]

# Selected Points
bhLayer = arcpy.GetParameterAsText(6)

# borehole id field
bhIdField = arcpy.GetParameterAsText(7)

# depth field
bhDepthField = arcpy.GetParameterAsText(8)

# intervals table
intervalsTable = arcpy.GetParameterAsText(9)

# borehole id field in interval table
intBhIdFld = arcpy.GetParameterAsText(10)

# interval top depth - depth in relation to the top of the borehole, not elevation
# if left blank will interpolate elevation from DEM
intTopDepthFld = arcpy.GetParameterAsText(11)

# interval bottom depth
intBotDepthFld = arcpy.GetParameterAsText(12)

# stick log output feature class
outFC2 = arcpy.GetParameterAsText(13)
outName2 = os.path.splitext(os.path.basename(outFC2))[0]

# specify the length of the buffer on each side of the output line, in map units
buffSize = arcpy.GetParameterAsText(14)

# Field specifying borehole elevation. Interpolated from DEM if left blank
bhElev = arcpy.GetParameterAsText(15)

# Display groundwater depth, yes or no?
gwShow = arcpy.GetParameterAsText(16)

#Groundwater_WW table
gwTable = arcpy.GetParameterAsText(17)

#Groundwater depth, obvs
gwDepthField = arcpy.GetParameterAsText(18)

# borehole id field in water table
bhIdField2 = arcpy.GetParameterAsText(19)

###############################################################################################
# MAIN SCRIPT
################################################################################################

scratchDir = arcpy.env.scratchWorkspace
arcpy.env.workspace = scratchDir

####################################
#  PART 1, GENERATE SURFACE PROFILE
####################################
```

```

#add an rkey field to the table that consists of values from the OID

desc = arcpy.Describe(linesLayer)
idField = desc.OIDFieldName
addAndCalc(linesLayer, 'ORIG_FID', '[' + idField + ']')

#interpolate the lines
zLines = outName + '_z'
arcpy.AddMessage('Getting elevation values for features in ' + linesLayer)
arcpy.InterpolateShape_3d(dem, linesLayer, zLines)
arcpy.AddMessage('    ' + zLines + ' written to ' + arcpy.env.scratchWorkspace)

#measure the lines
zmLines = outName + '_zm'
arcpy.AddMessage('Measuring the length of the line(s) in ' + zLines)
arcpy.CreateRoutes_lr(zLines, 'ORIG_FID', zmLines, 'LENGTH', '#', '#', cp)
arcpy.AddMessage('    ' + zmLines + ' written to ' + arcpy.env.scratchWorkspace)

#hook the attributes back up
#transferAtts(inFC, joinTable, parentKey, childKey, fInfo, outName)
zmAtts = outName + '_zmAtts'
transferAtts(zmLines, linesLayer, 'ORIG_FID', 'ORIG_FID', '#', zmAtts)

#make an empty container with an 'Unknown' SR
zmProfiles = outName + '_profiles'
arcpy.CreateFeatureclass_management(scratchDir, zmProfiles, 'POLYLINE', linesLayer, 'ENABLED', 'EN
ABLED')
arcpy.Append_management(zmAtts, zmProfiles, 'NO_TEST')
plan2side(zmProfiles, ve, he)

#some cleanup
arcpy.DeleteField_management(zmProfiles, 'ORIG_FID')
arcpy.DeleteField_management(linesLayer, 'ORIG_FID')
arcpy.SelectLayerByAttribute_management(linesLayer, "CLEAR_SELECTION")
arcpy.Delete_management("lay")

#copy the final fc from the scratch gdb to the output directory
srcProfiles = os.path.join(scratchDir, zmProfiles)
arcpy.CopyFeatures_management(srcProfiles, outFC)
outLayer = outFC

################################
#PART 2, GENERATE STICK LOGS
################################

#interpolate Z values for the boreholes
# first, select the borehole location points based on the buffer distance
#to minimize the processing time

zBoreholes = outName2 + '_zBoreholes'
arcpy.InterpolateShape_3d(dem, bhLayer, zBoreholes)

#add DEM Z values to zBoreholes attribute table
#might already be there so we'll try to add it
try:
    arcpy.AddField_management(zBoreholes, 'zDEM', 'FLOAT')
except:
    pass
    #and calc in the geometry x
try:
    arcpy.CalculateField_management(zBoreholes, 'zDEM', '!SHAPE.FIRSTPOINT.Z!', 'PYTHON_9.3')
except:
    #if the elevation cannot be determined for some reason, calc 0
    arcpy.CalculateField_management(zBoreholes, 'zDEM', 0, 'PYTHON_9.3')

#'DEM_Z' becomes the collar elevation field
zField = 'zDEM'

# locate boreholes points along the cross-section
eventTable = outName2 + '_bhEvents'
rProps = 'rkey POINT RouteM'
arcpy.AddMessage('Locating ' + zBoreholes + ' on ' + zmLines)
arcpy.LocateFeaturesAlongRoutes_lr(zBoreholes, zmLines, 'ORIG_FID', "5000 FEET", eventTable, rProps, '#', 'DISTANCE') #change the distance here if you want to include stick logs farther than 5000 map units from the cross section line
arcpy.AddMessage('    ' + eventTable + ' written to ' + arcpy.env.scratchWorkspace)

#remove duplicate records that result from what appears to be
#an unresolved bug in the Locate Features Along Routes tool
#some points will get more than one record in the event table
#and slightly different, sub-mapunit, mValues
arcpy.DeleteIdentical_management(eventTable, bhIdField)

# make the borehole lines to be used as routes
bhLines = outName2 + '_bhLines'
arcpy.AddMessage('Building lines in cross-section view from ' + eventTable)
boreholeLines()
arcpy.AddMessage('    ' + bhLines + ' written to ' + arcpy.env.scratchWorkspace)

bhRoutes = outName2 + '_bhRoutes'
arcpy.AddMessage("Measuring the length of borehole lines in " + bhLines)
arcpy.CreateRoutes_lr(bhLines, bhIdField, bhRoutes, 'ONE_FIELD', bhDepthField, '#', 'UPPER_LEFT')
arcpy.AddMessage('    ' + bhRoutes + ' written to ' + arcpy.env.scratchWorkspace)

#place borehole intervals (line events) on borehole routes
props = intBhIdFld + ' LINE ' + intTopDepthFld + ' ' + intBotDepthFld
arcpy.AddMessage("Placing borehole intervals on routes in " + bhRoutes)
arcpy.MakeRouteEventLayer_lr(bhRoutes, bhIdField, intervalsTable, props, 'lyr', '#', 'ERROR_FIELD')

#extract only valid route events from this in-memory layer
arcpy.AddMessage('Filtering interval records with location errors.')
bhIntervals = outName2 + '_intervals'
arcpy.Select_analysis('lyr', bhIntervals, "\"LOC_ERROR\" <> 'ROUTE NOT FOUND'")
arcpy.AddMessage('    ' + bhIntervals + ' written to ' + arcpy.env.scratchWorkspace)

# Create a field to represent the perpendicular distance from the cross section to the exploration. This will be populated later.
arcpy.AddField_management(bhIntervals, 'Dis2XSec', 'DOUBLE')
layer2 = arcpy.MakeFeatureLayer_management(bhIntervals, 'lyr2')
arcpy.env.qualifiedFieldNames = False

# Create the final output feature class

srcIntervals = os.path.join(scratchDir, bhIntervals)
arcpy.CopyFeatures_management(srcIntervals, outFC2)
arcpy.AddMessage('    ' + bhIntervals + ' copied to ' + outFC2)
outLayer = outFC2

```

```python
# Join the out borehole feature class with the eventTable in order to pass over the 'DISTANCE' field
# which is the distance the sticklog is away from the cross-section line

arcpy.JoinField_management(outFC2, "EXPLOR_ID", eventTable, "EXPLOR_ID")
arcpy.CalculateField_management(outFC2, "Dis2XSec", "!Distance!", "PYTHON_9.3", "")

# Some cleanup
arcpy.DeleteField_management(arcpy.GetParameterAsText(0), 'ORIG_FID')


###############################################################################################
# PART 3 Prepare to apply symbology, display lines as layers
###############################################################################################

# Apply a buffer to the stick logs generated to better visualize the layers

outBuff = outFC2 + '_Buffer'
arcpy.Buffer_analysis(outFC2, outBuff, buffSize, "FULL", "FLAT", "NONE", "", "PLANAR")

# Sort the buffer by the dis2Xsec field to simulate 3D placement (boreholes closer to the viewer will appear ahead of others)

sortBuff = outName2 + '_finalSticks'
arcpy.Sort_management(outBuff, sortBuff, [["Dis2XSec", "ASCENDING"]])

# Add the buffer to the dataframe, if not done automatically

mxd = arcpy.mapping.MapDocument("CURRENT")
dataFrame = arcpy.mapping.ListDataFrames(mxd, "*")[0]
addlayer = arcpy.mapping.Layer(sortBuff)
arcpy.mapping.AddLayer(dataFrame, addlayer, "TOP")


################################################################################################
# PART 4 Add Groundwater Depth Indicators
################################################################################################

if gwShow == 'true':
    waterView = outName2 + '_waterView'
    arcpy.MakeFeatureLayer_management (zBoreholes, waterView)
    gwView = outName2 + '_gwTableView'
    arcpy.MakeTableView_management (gwTable, gwView)
    arcpy.AddJoin_management (waterView, bhIdField, gwView, bhIdField2)

    eventTable2 = outName2 + '_bhEvents2'
    rProps = 'rkey POINT RouteM'
    arcpy.AddMessage('Locating ' + zBoreholes + ' on ' + zmLines)
    arcpy.LocateFeaturesAlongRoutes_lr(waterView, zmLines, 'ORIG_FID', "5000 FEET", eventTable2, rProps, '#', 'DISTANCE')
    arcpy.AddMessage('    ' + eventTable + ' written to ' + arcpy.env.scratchWorkspace)

    waterLines = outName2 + '_waterLines'
    gwaterLines()

    # Add XY data to the waterLines so that points can be made at the end representing groundwater depth, if present
    arcpy.AddGeometryAttributes_management(waterLines, "LINE_START_MID_END")

    # Add the waterLines to the map
    mxd = arcpy.mapping.MapDocument("CURRENT")
    dataFrame = arcpy.mapping.ListDataFrames(mxd, "*")[0]
    addlayer = arcpy.mapping.Layer(waterLines)
    arcpy.mapping.AddLayer(dataFrame, addlayer, "TOP")


    arcpy.SelectLayerByAttribute_management(waterLines, "NEW_SELECTION", "START_X IS NULL OR START_Y IS NULL")
    arcpy.DeleteFeatures_management(waterLines)

    try: # Move the points to the left of the buffer with an update cursor
        fields = ['END_X', 'newX']
        arcpy.AddField_management(waterLines, 'newX', "DOUBLE")
        with arcpy.da.UpdateCursor(waterLines, fields) as cursor:
            for row in cursor:
                row[1] = row[0] - (int(buffSize) + 5)
                cursor.updateRow(row)


        # Create an XY event layer using the new end X field and Y end field to show groundwater presence as points

        tempOut = outName2 + '_Temp'
        finalOut = outName2 + '_groundwater'

        spatial_ref = arcpy.Describe(waterLines).spatialReference
        arcpy.MakeXYEventLayer_management(waterLines, "newX", "END_Y", tempOut, spatial_ref)
        arcpy.CopyFeatures_management(tempOut, finalOut)
        addlayer = arcpy.mapping.Layer(finalOut)
        arcpy.mapping.AddLayer(dataFrame, addlayer, "TOP")

    except:
        arcpy.Delete_management(waterLines)
        arcpy.Delete_management(waterView)
        arcpy.Delete_management(gwView)
        arcpy.Delete_management(eventTable2)


    # Some Cleanup
    dropFields = ['START_Z', 'START_M', 'MID_X', 'MID_Y', 'MID_Z', 'MID_M', 'END_Z', 'END_M']
    arcpy.DeleteField_management(finalOut, dropFields)
    arcpy.Delete_management(waterLines)
    arcpy.Delete_management(waterView)
    arcpy.Delete_management(gwView)
    arcpy.Delete_management(eventTable2)

else:
    pass

###############################################################################################
# PART 5 Cleanup
###############################################################################################



# Delete unnecessary and redundant feature classes.
# Consider setting the environment to the in memory workspace to avoid this step.

arcpy.Delete_management(outBuff)
arcpy.Delete_management(zmAtts)
arcpy.Delete_management(zmProfiles)
arcpy.Delete_management(zLines)
arcpy.Delete_management(zmLines)
arcpy.Delete_management(outBuff)
arcpy.Delete_management(bhLines)
arcpy.Delete_management(zBoreholes)
arcpy.Delete_management(bhIntervals)
arcpy.Delete_management(bhRoutes)
arcpy.Delete_management(outBuff)
arcpy.Delete_management(eventTable)
```

2. Symbology

```
# Applies symbology from a pre-packaged layer file to the output of the
# previous stick log and profile tool

##################################################
# IMPORT MODULES
##################################################

# Import modules consistently with previous stick log and profile tool

import arcpy, os
from arcpy import env


##################################################
# PARAMETERS AND ENVIRONMENT
##################################################

scratchDir = arcpy.env.scratchWorkspace
arcpy.env.workspace = scratchDir
arcpy.env.overwriteOutput = True

# Input sticklogs. This should be the buffer layer from the previous tool output.
stickLogs = arcpy.GetParameterAsText(0)
# Major material symbology layer file to apply
materialSymbology = arcpy.GetParameterAsText(1)

#groundwater depth point locations
groundwater = arcpy.GetParameterAsText(2)
# groundwater symbology layer
groundwaterSymbology = arcpy.GetParameterAsText(3)

# Density symbology layer file to apply
densitySymbology = arcpy.GetParameterAsText(4)
# Name of the point layer generated to display density
densityOutPoints = arcpy.GetParameterAsText(5)
outName = os.path.splitext(os.path.basename(densityOutPoints))[0]

#Distance to shift points from center to edge of buffered stick logs;
#should be equal to or slightly greater than 'buffer distance' input from stick log tool
moveEdge = arcpy.GetParameterAsText(6)

# apply density, yes or no?
applyDens = arcpy.GetParameterAsText(7)

# apply groundwater, yes or no?
applyGW = arcpy.GetParameterAsText(8)

```

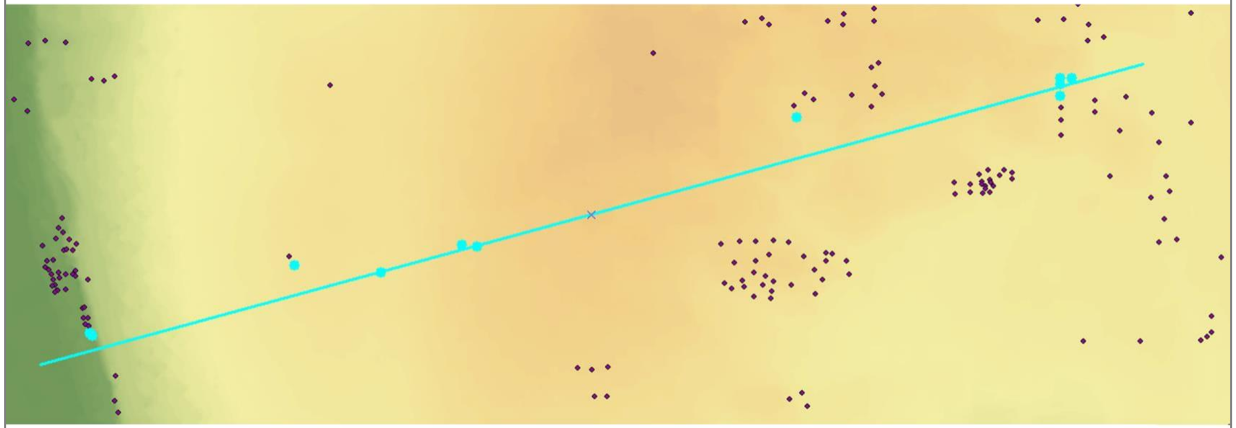
```
##################################################
# MAIN SCRIPT
##################################################

# Apply major material symbology from specified layer

arcpy.ApplySymbologyFromLayer_management(stickLogs, materialSymbology)

# Apply groundwater symbology from specified layer, if selected
if applyGW == 'true':
    arcpy.ApplySymbologyFromLayer_management(groundwater, groundwaterSymbology)
else:
    pass

# Apply density symbology
# Create point symbols at the center of the layer buffer polygons to be used for density symbology

if applyDens == 'true':
    densPoints = outName + '_Pts'
    arcpy.FeatureToPoint_management(stickLogs, densPoints, "CENTROID")

# add points to the map, since the input won't be recognized otherwise

    mxd = arcpy.mapping.MapDocument("CURRENT")
    dataFrame = arcpy.mapping.ListDataFrames(mxd, "*")[0]
    addlayer = arcpy.mapping.Layer(densPoints)
    arcpy.mapping.AddLayer(dataFrame, addlayer, "TOP")

    arcpy.AddXY_management(densPoints)
    fields = ['POINT_X', 'newX']
    arcpy.AddField_management(densPoints, 'newX', "DOUBLE")
    with arcpy.da.UpdateCursor(densPoints, fields) as cursor:
        for row in cursor:
            row[1] = row[0] + int(moveEdge)
            cursor.updateRow(row)

    tempOut = outName + '_Temp' #jrs added this
    finalOut = outName + '_Final'
    spatial_ref = arcpy.Describe(densPoints).spatialReference
    arcpy.MakeXYEventLayer_management(densPoints, "newX", "POINT_Y", tempOut, spatial_ref)
    arcpy.CopyFeatures_management(tempOut, finalOut)
    addlayer = arcpy.mapping.Layer(finalOut)
    arcpy.mapping.AddLayer(dataFrame, addlayer, "TOP")
    inputLayer = arcpy.mapping.ListLayers(mxd, '', dataFrame)[0]#add this (top layer in data frame
) for input instead of using finalOut as input in line below:
    arcpy.ApplySymbologyFromLayer_management(inputLayer, densitySymbology)#this isn't working

    arcpy.RefreshActiveView()

    arcpy.Delete_management(densPoints)
    arcpy.Delete_management(tempOut)
    del cursor

else:
    pass
```

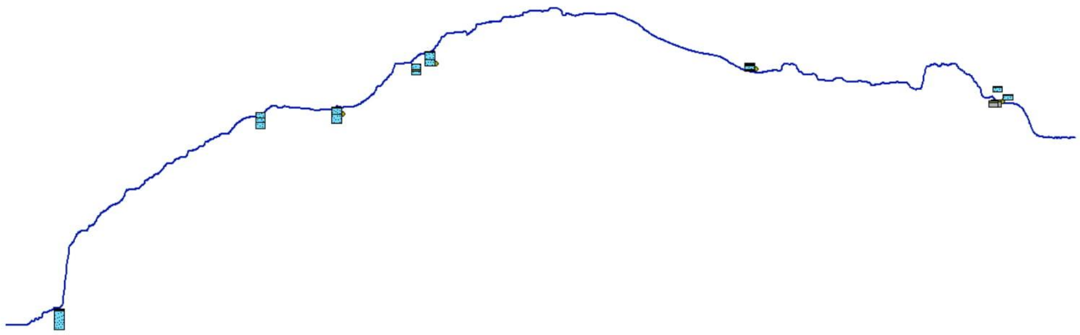
3. Export to Graphic

```python
'''''
Description: This scripts exports the current visible extent of an open mxd to a graphic file format.
The mxd can be in data view or layout view. User can choose resolution parameter (dpi) for all formats, and image
quality for PDF, AI, and SVG file types.


Authors: Jesse Schaefer, Drew Schwitters, Martin Weiser; University of Washington MGIS GEOG569 Capstone project
'''

#import modules
import arcpy

#parameters

file_format = arcpy.GetParameterAsText(0) #pdf, ai, svg, jpg, tiff
dpi = arcpy.GetParameterAsText(1) #resolution in dpi
quality = arcpy.GetParameterAsText(2) #for pdf, ai, svg only; BEST, BETTER, NORMAL, FASTER, FASTEST
output = arcpy.GetParameterAsText(3)

#variables

mxd = arcpy.mapping.MapDocument("CURRENT")

#############
#main script
#############

try:
    if file_format == 'pdf':
        arcpy.mapping.ExportToPDF(mxd, output, resolution = dpi, image_quality = quality)
        #default pdf resolution is 300
    elif file_format == 'ai':
        arcpy.mapping.ExportToAI(mxd, output, resolution = dpi, image_quality = quality)
        #default pdf resolution is 300
    elif file_format == 'jpg':
        arcpy.mapping.ExportToJPEG(mxd, output, resolution = dpi)
        #default jpeg resolution is 100
    elif file_format == 'tiff':
        arcpy.mapping.ExportToTIFF(mxd, output, resolution = dpi)
    elif file_format == 'svg':
        arcpy.mapping.ExportToSVG(mxd, output, resolution = dpi, image_quality = quality)
    arcpy.AddMessage('Exporting to ' + file_format)
    arcpy.AddMessage('Map was exported to ' + output)
except:
    arcpy.AddMessage('Could not export map to ' + file_format)

#cleanup
del mxd
```

Appendix C. Toolbox Instructions Document

Geologic Cross Section Toolbox Instructions





Tools developed by Jesse Schaefer, Drew Schwitters, and Martin Weiser
UW MGIS program GEOG 569 Capstone Workshop
August 17th, 2018

Introduction

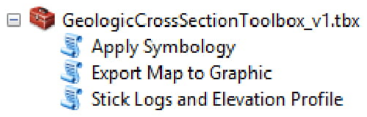
This deliverable contains a folder containing subfolders with help material, layer files to be used for the application of symbology, Python scripts written to power the tools, and an ArcToolbox file with three geoprocessing tools for creating cross section views from GeoMapNW data.

The Geologic Cross Section Toolbox contains three separate tools, which will typically run in the following order:

1) Stick Log and Elevation Profile: this tool creates a 2D cross section view of the elevation profile created from a cross section line and an input DEM, as well as stick logs and groundwater depth indicators for selected GeoMapNW explorations.

2) Apply Symbology: this tool applies included layer symbology (or custom symbology supplied by the user) to the stick log polygon output from the previous tool, and optional groundwater symbology to prior groundwater point outputs and density labels to each subsurface layer in the prior stick log output.

3) Export to Graphic: this tool allows you to export the current map view to a graphic file format of your choice and quality.


GeologicCrossSectionToolbox_v1.tbx
Apply Symbology
Export Map to Graphic
Stick Logs and Elevation Profile

Contents

1: Workspace Setup

- Open ArcMap V 10.X (either a new or existing map document).

    - Keep in mind, when using the “Export to Symbology” tool your exported graphic will be exported from the layout view. If using an existing map document, all elements from the layout view (including map title, legend, scale bars, etc) will be included in your final graphic.

    - Tools have been tested in ArcMap V10.4 and 10.5. Compatibility is not guaranteed with other versions.

- Open ArcToolbox. Right click on the white space and click ‘Add Toolbox’ from the menu that appears. Navigate to the location of the toolbox on your computer and add the toolbox.

    - You can right click on any of the three tools in the toolbox and select ‘Properties’ from the menu to see the location of the script that powers the tool, or change the script to a new version if edits are required.

- Select an output geodatabase and set it as your home geodatabase. The tools will create approximately 5 to 7 feature classes depending on user selections, and these will be written to the Default.gdb unless otherwise specified. You can always create a new geodatabase at a location that is convenient for you. If you are unsure of where tool outputs are being delivered, switch to the source view in the ArcMap table of contents.

- Add your data to the map. At the very least, you will need a cross section line, a DEM covering the area of interest, and the GeoMapNW exploration data points. Additional tool inputs include the subsurface layer table (SUBSURF_LAYER) and groundwater table, (GROUNDWATER_WW). These tables do not need to be added to the map, but having them in a single location is useful.

    - Cross section lines can be a selection from existing line feature classes (such as a selected road from a road dataset), a feature class, or a shapefile.

- ❖ Prepare a cross section line. It is recommended that the user create a line feature class in the home geodatabase to use for the cross section line. Once created, line features can be edited, copied, or imported into that feature class. Editing vertices of a line allow it to be moved and stretched as needed for multiple uses. New lines can be created by starting an edit session on this feature class and using the 'create features' window.

- ❖ **All data should use the same units of measurement (feet, meters, etc).** If data have different units, convert them to a common unit.

➢ Finally, ensure that the **3D Analyst extension in enabled** by selecting 'Customize' from the ArcMap toolbar, then 'Extensions' and checking the 3D analyst box. This tool calls the Interpolate Shape 3D tool which is only available with that extension.

2: Run the Stick Logs and Elevation Profile tool

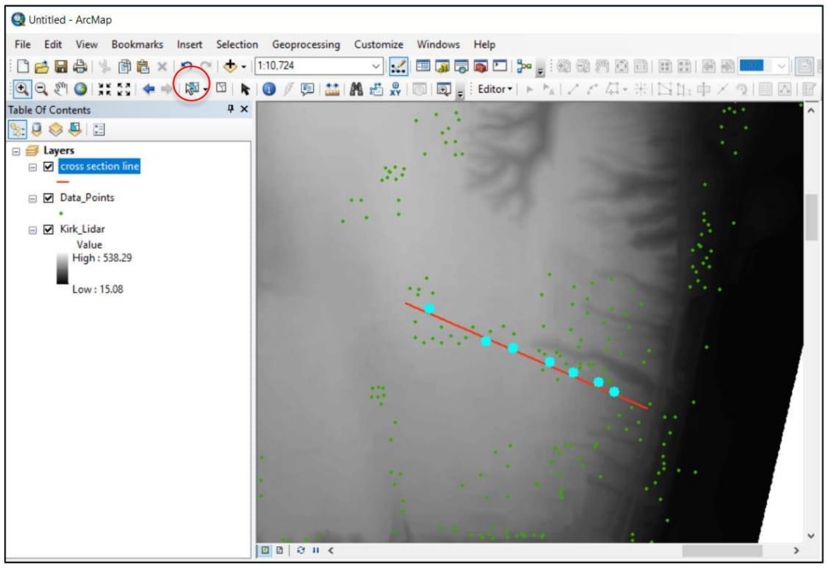


Figure 1. Example of the ArcMap setup with data points selected for use with the Stick log and Elevation profile tool.

- This tool creates a 2D display of elevation profile and stick logs for selected explorations

  - Optional: this tool will also create points for the depth of groundwater encountered in explorations with associated data.

- Open the tool from the added toolbox. Fill in the fields as prompted. Refer to the image below as an example. Required data inputs and brief instructions are provided below:

- **Required Inputs:**

  - Cross Section Line: a cross section line (preferably a geodatabase feature class. See Section 1 for line specifications)

- DEM: a DEM covering the entire area of interest. The cross section line must exist entirely within this DEM.

- Start drawing from: choose a direction to start drawing from. For right to left, select northwest or southwest. For right to left, select southeast or northeast.

- Vertical and Horizontal Exaggeration: specify a vertical and/or horizontal exaggeration factor (choose an integer). VE will be applied to the elevation profile and stick log heights. HE will be applied to the surface profile and stick log position along the cross section. The default value is 1 (no exaggeration).

- Output Surface Profile: specify an output location and name for your output elevation profile of the cross section line. Usually, this will be your home geodatabase selected in Part 1.

- Selected Explorations: geologic exploration points to be displayed as stick logs (use the ArcMap select tool circled in red above to create a selection of points from main database, or choose a subset of points exported to their own feature class)

- Exploration ID Field: the unique exploration ID field from the explorations feature class added above.

- Exploration Depth: the exploration depth field from the above exploration feature class.

- Subsurface Layer Table: the subsurface layer table describing explorations, referenced by a shared UID. This table may be from inside your home geodatabase or anywhere else.

- Exploration ID in Table, Layer Top Depth, Layer Bottom Depth: select the exploration ID field, layer top depth field, and layer bottom depth field from the subsurface layer table.

- Output Stick Logs: specify an output location (usually your home geodatabase specified in part 1) and a name for your output stick log feature classes.

- Buffer Size: specify a buffer size, in map units (generally, this will be feet since GeoMapNW data is in US feet). The buffer will be used to create rectangular polygons from stick log lines for easier visualization, and extends the specified distance in either direction from the line. The default value is 25 map units.

- **Optional inputs:**

  - Borehole Elevation: here you may select the field that represents the beginning (top) elevation of the exploration. If you do, this elevation will be used to draw the start of the stick log for the selected exploration. If you do not, a starting elevation will be interpolated from the DEM.

  - Display groundwater depth? Check this box if you wish to create points in a new feature class that represent the depth at which groundwater is encountered.

    - **If you do wish to display Groundwater indicators, you must provide all of the following three optional inputs:**

    - Groundwater Table: provide the location of the input groundwater table. This may be a table from the geodatabase or any other location

    - Groundwater Depth Field: provide the groundwater depth field from the table. Explorations with no data or null values will not be included in the output.

    - Exploration ID Field in GW Table: provide the unique exploration ID field from the groundwater table.

- **Generated outputs:**

  The following feature classes are created after selecting 'OK' to run the tool:

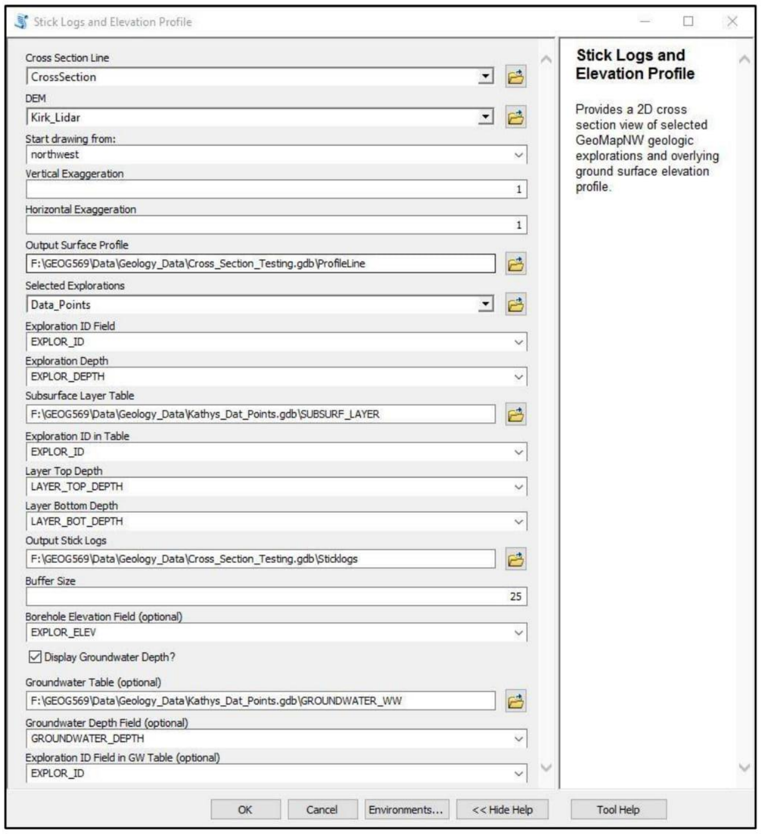
  - Two stick log outputs: a stick logs polygon and stick log line feature class (the polygon feature class is your final output and will be named as you specified, with an added '_finalSticks' label.

  - An elevation profile line feature class, named as specified

- ➢ An optional groundwater depth point feature class

- **Note**: Outputs have no spatial reference so they appear on the map in an arbitrary location, usually far from the location of the input data. Zoom to one of the output layers by right clicking on it in the table of contents and clicking 'Zoom to Layer' to find them on the map.

- The resulting X and Y coordinates of your stick logs and elevation profile are generated by the script. X values are calculated from M values (the measured distance, in map units, from the beginning of the line as specified by your drawing distance and multiplied by the HE). Y values are calculated from Z values interpolated from the DEM multiplied by the VE).


Stick Logs and Elevation Profile

Cross Section Line
CrossSection
DEM
Kirk_Lidar
Start drawing from:
northwest
Vertical Exaggeration
1
Horizontal Exaggeration
1
Output Surface Profile
F:\GEOG569\Data\Geology_Data\Cross_Section_Testing.gdb\ProfileLine
Selected Explorations
Data_Points
Exploration ID Field
EXPLOR_ID
Exploration Depth
EXPLOR_DEPTH
Subsurface Layer Table
F:\GEOG569\Data\Geology_Data\Kathys_Dat_Points.gdb\SUBSURF_LAYER
Exploration ID in Table
EXPLOR_ID
Layer Top Depth
LAYER_TOP_DEPTH
Layer Bottom Depth
LAYER_BOT_DEPTH
Output Stick Logs
F:\GEOG569\Data\Geology_Data\Cross_Section_Testing.gdb\Sticklogs
Buffer Size
25
Borehole Elevation Field (optional)
EXPLOR_ELEV
☑ Display Groundwater Depth?
Groundwater Table (optional)
F:\GEOG569\Data\Geology_Data\Kathys_Dat_Points.gdb\GROUNDWATER_WW
Groundwater Depth Field (optional)
GROUNDWATER_DEPTH
Exploration ID Field in GW Table (optional)
EXPLOR_ID

Stick Logs and Elevation Profile

Provides a 2D cross section view of selected GeoMapNW geologic explorations and overlying ground surface elevation profile.

Figure 2. Example filled inputs for the stick log and elevation profile tool.

3. Run the Apply Symbology Tool

- This tool applies symbology from pre-packaged layer files to symbolize major material class and material density for subsurface layers represented in the stick logs. It also applies symbology to groundwater points, if selected.

- **Required tool inputs:**

  - Input stick log buffer layer: this is your buffered stick log feature class. Unless the script has been altered, choose the output from the previous tool with the name "(your_output_name)_finalSticks". Use the drop down menu to select this layer from your map.

  - Input major material symbology layer: use the folder icon to navigate to the tool deliverable, open the 'Layers' folder, and choose the "MajorMaterial_Symbology.lyr" file.

    - **NOTE**: The tool supports symbolizing the stick logs by any field present in the geologic explorations attribute table. To symbolize the stick logs by another field (such as material class), apply symbology as desired by right clicking the stick log layer in the ArcMap table of contents and clicking on 'Properties'. Navigate to the Symbology tab and choose to symbolize by categories, and then select a field. When finished, right click on the layer in the table of contents and select 'Save as Layer File". You may now use this saved layer file instead of the pre-packaged layer file to apply symbology. The same method will work on all other inputs that require a layer file.

- **Optional tool inputs:**

  - Groundwater depth location: if groundwater indicators were created with the previous tool, input them here. They are the point feature class ending with "_groundwater" and are selectable from the drop down menu. If none were created, leave the field blank.

- Groundwater depth symbology: as above, navigate to the layer folder and select the "Groundwater_Symbology.lyr" file or a custom layer file if desired. Make sure to check the box to apply groundwater symbology below.

- Input density layer: as above, navigate to the layer folder and select the "MaterialDensity_LettersSymbology.lyr" file or a custom layer file if desired. Make sure to check the box to apply density symbology below.

- Output density points: if you select to symbolize density in the check box below, specify a file path and name for the resulting point feature class that is created and used to apply density labels for your stick log layers. Usually this will be in your home geodatabase.

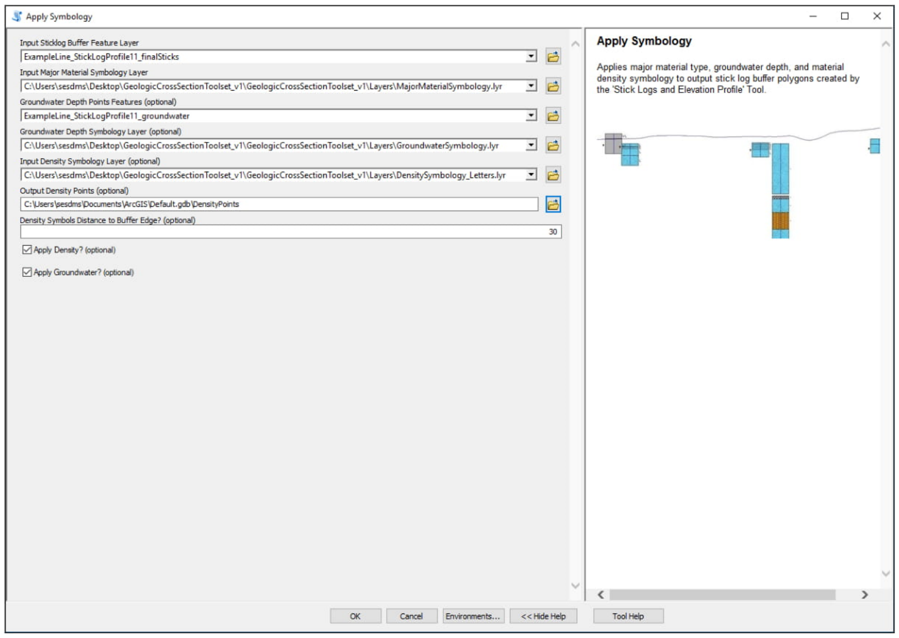
- Density Symbol Distance to Buffer Edge? This is the distance that the density labels are moved from the center of the polygon to the right, in map units. For optimal viewing at most scales, select the buffer width specified in the previous tool and add 5 (default value is 30, 5 more than the default value for the buffer width in the previous tool).

- Apply Density? Check the box if you wish to symbolize density.

- Apply Groundwater? Check the box if you wish to symbolize groundwater depth indicators.

- **Generated Outputs:**

  - A density points layer with applied symbology is the only output from this tool, and is only generated if the density symbology is applied.


Apply Symbology

Input Sticklog Buffer Feature Layer
ExampleLine_StickLogProfile11_finalSticks

Input Major Material Symbology Layer
C:\Users\sesdms\Desktop\GeologicCrossSectionToolset_v1\GeologicCrossSectionToolset_v1\Layers\MajorMaterialSymbology.lyr

Groundwater Depth Points Features (optional)
ExampleLine_StickLogProfile11_groundwater

Groundwater Depth Symbology Layer (optional)
C:\Users\sesdms\Desktop\GeologicCrossSectionToolset_v1\GeologicCrossSectionToolset_v1\Layers\GroundwaterSymbology.lyr

Input Density Symbology Layer (optional)
C:\Users\sesdms\Desktop\GeologicCrossSectionToolset_v1\GeologicCrossSectionToolset_v1\Layers\DensitySymbology_Letters.lyr

Output Density Points (optional)
C:\Users\sesdms\Documents\ArcGIS\Default.gdb\DensityPoints

Density Symbols Distance to Buffer Edge? (optional)
30

☑ Apply Density? (optional)

☑ Apply Groundwater? (optional)

Apply Symbology

Applies major material type, groundwater depth, and material density symbology to output stick log buffer polygons created by the 'Stick Logs and Elevation Profile' Tool.

Figure 3. Tool UI with example parameters filled in for the Apply Symbology tool.

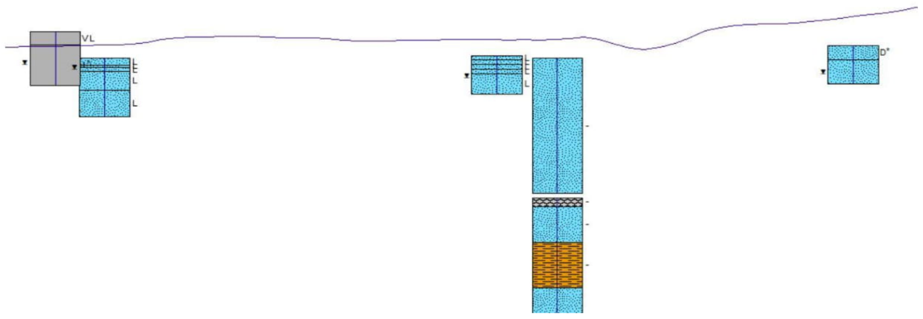
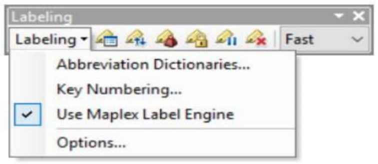


Figure 4. Profile line and stick logs with major material, density, and groundwater symbology applied.

- **NOTE:** This tool does not label the output stick logs with the exploration ID, and this must be done manually in ArcMap. To do so:

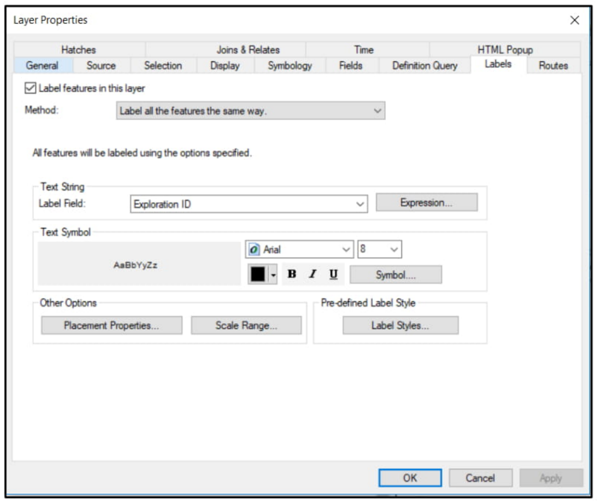
3.1 Apply Labels

- Open the labeling toolbar and under the "Labeling" menu select "Use Maplex Label Engine."

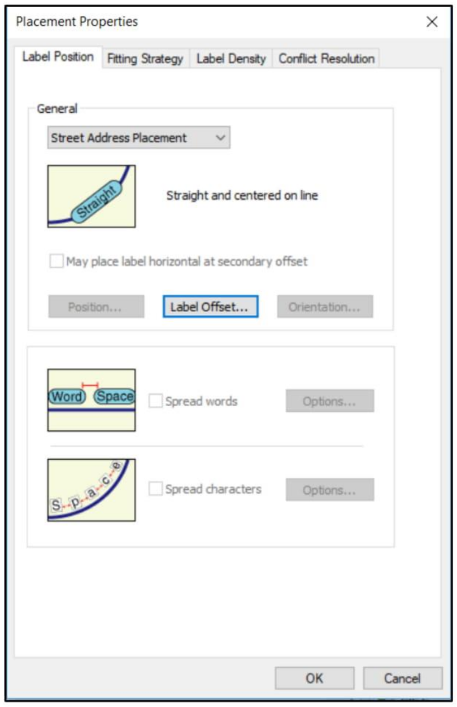


- In order to apply a vertically oriented label that is displayed above the stick log, you need to label the stick log LINES output (rather than the polygons).

- Open the layer properties for the stick log LINES output (this will be named whatever base name you chose for output 2 of the tool, whereas the polygons are named basename_finalSticks). Check the box for "Label features in this layer," set the label field to "Exploration ID," and set the text symbol properties (size and font) as desired.



➢ Under "Other Options", open "Placement Properties." Under "General," choose "Street Address Placement", and then open "Label Offset."


Placement Properties

Label Position | Fitting Strategy | Label Density | Conflict Resolution

General

Street Address Placement

Straight and centered on line

May place label horizontal at secondary offset

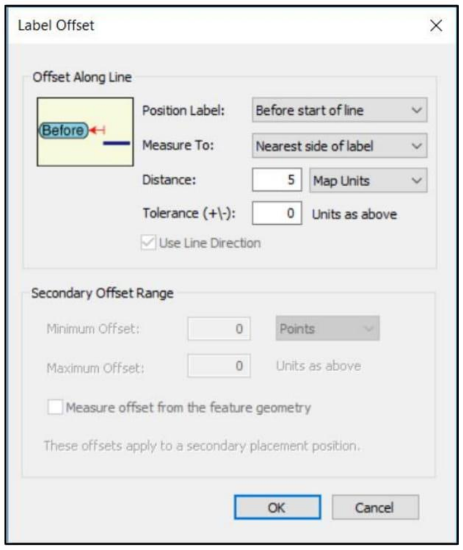
Position... | Label Offset... | Orientation...

Spread words | Options...

Spread characters | Options...

OK | Cancel

➢ For label offset, Position Label is "Before start of line" and Measure to "Nearest side of label." Then select an offset distance. This may depend on the scale of the map you are exporting; the example provided above uses an offset of 5 (units are map units, in this case feet).


Label Offset

Offset Along Line

Position Label: Before start of line

Measure To: Nearest side of label

Distance: 5 Map Units

Tolerance (+\-): 0 Units as above

Use Line Direction

Secondary Offset Range

Minimum Offset: 0 Points

Maximum Offset: 0 Units as above

Measure offset from the feature geometry

These offsets apply to a secondary placement position.

OK | Cancel

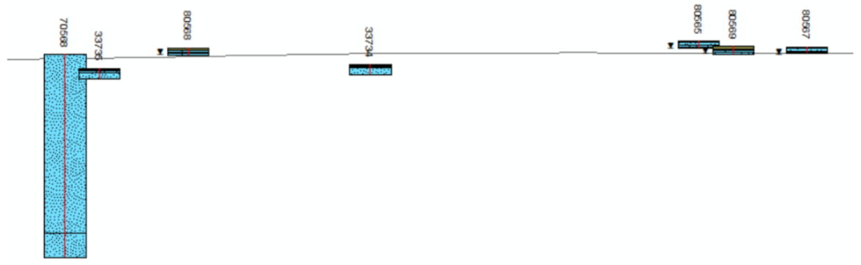
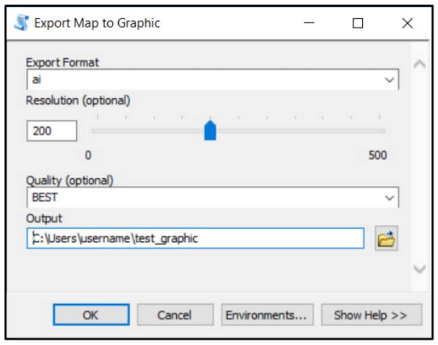


Figure 5. Result of manual labeling of explorations by unique ID in ArcMap

4. Run the Export to Graphic Tool

- This tool exports the current map extent to a graphic file format. The current map layout will also be exported, so make sure to format the layout view before exporting.
- Before exporting, turn off or remove any layers from the map view that you do not want included in the graphic
- Before running, zoom to the extent of the map that you would like to export or create a layout view with the extent you want to export and page layout properties (page size) applied.
- To turn off the line present in figure 6, turn off the neatlines from the data frame properties in ArcMap.


Export Map to Graphic

Export Format: ai

Resolution (optional): 200

Quality (optional): BEST

Output: C:\Users\username\test_graphic

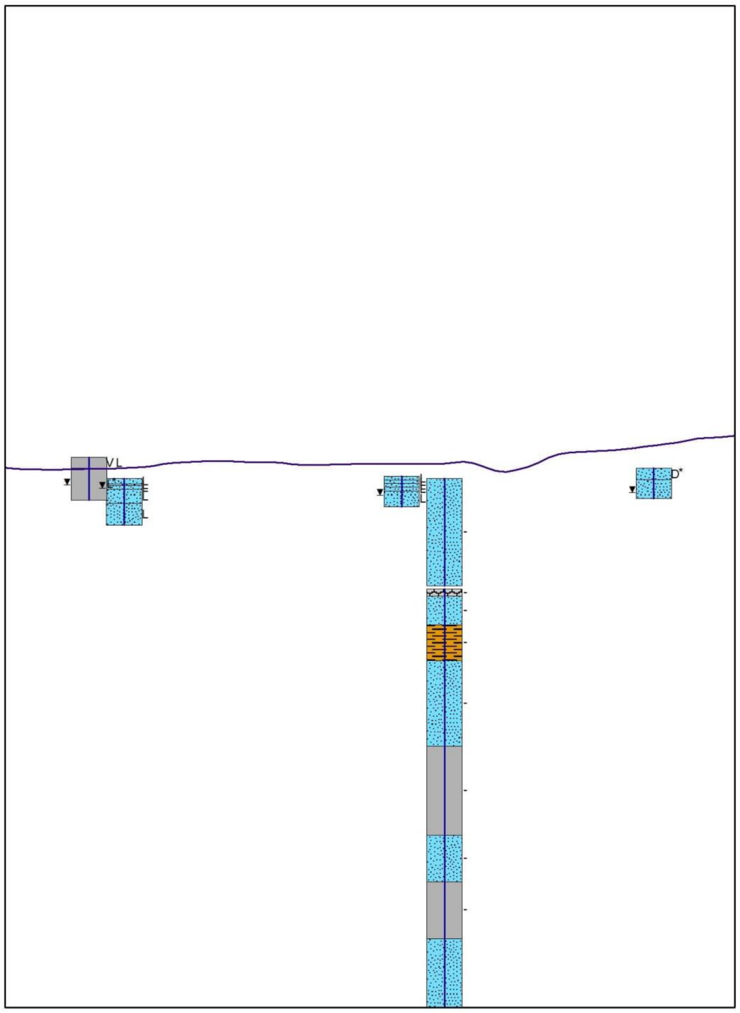


Figure 6. Output exported to jpeg file (with neatlines)

Appendix D. "Tool parameter documentation" file

Toolbox Name: Geologic Cross Section Toolbox			
Parameter	***Tool Explanation***	***Data Type***	***Script Explanation***
1. Stick Logs and Elevation Profile | Script: StickLog&Groundwater&Profile			

Cross Section Line	Input cross section line layer used for creating the elevation profile. This can be an active selection or a feature class with a single line.	Feature layer	linesLayer = arcpy.GetParameterAsText()
			transferAtts(inFC, joinTable, parentKey, childKey, fInfo, outName):
			
			Transfers attributes from a table to a fc: OIDs must match. Get the attributes through a join which only works on a feature layer. Make the join based on key field.

DEM	Input bare earth DEM.	Raster layer	dem = arcpy.GetParameterAsText()
			arcpy.InterpolateShape_3d(dem, linesLayer, zLines)
			
			Interpolate the lines as "z" locations within DEM for profile line, sticklog, and groundwater.

Start drawing from:	Corner of the map from which to start drawing the profile line and stick logs.	String	cp = getCPValue(arcpy.GetParameterAsText()
			getCPValue(quadrant):

Vertical Exaggeration	Vertical exaggeration value applied to the profile line and stick logs.	Double	ve = arcpy.GetParameterAsText()
			plan2side(ZMlines, ve, he):
			
			Flip map view lines to cross section view without creating a copy this function updates the existing geometry.

Horizontal Exaggeration	Horizontal exaggeration value applied to the profile line and stick log spacing.	Double	he = arcpy.GetParameterAsText()
			plan2side(ZMlines, ve, he):
			
			Flip map view lines to cross section view without creating a copy this function updates the existing geometry.

Output Surface Profile	Output location and file name for elevation profile line(s).	Feature class	outFC = arcpy.GetParameterAsText()
			outName = os.path.splitext()
			addAndCalc()
			arcpy.InterpolateShape_3d()
			arcpy.CreateRoutes_lr()
			arcpy.CreateFeatureclass_management()
			arcpy.Append_management()
			
			Interpolate the lines, measure the lines, hook the attributes back up transferAtts(inFC, joinTable, parentKey, childKey, fInfo, outName), copy the final fc from the scratch gdb to the output directory

Selected Explorations	Exploration points that will be used to create stick logs. This can be an active selection or a feature class containing just the desired points.	Feature layer	bhLayer = arcpy.GetParameterAsText()
			arcpy.InterpolateShape_3d()
			arcpy.AddField_management()
			arcpy.CalculateField_management()
			arcpy.LocateFeaturesAlongRoutes_lr()
			arcpy.DeleteIdentical_management()
			arcpy.CreateRoutes_lr()
			arcpy.MakeRouteEventLayer_lr()
			arcpy.Select_analysis()

			Interpolate Z values for the boreholes. This can be an active selection or a feature class containing just the desired points.

Exploration ID Field	Unique ID field in the exploration points layer.	Field	bhIdField = arcpy.GetParameterAsText()
			arcpy.CalculateField_management()
			
			Unique ID field from subsurface layers table, used for joining table to selected explorations.

Exploration Depth	Exploration depth field from the selected exploration points.	Field	bhDepthField = arcpy.GetParameterAsText()
			arcpy.CalculateField_management()
			
			Exploration depth field from the selected exploration points and joined subsurface table.

Subsurface Layer Table	Table containing attributes for each subsurface layer.	Table	intervalsTable = arcpy.GetParameterAsText()
			arcpy.JoinField_management()
			
			Table containing attributes for each subsurface layer.

Exploration ID in Table	Unique ID field from subsurface layers table, used for joining table to selected explorations.	Field	intBhIdFld = arcpy.GetParameterAsText()
			arcpy.JoinField_management()
			arcpy.LocateFeaturesAlongRoutes_lr()
			
			Unique ID field from subsurface layers table, used for joining table to selected explorations.

Layer Top Depth	Layer top depth field from subsurface layers table.	Field	intTopDepthFld = arcpy.GetParameterAsText()
			arcpy.JoinField_management()
			arcpy.LocateFeaturesAlongRoutes_lr()
			Layer top depth field from subsurface layers table.

Layer Bottom Depth	Layer bottom depth field from subsurface layers table.	Field	intBotDepthFld = arcpy.GetParameterAsText()
			arcpy.JoinField_management()
			arcpy.LocateFeaturesAlongRoutes_lr()
			
			Layer bottom depth field from subsurface layers table.

Output Stick Logs	Output location and file name for stick logs.	Feature class	outFC2 = arcpy.GetParameterAsText()
			outName2 = os.path.splitext()
			
			Output location and file name for stick logs.

Buffer Size	Width in map units of the buffer applied to the stick log lines. This determines how wide each stick log polygon appears and is for optimizing display. Default is 25.	Double	buffSize = arcpy.GetParameterAsText()
			arcpy.Buffer_analysis()
			arcpy.Sort_management()
			
			Width in map units of the buffer applied to the stick log lines. This determines how wide each stick log polygon appears and is for optimizing display. Default is 25.

Borehole Elevation Field *	Elevation field from selected explorations. If null or zero, or if not specified, tool will use elevation value from DEM at the exploration point.	Field	bhElev = arcpy.GetParameterAsText()
			arcpy.CalculateField_management()
			
			Elevation field from selected explorations. If null or zero, or if not specified, tool will use elevation value from DEM at the exploration point.

Display Groundwater Depth?	Do you want to include groundwater depth for sticklogs?	Boolean	gwShow = arcpy.GetParameterAsText()
			arcpy.CreateFeatureclass_management()

Groundwater Table*	Location of table containing a groundwater depth field. Required only if you want to include	Table	gwTable = arcpy.GetParameterAsText()
			arcpy.SearchCursor()
			arcpy.InsertCursor()

	groundwater depth.		arcpy.CreateObject()
			arcpy.AddJoin_management()
			
			Creates search cursor insert cursor and creates object from selected field, joins table with exploration points.

Groundwater Depth Field*	Groundwater depth field from groundwater table . Required only if you want to include groundwater depth.	Field	gwDepthField = arcpy.GetParameterAsText()
			arcpy.CalculateField_management()
			
			Selects groundwater depth field from groundwater table.

Exploration ID Field in GW Table*	Unique ID field in the groundwater table. Required only if you want to include groundwater depth.	Field	bhIdField2 = arcpy.GetParameterAsText()
			arcpy.AddJoin_management()
			
			Unique ID field in the groundwater table. Used to join groundwater table and exploration points. Required only if you want to include groundwater depth.

2. Apply Symbology | Script: Symbology			
Input Stick Log Buffer Feature Layer	Feature layer of stick log polygons; output from Profile and Stick Log tool.	Feature layer	stickLogs = arcpy.GetParameterAsText() Select feature layer from stick log output
Input MajorMaterial Symboloy Layer*	Layer file with desired major material symbology.	Layer file	materialSymbology = arcpy.GetParameterAsText() arcpy.ApplySymbologyFromLayer_management () Select major material layer file
Groundwater Depth Points Features*	Points feature layer of groundwater depth locations for stick logs. This is an output created by the 'Stick Logs and Elevation Profile' Tool. Required only if you want to apply groundwater symbology.	Feature layer	groundwater = arcpy.GetParameterAsText() arcpy.mapping.AddLayer Select groundwater points output
Groundwater Depth Symbology Layer*	Layer file with desired groundwater symbology. Required only if you want to apply groundwater symbology.	Layer file	groundwaterSymbology = arcpy.GetParameterAsText() arcpy.ApplySymbologyFromLayer_management () Select groundwater symbology layer file
Input Density Symbology Layer*	Layer file with desired density symbology. Required only if you want to apply density symbology.	Layer file	densitySymbology = arcpy.GetParameterAsText() Select density layer file

Output Density Points*	Output file with symbolized density points; these will display for each layer along the right side of the stick log. Required only if you want to apply density symbology.	Feature class	densityOutPoints = arcpy.GetParameterAsText()
			outName = os.path.splitext()
			
			Select output file path

Density Symbols Distance to Buffer Edge?*	Buffer distance applied to place the density symbols along the edge of the stick log. This will depend on the value chosen for "Buffer Size" in the Stick Logs and Elevation Profile tool. A value of several units greater than that used for Buffer Size is ideal. Required only if you want to apply density symbology.	Long	moveEdge = arcpy.GetParameterAsText(()
			arcpy.FeatureToPoint_management()
			arcpy.MakeXYEventLayer_management()
			CopyFeatures_management()
			
			Creates a buffer distance from sticklog buffer output. Select a buffer size that is larger than the Stocklogs, Elevation Profile, and Groundwater Tool.

Apply Density?*	Check this box if you want to apply density symbology.	Boolean	arcpy.ApplySymbologyFromLayer_management ()

			Check box to apply density symbology.

Apply Groundwater?*	Check this box if you want to apply groundwater symbology.	Boolean	applyDens = arcpy.GetParameterAsText()
			arcpy.ApplySymbologyFromLayer_management()
			Check box to apply groundwater symbology.

3. Export Map to Graphic | Script: Export2Graphic			

Export Format	Select desired output file format. Options are PDF, AI, SVG, JPEG, and TIFF.	String	file_format = arcpy.GetParameterAsText()
			arcpy.mapping.ExportToABC()
			
			Select desired output file format. Options are PDF, AI, SVG, JPEG, and TIFF.

Resolution*	Output resolution (DPI). Default is 200.	Long	Select image resolution from file format.
Quality*	Output quality. Applies only to PDF, AI, SVG formats.	String	Select output quality. Applies to PDS, AI, SVG formats only.
Output Location and Name	Select a location and name for the output file.	File	Select output location.
** Denotes optional parameter*			