AN ABSTRACT OF THE PROJECT OF

Victoria Dutille for the degree of <u>Master of Science</u> in <u>Civil Engineering</u> presented on <u>July 28th, 2020.</u>

Title: GOSEP: Georeferenced Oregon Soil Engineering Properties

Abstract approved: _____

Dr. T. Matthew Evans and Dr. Armin Stuedlein

Geotechnical engineers design and analyze the interface between the natural and built environments, often based on uncertain and inherently variable data due to the nature of the building material, soil. Engineers must estimate the subsurface conditions at a site using historical, *in-situ*, and laboratory testing data. However, only discrete representative samples can be obtained during subsurface investigations and soil engineering properties can vary appreciably at a single site, both laterally and with depth. Designs based on incomplete, inaccurate or misinterpreted subsurface data can be dangerous and extremely costly, but comprehensive site investigation is also expensive, so engineers are constantly attempting to achieve an appropriate balance. To the extent possible, it is often beneficial to begin site characterization before leaving the office: information on weather conditions, geography, topography, regional geology, and adjacent structures is available for many sites. Prior borehole logs and historical subsurface tests, however, commonly remain un-aggregated, in original reports and in the respective project offices after the projects have been completed. It would therefore be beneficial to have a comprehensive database where engineers and geologists could search by location for previous subsurface explorations, tests and *in-situ* reports, soil engineering properties, and hazard reports. This document describes just such a database that has been developed using a geographic information system (GIS) to compile soil engineering properties for the state of Oregon. Researchers and engineers collect enormous quantities of geotechnical data from across the state as part of projects funded by the Oregon Department of Transportation (ODOT), the Cascadia Lifelines Program (CLiP), National Science Foundation (NSF), in addition to industrial projects. The Georeferenced Oregon Soil Engineering Properties Database (GOSEP) compiles existing data across projects from all over the state, including monotonic strength, laboratory characterization data, borehole logs, and *in-situ* test results. The database is world viewable and searchable via a web interface. Ultimately, more complete data sets facilitate better decision making and knowledge of soil engineering properties helps guide decisions about infrastructure hardening, protection, and post-disaster redeployment.

GOSEP: Georeferenced Oregon Soil Engineering Properties

by
Victoria Dutille

A PROJECT

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APPROVED:

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Major Professor, representing Civil Engineering

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Head of the School of Civil and Construction Engineering

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Dean of the Graduate School

I understand that my project will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my report to any reader upon request.

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Victoria Dutille, Author

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

1   INTRODUCTION

1.1   Problem Statement

Proper site and subsurface characterization is the first step in any civil engineering project or any project occurring on or under the ground. Construction and disaster protection, without sufficient subsurface investigation and analysis, can be dangerous and expensive. Additionally, the engineering properties of the local soils are important for assessing geohazards and other important factors for building and planning (El May et al. 2010). Engineers have developed a variety of methods for characterizing subsurface conditions and predicting soil responses. These approaches, including *in-situ* and laboratory tests, are being performed every day across Oregon. However, the state of Oregon does not currently have a comprehensive record of the previous soil characterization efforts. Project files exist in individual agencies and as part of research studies with no centralized repository of the data. Much of the older subsurface data is archived in hard copy only, or borehole data is provided as images in geotechnical reports, making it difficult to access and organize. Newer data is in electronic form, but relatively little of it is digitized into a structured and searchable database. When data is shared or used for different applications and analysis, data often must be re-entered manually in order to be useful for a project. This can result in omissions, inconsistencies, and limited ability to use previous subsurface data in future projects (Sharifi-Mood et al. 2020). If previous logs cannot be found, new subsurface penetrations are necessary. For example, instead of strategically performing a small handful of cone penetration tests and pairing them with historical data, borings will have to be performed across the entire site, often producing the same results. A cumulative database for the state of Oregon where engineers and geologists can search a building site and find previous subsurface explorations, previous tests

and *in-situ* reports, and soil engineering properties will help eliminate valuable data loss and inconsistencies.

1.2   Objectives

The objective of this project is to address the problems stated above by creating a GIS database which compiles soil engineering properties for the state of Oregon. The database will be published online through Oregon State University, consistent with current online Oregon georeferenced databases like those available on O-HELP (Oregon Hazard Explorer for Lifelines Program), so that it will be easy to access and use. The database should be as comprehensive and widespread as possible, with data from across the state in each Oregon County. Data should also be compiled from a variety of sources and types of testing including borehole logs, *in-situ* test results, liquefaction triggering, monotonic strength, and laboratory characterization data. The database and website should be extensible since subsurface investigations are being performed often, as part of ODOT, CLiP, NSF, industrial, and other projects. Therefore, the database should be methodically constructed so that it can be easily updated and so that future researchers and students can build on the content and technology involved. The ultimate goal is to create a continually expanding dataset, to help facilitate project efficiency and better decision making in geotechnical engineering, geology, construction, and disaster and post-disaster planning. There are rarely downsides of having more data, more organized data, and more available data. There are many advantages for this database, along with addressing the problems stated above, creating a reliable source of subsurface investigations can help to document and model the soil engineering properties and strength uncertainty throughout the study area (Sharifi-Mood et al. 2020). Soil engineering property databases can also play a critical role where the subsurface deposits are complex and require comprehensive assessments (Raper and Wainwright, 1987). While the idea of a

georeferenced database itself is not novel, the application is: organizing and georeferencing data that is already paid for and procured such that it is readily accessible. The database produced as a part of this work is termed GOSEP: Georeferenced Oregon Soil Engineering Properties.

1.3 Report Organization

This report shows how the GOSEP database was created and how to navigate the website on which it is hosted. It details how the database will be advantageous to Oregon's state and private agencies, researchers, and taxpayers alike, as well as how the georeferenced database can be expanded and improved upon in the future. The organization of this report is as follows.

Section 1 introduces the project generally, the problem statement, and the project objectives. Section 2 provides a summary of literature pertaining to the development of the database including literature on Oregon's unique geology, GIS methods, and GIS implementation in geotechnical engineering, and previous cases and situations where soil engineering properties have been georeferenced. Section 3 presents the database framework and implementation within ArcGIS Pro. Section 4 highlights the results of the project and provides a discussion on the effectiveness of the database and its validity. Section 5 summarizes this report and suggests directions for future work. The code that was developed to host the GOSEP website is published in Appendix A, and the user's manual for the Georeferenced Oregon Soil Engineering Properties database and website is contained in Appendix B.

2 LITERATURE REVIEW

2.1 Oregon Geology

Oregon's geology and hazard potential are explained by a unique geological history dominated by the subduction of oceanic plates. The state has been shaped by volcanoes depositing expanses of

volcanic rock, the glaciers capping volcanoes of the Cascade Range, and the rivers incising the state. Oceanic sediments have erected thick deposits of marine sedimentary rock beneath the Oregon Coast Range. Coupled with ongoing volcanic eruptions, massive floods, tens of thousands of landslides, and subduction megathrust earthquakes on the Cascadia Subduction Zone about every five hundred years (Madin, 2009), Oregon's geologic landscape is complex.

The Cascadia subduction zone is a convergent plate boundary about 60 miles offshore and stretching from Vancouver Island in Canada to Northern California in the United States, passing through Oregon. Here, the Juan de Fuca plate moves to the east and slides below the much larger North American Plate, posing the threat of earthquakes and tsunamis to the Oregon Coast and elsewhere (Goldfinger et al. 2012).

Because of Oregon's position on the leading edge of a moving crustal plate, a striking diversity of geologic events have molded its topography. While its geology is complex, for summarization purposes, it can be categorized into eight different provinces: Blue Mountains, Klamath Mountains, Basin and Range, Owyhee Plateau, High Lava Plans, Deschutes-Columbia Plateau, Cascade Range, Willamette Valley, and the Coast Range. Figure 1 shows the eight geologic regions.

A brief description of each of these geologic regions follows (Orr and Orr 2012):

- The Blue Mountains originated as volcanic islands and ocean crust and their foundation includes fossils, sediments, and volcanic rocks. In the Mesozoic Era, a vast seaway covered the area and deposited thousands of feet of silt and sand.

- The Klamath Mountains also originated as volcanic archipelagos and crustal slabs. The region has since had a history of flooding, sediment and terrane rock deposition, faulting, and basin rifting that has left the province rich and diverse geologically.

- The Oregon Basin and Range, as the name suggests, is made up of long, narrow, north-south mountains between broad valleys. The area is notable for multiple processes of crustal extension, leading to faulting and volcanism. The crust is thick with a high heat flow, and during the Pleistocene Epoch, a cooling climate, glaciation, and increased rainfall filled the lowlands with vast pluvial lakes. Fossil remains of the birds and mammals attracted to the area's epithermal lakes at this time litter the sandy flat valleys.
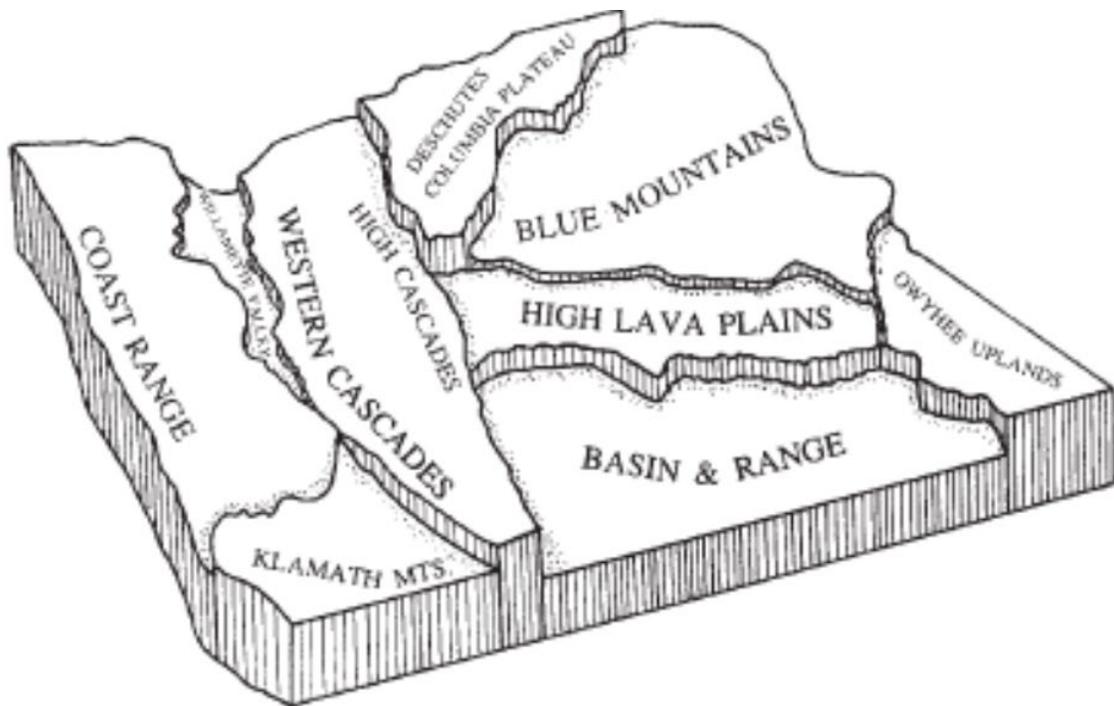
Figure 1: Generalized geological provinces in the state of Oregon (Orr and Orr 2012).

- The Owyhee plateau covers the extreme southeastern corner of Oregon and has a long history of volcanism, faulting and graben formation, and is inundated with volcanic rocks.

Miocene flood basalts and volcanism created massive calderas and spread lava across the province. Faulting also lead to deposits of sediment in the area by creating grabens, or depressions, that broke into smaller basins where stream and lake sediments accumulated.

- The High Lava Plains is an elevated desert plateau in the center of the state. Volcanism has molded the geology and topography of the area with a variety of young lava flows, cones and buttes in an otherwise relatively flat area. The lavas in the High Lava Plains often vary from rhyolite to basalt in composition.

- The Deschutes-Columbia plateau is characterized by stacked sheet flows created by Columbia River flood basalts. Volcanic and fluvial sediments with preserved animal remains cover the basalt surfaces. Floods from glacial lakes in the late Pleistocene brought water and sediment and the area now has many rivers and tributaries.

- The Cascade Range was erected from ash and lava from a line of cones parallel and adjacent to the Pacific Ocean. Cascade lavas exhibit a diversity of timing, spacing, and composition most likely due to subduction and crustal action.

- The Willamette Valley and Coast Range had their beginnings as part of a wide continental shelf along the western margin of North America, where the two provinces shared closely related environments and sediments. The Willamette valley has abundant ground and surface water. However, a surplus of rainfall brings flooding and landslides, while movement along the many faults intersecting the valley results in damaging earthquakes. Seismic activity originating along the offshore Cascadia subduction zone could prove even more destructive. What is now the Oregon Coast has foundations of fluvial muds, sands, and volcanic debris. However, the geomorphology of the coast is continuously altered by uplift, landslides, waves, and erosion.

Figure 2 shows a map of the general geology of the State of Oregon from the Oregon Geologic Data Compilation by DOGAMI.
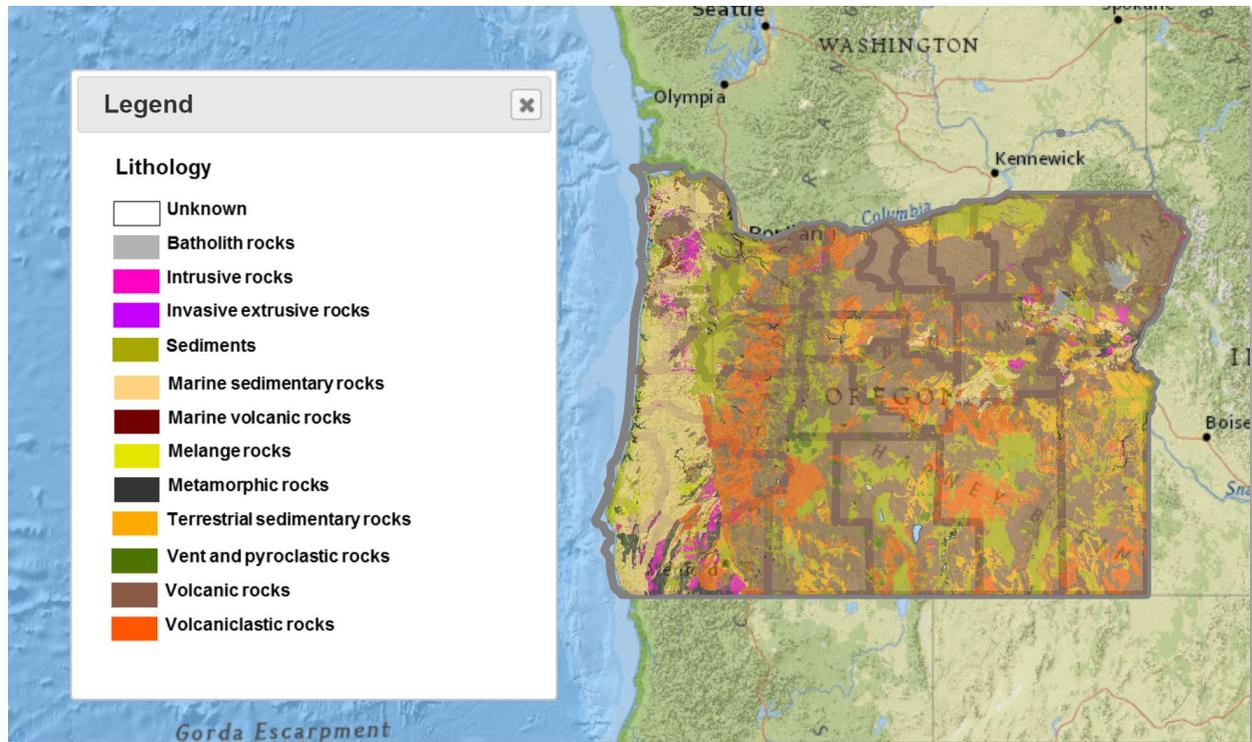
Figure 2: A complete, digitally compiled, general geology file with a vector polygon format from the Oregon Geologic Data Compilation by DOGAMI (Smith and Roe, 2015).

2.2   Current Practice of GIS in Geotechnical Engineering

Geographical Information System or GIS, is defined as "a fundamental and universally applicable set of value-added tools for capturing, transforming, managing, analyzing, and presenting information especially, in spatial data" (Tim, 1995). GIS gives the user the opportunity to store spatial information in a multilayered database. For this reason, GIS is used by many engineering disciplines and in any application where spatial data is available such as in environmental engineering, water resources, human resources, construction, transportation, planning and land development, and geotechnics (Wan-Mohamad, 2011). A system that facilitates the efficient

storage, analysis, and updating of data has many natural uses in geotechnical engineering. GIS is currently used in select applications to present information such as maps and tables from subsurface information. The next section discusses areas and organizations that have adopted GIS in their management of geotechnical data. However, using GIS to manipulate and use geotechnical data is not widespread and generally does not represent the current state of practice in Oregon and other locations around the world. Geotechnical data, including *in-situ* test results and boring logs acquired by subsurface investigations as well as extensive laboratory tests such as soil type, strength, liquefaction potential, behavior, and plasticity are critical for the economic and safe execution of civil and environmental projects. This critical and valuable data is often confined to original reports and in the respective project offices after the projects have been finished (Wan-Mohamad, 2011).

Rogers and Luna (2004) discuss the impact of GIS on geotechnical engineering and detail how GIS allows for vast quantities of spatial data to be combined and sorted in a user-friendly way. This work details challenges of compiling multiple data sets in the same framework. In geotechnical engineering, standard formatting varies significantly. Inconsistencies in formatting, data reliability and age are typical and present challenges in compiling multiple data sets. However, GIS can be used to combine and manipulate data sets relatively easily and the program can lull the user into thinking dissimilar data sets have been seamlessly joined. It is important to take care that mistakes and disparities do not go unaccounted and to standardize formatting as much as possible (Rogers and Luna, 2004).

Losier et al. (2011) presented gaps in geotechnical research and data processing. Their work highlights significant advances that have been made with geotechnical instruments and their ability

to generate and transmit data. These geotechnical instruments, such as cone penetrometers, can provide large quantities of high-quality field information. The authors argued that the gap in geotechnical research is no longer generation or transmission capacity of information, but more on the "integration, organization, manipulation and distribution of the raw data in order to help and support the decision making" (Lossier et al. 2011). Their work explores how georeferenced soil properties and position of field components like instruments or boreholes have a spatial dimension that needs geomatics skills to be applied adequately.

Hackeloeer et al. (2014) give an excellent overview of ongoing challenges of the georeferencing and GIS framework. They present the relevant methods and applications of georeferencing and make an argument for the criticality to improve map-agnostic location referencing algorithms.

2.3   DIGGS

Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS) is a data transfer protocol for geotechnical and geoenvironmental data. DIGGS is not a database, but aids in database form and in data transfer (ASCE 2020). A problem within Departments of Transportation (DOTs) throughout the country was recognized, and DIGGS was identified as the solution. DIGGS was developed to standardize data in all stages: recording, storing, and sharing. Figure 3 shows a schematic of the intended use of DIGGS to connect and transfer geotechnical data through all stages. Individual bits of data are connected to key metadata such as test reference and geographic location making finding and working with particular instances of data easier. DIGGS was developed under a Federal Highway Administration (FHWA) State Pooled Funding Study led by the Ohio Department of Transportation from 2005 to 2012.
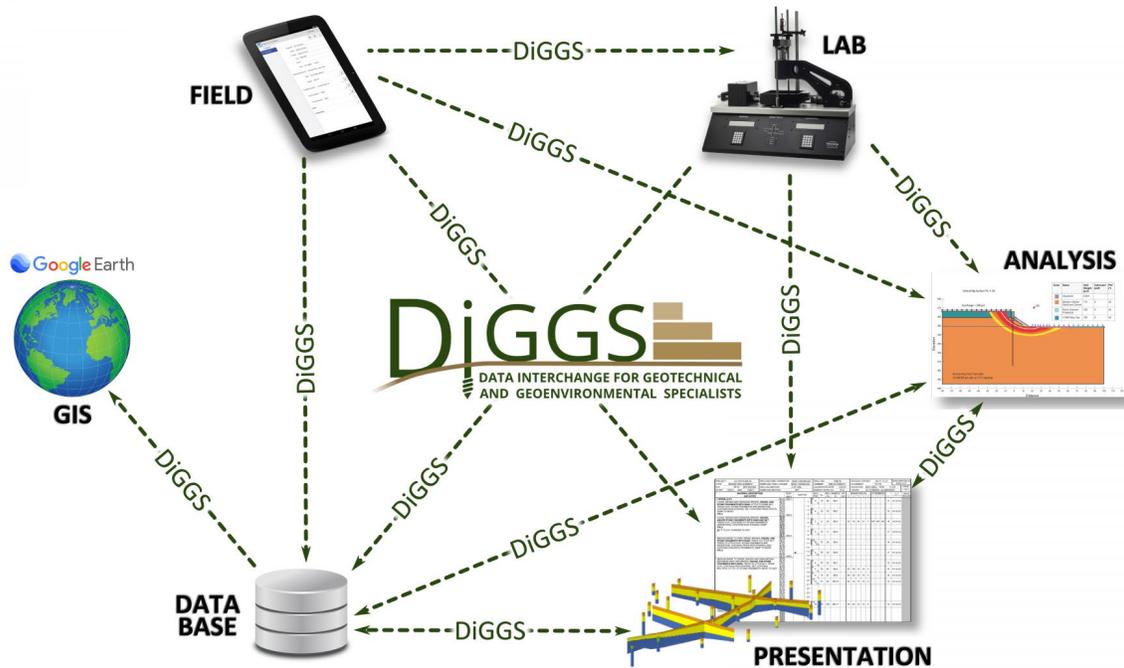
Figure 3: The intention of DIGGS is to become industry-standard for geotechnical and geoenvironemntal data transfer. Shown in the figure is how DIGGS is designed to transfer data through all stages and mediums (ASCE 2020).

DOTs have issues with consistently storing, managing, and recovering geotechnical data(Cadden and Keelor, 2017), as stated above in the Problem Statement. This is especially problematic since geotechnical site investigations are expensive, and the data they produce is valuable. When this data is collected, it is recorded in varying formats and there are often gaps in recorded information. This becomes a challenge for DOTs particularly when data is shared within the DOT, with external consultants and researchers, and with other stakeholders. A standard data transfer format allows data providers to capably serve these stakeholders and the geotechnical community. Since generated data does not have to be manually manipulated using DIGGS protocol, there is less wasted time, in formatting and in searching for boring logs in file cabinets, and less chance for data to be corrupted and lost. Table 1 shows the geotechnical tests that are included in the current DIGGS schema. The data produced by these tests using DIGGS will be in an open and consistent

format (Cadden and Keelor, 2017). DIGGS has the power to become industry standard, and to serve not only state DOTs, but a wide range of public and private industry organizations and university researchers.

Table 1: Complete list of the tests are included in the current DIGGS schema (ASCE 2020).

Type of Soil Test Included in DIGGS Schema	Laboratory or *In-Situ*	Specific Tests Included
Atterberg Limits	Lab	Fall Cone and Casagrande test for liquid limits
Driven Penetration test	In Situ	SPT and other hammer-based penetration tests
Particle Size	Lab	Sieve and hydrometer tests
Chemical Tests	Lab	
Compaction	Lab	Proctor, Modified Proctor, Porter Static, California Test 216
Density	Lab	
Photoionization detector test	Lab	
Specific Gravity	Lab	
Shrinkage Limit	Lab	
Static Cone Penetration test	In Situ	e.g., CPT
Water Content	Lab	
Wireline logs	In Situ	Any kind of downhole sensors, including suspension velocity logs

2.4   Case Studies

2.4.1   Geotechnical Database for Utah (GeoDU)

Sharifi-Mood et al. (2020) provide a summary of the Geotechnical Database for Utah or GeoDU and its organization and advantages. GeoDU is a geotechnical database developed for the Wasatch Front of Utah. It demonstrates examples of the advantages of geotechnical databases by applying it to quantify typical geotechnical properties for common geologic units. The goals and applications of GeoDU are similar to that of GOSEP in that both are a resource for future projects and makes for easy data sharing and planning of geotechnical site investigations. A main goal of this database, however, is to compile geotechnical data and quantify soil properties for liquefaction

evaluation. Liquefaction of soil occurs when the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading and can result in significant damage to infrastructure. Commonly, coarser soils with lower fines contents, and soils with lower plasticity, lower relative density, and strength will be more susceptible to liquefaction. Using the GeoDU database, Sharifi-Mood et al. (2020) were able to compare the corrected blow counts from SPT tests, or $(N_1)_{60cs}$, for different geological units. From these observations they evaluated the liquefaction potential of the geological units present along the Wasatch Front and found that certain units exhibited higher liquefaction potential.

Sharif-Mood et al. (2020) also explored whether combining these geologic units into simpler geologic groups would be statistically supported and would yield accurate estimations for those groups. Since they had some geographic areas and geologic groups with only a few *in-situ* tests, the authors wanted to determine if they could use the data they had to represent areas where the data was sparse. By comparing boreholes in the three counties of this study, the authors concluded that (Sharifi-Mood et al. 2020): "insufficient geotechnical information in one unit can be compensated using data from other boreholes with statistically similar properties, age, and depositional environment."

Many of the findings, concepts and techniques the creators of the GeoDU database detail in their work can be exploited for the current project. They acquired subsurface data from the Utah Department of Transportation (UDOT) and local geotechnical engineering firms. The state transportation agency collects the largest amount and the most widespread geotechnical data, and the data can be requested by the public since it is not a private agency. Also, the raw borehole data

that was collected was summarized in two tables called SITE and BLOW, which are linked via a unique site identification number (SITEIDNO) for each SPT (Sharifi-Mood et. al, 2020).

2.4.2 New Zealand Geotechnical Database (NZGD)

The New Zealand Geotechnical Database (NZGD) is available online (NZGD 2020) and is a database that provides searchable geotechnical data for all of New Zealand. It builds on the Canterbury Geotechnical Database (CGD), which was developed to organize geotechnical data for the Christchurch rebuild following the 2010/2011 Canterbury earthquake sequence (NZGD 2020). The NZGD provides efficient access to geotechnical information, and much like the goals of this project for the state of Oregon, it can be used for more strategic purposes such as assisting with natural disaster recovery, increasing resilience around New Zealand, catastrophe loss modelling, and informing land planning and regulatory processes.

2.4.3 Tunis City, Tunisia

El May et al. (2010) reported a case study where comprehensive engineering geological mapping was employed in Tunis City, the capital of Tunisia. At the time this paper was published, and still today, the population of the city was growing rapidly. Geotechnical data mapping was implemented as a scientific basis for planners and engineers for rational land use planning and urban development. In this case, factors that influence urban development were considered. Lithology, topography, slope, earthquake risk, water table depth, flooding susceptibility and seismic-induced effects such as liquefaction susceptibility were used to populate information layers using GIS. These information layers were then combined to produce uniform engineering geological maps in the GIS framework. The engineering geological map is based on the use of many steps that consist of geological and geotechnical data collection. Empirical correlations,

historical data, and geotechnical testing and properties of materials were used to create the information layers. ArcView 3.2 GIS was used, and the method was to first initiate the construction of a workable project in GIS. Topographic maps of Tunis City were then converted to digital format and georeferenced. Then, all maps were processed to form a GIS database of spatial data linked to attribute information. For this study, the end results were reported as a construction suitability map (El May et al. 2010). The methods and risk assessments presented in this work provide insight into how ArcGIS can be used for geotechnical data and combining multiple data layers.

2.4.4   St. Louis Metro Area

Chung and Rogers (2010) published a paper on work creating a GIS-based geotechnical database for the St. Louis metro area. Since the study area of the database spans many different counties and two states, Missouri and Illinois, the developers had to solve problems of differing map units, map scales, and storage formats, with geotechnical data stored in analog or digital formats. This is the case in many areas of the United States and is true in Oregon where different geodetic datum or coordinate system and different file storage formats are used in different counties and different parts of the state creating challenges when cataloging data. The article details how the different formats were integrated into a single geotechnical database within ArcGIS that can be used to manipulate and retrieve subsurface data and to perform an array of spatial analyses. This database does a good job of standardizing geotechnical data and geologic interpretations across the study area. The authors used the data to extract useful information on the surficial geology, measured values of shear wave velocity, loess thickness, bedrock geology, and well locations across the area (Chung and Rogers, 2010).

3   MATERIALS AND METHODS

3.1   Data Compilation

The first step in creating a database is collection of data. This project aimed to create a database where data is spread over the entire state of Oregon. The data that was collected for the GOSEP database is detailed in Table 2. Data was compiled from existing and previous research projects at Oregon State. The data from OSU ranges from standard penetration tests and cone penetration tests to cyclic shear testing, Atterberg limits, triaxial testing, and other standard laboratory tests. Oregon State Facilities provided a complete set of borings and subsurface explorations performed on and around the Oregon State campus in Corvallis, Oregon. The O-HELP database already had some boring logs in the downtown Portland area in a GIS layer named BODO; the data from that layer was also incorporated into the GOSEP database. In order to create such a database with soil data from each county, it was decided that Oregon Department of Transportation (ODOT), may provide a highly-suitable source of data as their geological data is public and robust. Data from all five ODOT regions was strategically compiled, gathering as much data as possible from across the state. ODOT provided the project with data from a total of 5,603 explorations from projects across the state. The ODOT data that was sent to us ranges from the years 1992 to 2019 and includes SPTs, CPTs, test pits, and hand auger logs. ODOT provided many of the explorations in the form of gINT files. gINT (gINT, 2020) is a program used for subsurface reporting for, e.g., soils, borehole logs, and lab tests. gINT structures geotechnical data in customizable tables with various fields. ODOT also supplied some information as portable document format (PDF) files.

Table 2: Data sources for the GOSEP database.

Data Source	Data Type	Included in GOSEP
Oregon State University Geotechnical Research Group	SPT, CPT, cyclic shear testing, Atterberg limits, triaxial testing, and other standard laboratory tests	Yes
OSU Facilities	GIS layer of borehole locations, PDF images of borehole logs	Yes
ODOT	gINT boring logs, PDF images of borehole logs	Yes
BPA	PDF geotechnical reports	No
Port of Portland	PDF geotechnical reports	No
BODO 20181018	GIS layer featuring locations of boreholes in the downtown Portland Area, adapted from DOGAMI 3D borehole database (Roe and Madin, 2013)	Yes

The Bonneville Power Administration (BPA) provided their entire library of geotechnical reports for Oregon. Nearly 1,000 documents were provided in PDF format, some containing boring logs while others did not. Because of the nature of the documents and the formatting, this data was not included in the first iteration of this database. In the future, the boring logs, CPT results, test data, and other pertinent information will be extracted from these PDF reports and uploaded to the GOSEP database. The Port of Portland, independent of data provided by OSU researchers that was part of Port of Portland projects, offered data for the boring logs and soil reports at PDX Portland International Airport. This data dates from 1944 to the present and similar to the BPA data, exists mostly in PDFs in geotechnical reports and would need to be manually separated from the reports. There is more data available for other Port of Portland locations, but is in a similar format and would take time filter through geotechnical reports. It was decided to not include this data in GOSEP's first iteration, and an evaluation of this data's pertinence as to whether to include it in future iterations will be had at later date, with stakeholders and database creators.

3.2   Database Development

3.2.1   Database Structure

To be useful to engineers and geologists, soil properties must be referenced to a physical location. In order to reference the location of each of the boring logs and *in-situ* tests that were collected, the data was imported to ArcGIS Pro. Most of the data that was collected was in the form of .gINT files. To convert the .gINT data to useable tables for import into the Esri application ArcGIS Pro, Bentley gINT Professional was used to open and read the gINT logs. Bentley gINT Professional is a software that allows users to report and manage subsurface data. .gINT files were opened in .gINT Professional then exported to Microsoft Excel files. While a boring log is open in .gINT professional, it can be exported by choosing: File>Import/Export>Export to Excel. This way, each project and borehole were saved as an Excel file to a common file path. This process was repeated for each project file until every boring log was in the form of an Excel file.

When the files are exported from the gINT application, the typical format in Excel is such that six sheets are created in each file. The first sheet, *Project*, lists the Name, Highway, Geologist, County, EA_Number and units. The second sheet, *Point*, gives point information such as the PointID, the geographical coordinates, the dates corresponding to the initiation and termination of an exploration, the ground elevation, the equipment used and the purpose for the exploration. The third sheet, *Lithology*, shows the recorded soil type with depth. The fourth sheet, *Remarks*, shows the comments the driller made at specified depths. The fifth sheet, *Sample*, has any recorded and *in-situ* tests at specified soil depths such as penetration resistance, N value, moisture content, plasticity, USCS classification and more. It should be noted that gINT erroneously lists penetration resistance as "driving resistance", and necessary corrections in terminology must be made when

downloading and using data exported from gINT logs. The last sheet, *Well*, holds the depth of water data. Few project files included more sheets for separate water level information or a separate sheet for laboratory tests. There was little uniformity in data across borehole logs, project sites, and data sources. Figure 4 shows an example of a typical Excel file containing borehole data.

	A	B	C	D	E	F
1	PointID	Depth	Bottom	Graphic	Description	Formation
2	'Hole #					
3	HA05329-01	0	1.8	CML	SILT to Silty CLAY with	Fine Grained Fill
4	HA05329-01	1.8	7	MH	SILT to ELASTIC SILT; I	Overbank Silt
5	HA05329-02	0	2.7	CML	SILT to Silty CLAY with	Fine Grained Fill
6	HA05329-02	2.7	9.6	MH	SILT to ELASTIC SILT; I	Overbank Silt
7	TB05329-01	0	2	ASPHALT	Asphalt Concrete and	Pavement
8	TB05329-01	2	5	GP-GM	Silty Sandy GRAVEL; G	Coarse Grained Fill
9	TB05329-01	5	10	CML	SILT to Silty CLAY with	Fine Grained Fill
10	TB05329-01	10	15	MH	SILT to ELASTIC SILT; I	Overbank Silt
11	TB05329-01	15	22.5	SM	SILT with some Sand t	Alluvium
12	TB05329-01	22.5	31.5	CH	FAT CLAY with trace s	Decomposed Rock
13	TB05329-02	0	2	ASPHALT	Asphalt Concrete and	Pavement
14	TB05329-02	2	3.3	GP-GM	Silty Sandy GRAVEL; G	Coarse Grained Fill
15	TB05329-02	3.3	10	CML	SILT to Silty CLAY with	Fine Grained Fill
16	TB05329-02	10	20.2	SM	SILT with some Sand t	Alluvium
17	TB05329-02	20.2	26.5	CH	FAT CLAY with trace s	Decomposed Rock
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						

PROJECT | POINT | **LITHOLOGY** | SAMPLE | WATER_LEVELS | WELL | (+)

Figure 4: Example Excel file containing borehole information. Note the sheets, *Project*, *Point*, *Lithology* (shown), *Sample*, *Water_Levels*, and *Well*.

Since the location data for all of the data points from ODOT are exported to the *Point* sheet in each of the Excel files, a master point table was created. The master point table includes a row for each

borehole with all the data from each individual *Point* sheet, on one Excel table. The structure of the master point table that was imported to ArcPro is shown in Figure 5 with a few of the points and their geographical information shown on the table.

Each point has a unique PointID which corresponds to all of the data related to that point. When files were exported from gINT to Excel, the only Excel sheet that did not have PointID was the Project sheet. Therefore, the PointIDs for each test location were manually copied onto the Project sheet so that the data contained in the Project sheet would correspond to the correct boring when uploaded to the GIS database. A problem that occurred when creating the master point table was that many projects similarly labeled their boring logs. For example, many projects simply gave boreholes a PointID of simply "BH-01, BH-02" and so on. Since each borehole needs a unique PointID so that all of the data attached to that borehole can be properly traced to the correct location, many of the boreholes had to be manually renamed. The convention that was followed for renaming the boreholes was typically adding the unique EA Number to the existing PointID. For future borehole logging a common naming convention should be used that includes the unique project number.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	PointID	North	East	Equipment	Start_Date	End_Date	Purpose	Driller	Recorder	HoleDepth	Key_No	Start_Card	Bridge_No	Elevation	Tube_Heig	Plunge
2	TB-501	197759.4	2338556	Mobile B-50 75-899	5/12/1992	5/12/1992	Bridge Foundation	Terry Lauinger	Paul Tiller	18.71	03346			46		
3	TB-505	197952.6	2338655.3	Mobile B-50 75-899	4/7/1992	4/9/1992	Bridge Foundation	Terry Lauinger	Mahasti Hastings	12.22	03346			57.5		
4	TB-505A	197952.7	2338656	Mobile B-50 75-899	4/9/1992	4/9/1992	Bridge Foundation	Terry Lauinger	Mahasti Hastings	3.65	03346			57.5		
5	TB-506	197982	2338643	Mobile B-50 75-899	4/20/1992	4/21/1992	Bridge Foundation	Terry Lauinger	Paul Tiller	9.81	03346			58.25		
6	TB-506A	197982.8	2338631.4	Mobile B-50 75-899	4/21/1992	4/21/1992	Bridge Foundation	Terry Lauinger	Paul Tiller	4.72	03346			54.2		
7	TB-507	197953.5	2338722	Mobile B-50 75-899	5/9/1992	5/9/1992	Bridge Foundation	Terry Lauinger	Paul Tiller	3.5	03346			60.5		
8	TB-508	197995.4	2338555	Mobile B-53, 83-894	4/27/1992	4/27/1992	Bridge Foundation	John Lee	Rob Heyman	10.66	03346			51.8		
9	TB-508A	197995.4	2338556.3	Mobile B-53, 83-894	4/27/1992	4/27/1992	Bridge Foundation	John Lee	Rob Heyman	3.65	03346			51.8		
10	TB-509	198000.7	2338534.8	Mobile B-53, 83-894	4/22/1992	4/24/1992	Bridge Foundation	John Lee	Rob Heyman	13.71	03346			55.6		
11	TB-509A	198000.4	2338535.3	Mobile B-53, 83-894	4/24/1992	4/24/1992	Bridge Foundation	John Lee	Rob Heyman	5.18	03346			55.6		
12	TB-510	197972.1	2338521.4	Mobile B-50 75-899	4/21/1992	4/22/1992	Bridge Foundation	Terry Lauinger	Paul Tiller	12.8	03346			54.8		
13	TB-510A	197972.2	2338522	Mobile B-50 75-899	4/22/1992	4/22/1992	Bridge Foundation	Terry Lauinger	Paul Tiller	5.27	03346			54.8		
14	TB-511	197964.9	2338550.2	Mobile B-53, 83-894	4/18/1992	4/18/1997	Bridge Foundation	John Lee	Rob Heyman	10.66	03346			51.7		
15	TB-511A	197965	2338551	Mobile B-53, 83-894	4/18/1992	4/18/1992	Bridge Foundation	John Lee	Rob Heyman	3.65	03346			51.7		
16	TB-514	198326.6	2338510.7	Mobile B-50 75-899	5/1/1992	5/4/1992	B.P. Tunnel	Terry Lauinger	Paul Tiller	7.92	03346			62.8		
17	TB-515	198356	2338497	Mobile B-50 75-899	4/30/1992	4/30/1992	B.P. Tunnel	Terry Lauinger	Paul Tiller	4.87	03346			64		
18	TB-516	198280.3	2338504	Mobile B-50 75-899	5/7/1992	5/8/1992	Wall Foundation	Terry Lauinger	Paul Tiller	6.24	03346			61.8		
19	TB-516A	19827805	2338504.7	Mobile B-50 75-899	5/8/1992	5/8/1992	Wall Foundation	Terry Lauinger	Paul Tiller	4.96	03346			61.8		
20	TB-517	198335.2	2338476.7	Mobile B-50 75-899	5/4/1992	5/6/1992	Wall Foundation	Terry Lauinger	Paul Tiller	12.95	03346			63.7		

Figure 5: Structure of the master point table with all the location data for the points as well as some basic information.

The data was then uploaded to ArcGIS Pro. A folder connection was created in ArcPro so that the exported data and the other data collected could be accessed from within the application. A master point table was created for each of ODOT's five regions as the data that was collected from ODOT was provided in this format. Each Region Geologist gave us separate data sets with boring logs from their corresponding regions. Each point table was uploaded to ArcPro using the catalog pane, clicking and dragging the tables from their parent folders onto the working map. The tables are then stored as standalone tables in the contents pane. To display the data points on the map, each table was selected by right clicking on the table name, then choosing the "Display XY Coordinates" function. Selecting the "Display XY Coordinates" function opens the Geoprocessing pane opens with the tool "XY Table to Point". The Input Table was in this case the point table, the Output Feature Class was the feature class that would be created. A feature class is lines, points or polygon features on a map. The X and Y fields must be selected. These are either Longitude and Latitude respectively, or East and North, depending what the data table used. The majority of the Oregon data that was collected gave Easting and Northing coordinates.

3.2.2   Reconciling Coordinate Systems

Since none of the data specified which Coordinate System was used, it made the most sense to use an Oregon statewide coordinate system. The NAD 1983 2011 Oregon Statewide Lambert Ft Intl coordinate system is commonly used throughout the state and is what the current boreholes in the OHELP database were projected with. However, after running the tool, it was clear that many different coordinate systems were used to record the locations of boreholes and *in-situ* tests throughout the state. Figure 6 shows a distribution of points when all projected to the Statewide Lambert coordinate system.
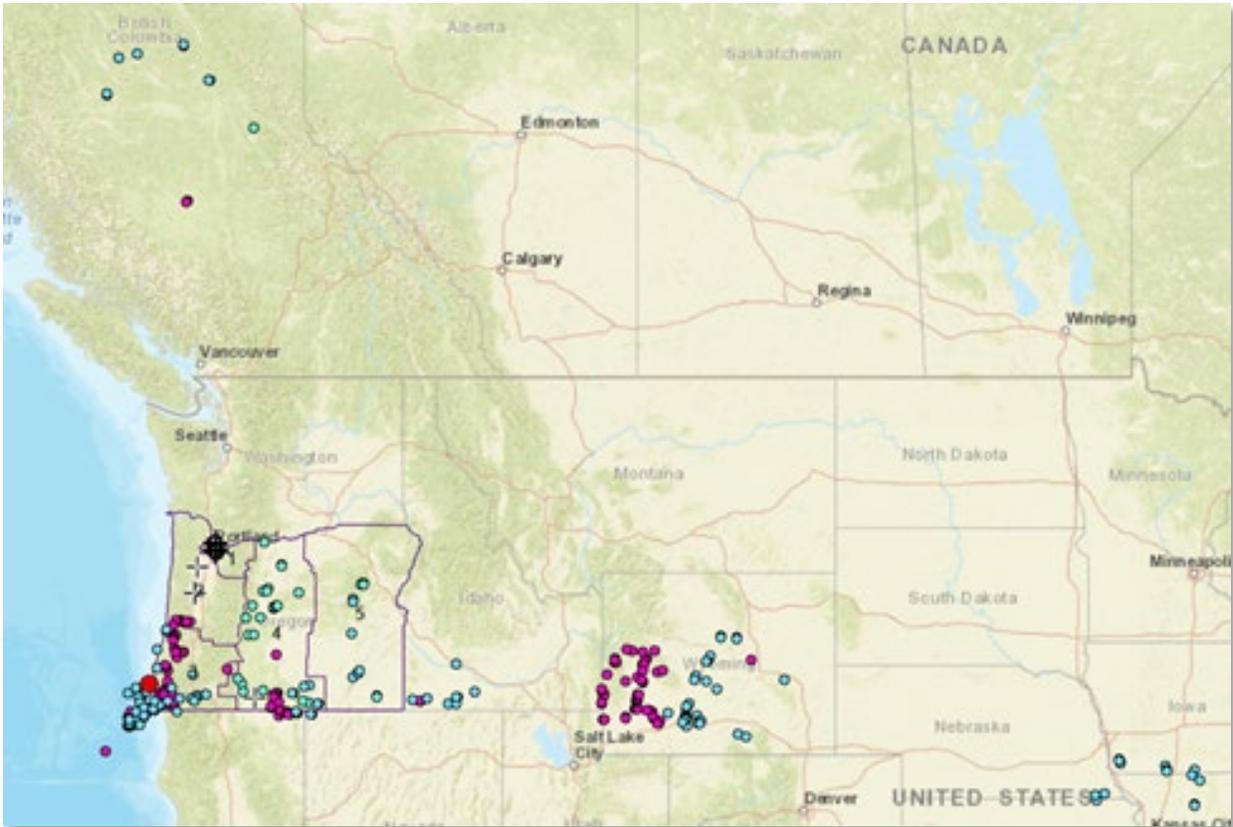
Figure 6: Borehole points obtained from ODOT and DOGAMI plotted with the Oregon Statewide Lambert coordinate system before any manipulation of the points to find what coordinate system was used when logging their geographical information.

Points are scattered as far as the Pacific Ocean, Wyoming, and Missouri, among others. The points that were in Oregon did not necessarily fit to their known general location or to roads and highways. The *Define Projection* tool was used to change the projection of the feature class. After running the tool, all the data points that fit that projected coordinate system were selected. Then left clicking on the feature class in the contents pane and selecting Data, Export Features, a new feature class was created with just those points which fit the projection. The selected points were then deleted from the origin feature class. The process was repeated changing the coordinate system and creating feature classes until a projection was found that put all or most points into

their correct locations. All coordinate systems for the state of Oregon were tested. Figure 7 shows feature classes created using five different coordinate systems for the Portland area, as well as the final feature class where all the different feature classes were merged into one. Twenty-eight coordinate systems were used to georeference all of the data that was collected. Table 3 shows all the coordinate systems used.
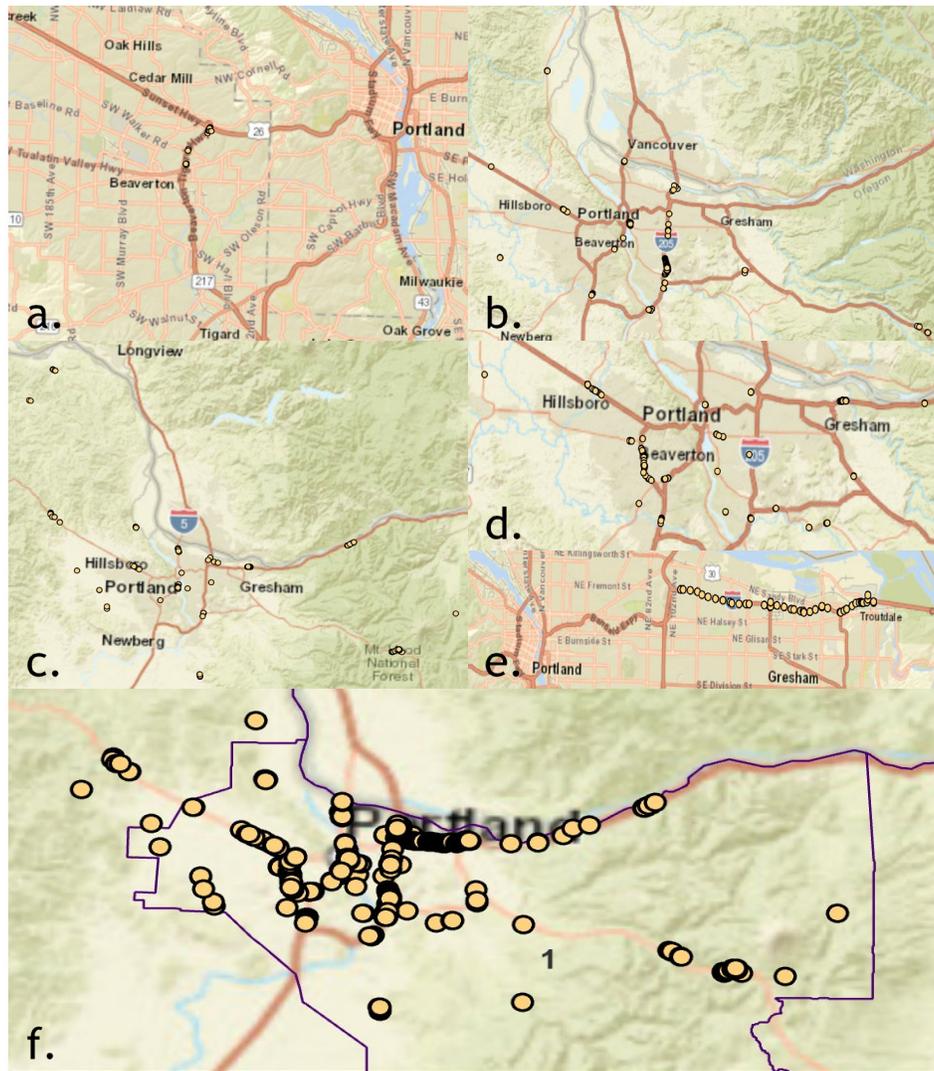
Figure 7: a.) NAD 1927 StatePlane Oregon North FIPS 3601; b.) NAD 1983 2011 StatePlane Oregon North FIPS 3601; c.) NAD 1983 StatePlane Oregon North FIPS 3601 Feet Intl; d.) OCRS Portland NAD 1983 2011 LCC Feet Intl; e.)NAD 1983 UTM Zone 10N; f.)ODOT Region 1 points reprojected into a common coordinate system

Table 3: Complete list of the coordinate systems used when plotting . Many explorations were recorded using local datums as can be observed.

GCS WGS 1984	OCRS Columbia River East NAD 1983 2011 LCC Feet Intl
NAD 1927 StatePlane Oregon North FIPS 3601	OCRS Columbia River West NAD 1983 2011 OM Feet Intl
NAD 1927 StatePlane Oregon South FIPS 3602	OCRS Eugene NAD 1983 2011 TM Feet Intl
NAD 1983 (2011) Oregon Statewide Lambert Ft Intl	OCRS Grants Pass-Ashland NAD 1983 2011 TM Feet Intl
NAD 1983 2011 StatePlane Oregon North FIPS 3601	OCRS Gresham-Warm Springs NAD 1983 2011 TM Feet Intl
NAD 1983 2011 StatePlane Oregon South FIPS 3602	OCRS La Grande NAD 1983 2011 TM Feet Intl
NAD 1983 2011 StatePlane Oregon South FIPS 3602 Ft Intl	OCRS Oregon Coast NAD 1983 2011 OM Feet Intl
NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl	OCRS Pendleton NAD 1983 2011 TM Feet Intl
NAD 1983 StatePlane Oregon North FIPS 3601 Feet Intl	OCRS Pendleton-La Grande NAD 1983 2011 TM Feet Intl
NAD 1983 UTM Zone 10N	OCRS Portland NAD 1983 2011 LCC Feet Intl
OCRS Baker NAD 1983 2011 TM Feet Intl	OCRS Salem NAD 1983 2011 TM Feet Intl
OCRS Bend-Klamath Falls NAD 1983 2011 TM Feet Intl	OCRS Salem NAD 1983 2011 TM Meters
OCRS Bend-Redmond-Prineville NAD 1983 2011 LCC Feet Intl	OCRS Siskiyou Pass NAD 1983 2011 LCC Ft Intl
OCRS Bend-Redmond-Prineville NAD 1983 2011 LCC Meters	OCRS Wallowa NAD 1983 2011 TM Ft Intl

After each coordinate system for the state of Oregon and the northwest was exhausted and feature classes were created for each system with matching data points, the data was re-projected into a common coordinate system. Using the *Merge* tool, each feature class that was created with the different coordinate systems was entered as an input dataset. The output dataset is the merged feature class. In the Environments tab, it is important to designate the Output Coordinate System so that the output dataset has a common and intentional coordinate system. Many coordinate

systems are used in the state and it is important for future data display, analysis, publishing and transfer that a common projection is agreed upon for researchers in universities and engineers within state agencies. The Oregon Geographic Information Council endorsed the use of Oregon Lambert as a standard for state agencies, but it has not been largely implemented. The Statewide Lambert Projection works across the state as a seamless projection meaning that data from all areas of the state will fit together. It was decided that this projection would be used for the GOSEP database and thus it was entered as the Output Coordinate System in the *Merge* tool geoprocessing pane. Figure 8 shows the basic map information and parameters for the Oregon Statewide Lambert Projection.
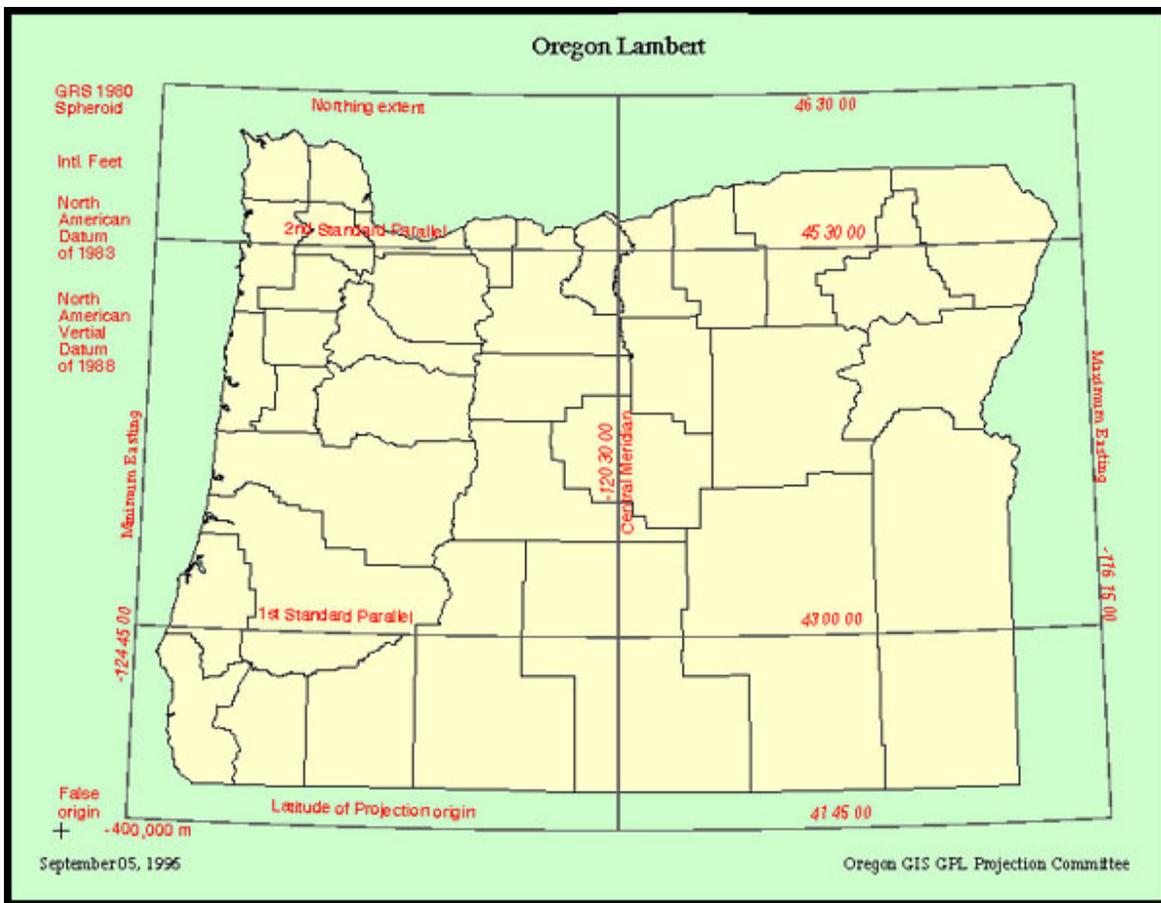
Figure 8: Oregon Statewide Lambert parameters
(https://www.oregon.gov/geo/pages/projections.aspx).

After running the *Merge* tool, all of the feature classes for each ODOT Region become one single feature class projected with the same coordinate system. There become four feature classes containing all of the data collected from Oregon Department of Transportation Region 1, Region 2, Region 3, and Region 4 and 5. The four re-projected layers at this stage in the database creation are shown in Figure 9. Note some older projects are located slightly outside of their delineated region since the data is organized by source. The *Merge* tool was used once more to create a single data layer and also to merge data from Oregon State researchers and other sources. The four layers were kept separate at this stage of database construction as the information related to each data was organized by data source.
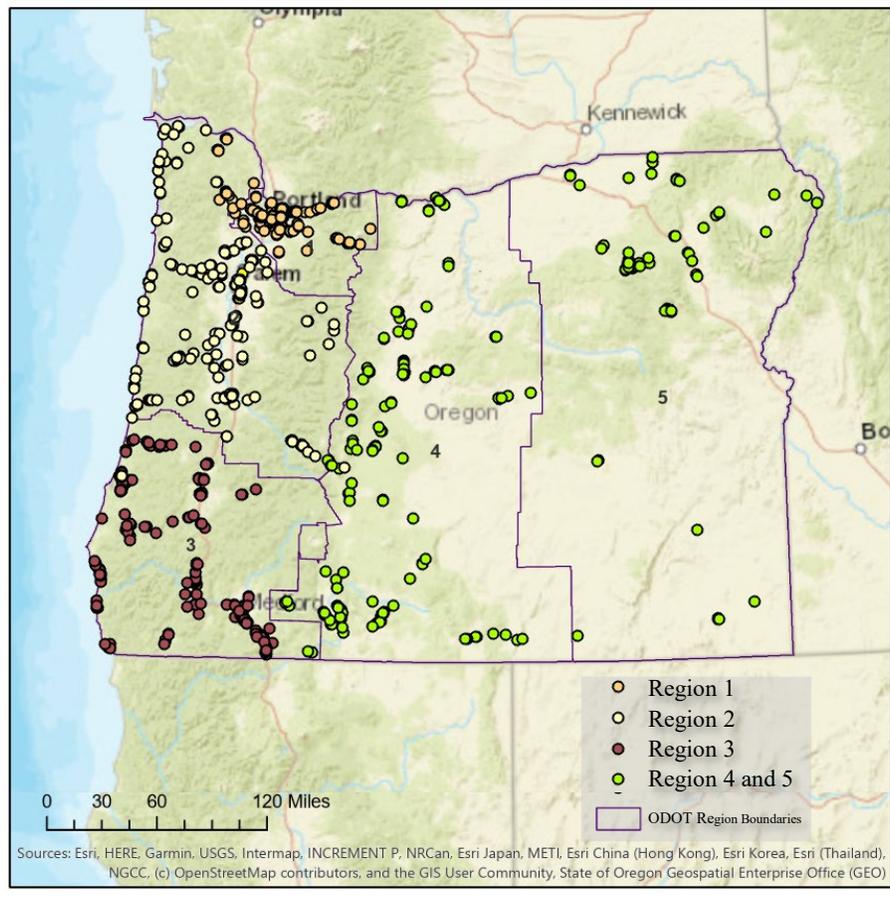
Figure 9: Data collected from ODOT, organized by ODOT Region, reprojected to a common coordinate system.

Note that the vertical elevations that were recorded in the borehole logs and explorations collected are also inconsistent and it was typical that no unit of measurement or datum was recorded along with each elevation measurement. To make sure borehole and exploration points were shown on the ground surface, the properties of the layer must be modified. In the *Elevation* tab, selecting the feature "On the ground" will align the layer with Esri's ground terrain. The true elevation can be estimated by extracting elevations from a digital elevation model. In the future, a separate column should be made so that the recorded elevation can be shown along with the estimated elevation.

3.2.3   Database Organization

Once the point data is georeferenced correctly, the engineering properties and data pertaining to the soil samples must be attached to each corresponding point. Through a common field, known as a key, data in one table can be associated with data in another table. For example, one could associate a table of parcel ownership information with the parcels layer, because they share a parcel identification field. For the GOSEP database, the soil engineering properties and characteristics are associated to the borehole point layer through a common PointID. One can make these associations in several ways, including by joining or relating tables temporarily in a map or by creating relationship classes in a geodatabase that maintain more permanent associations. Joins can also be based on spatial location. Since many associations would have to be made, and since these associations should be permanent and stored in the GOSEP database, the most straightforward approach was to create relationship classes between the borehole point layer and the tables that hold the borehole information.

To create a relationship class, the back-end information for the boreholes is first imported into the GOSEP database. A new map was inserted so the working contents pane would not become too

congested. Using the folder connection in the catalog pane, starting with ODOT Region 1, each project's sample sheet was added to the map. The sample sheet contains the information about the soil with depth as well as the penetration resistance and other tests performed on the soil. Therefore the sample tables for each project were the first and most important tables to attach to the subsurface exploration points since many engineering properties can be estimated via the SPT N value. For example, the relative density, which strongly influences the resistance of the soils to liquefaction and lateral spread, is commonly estimated from the SPT N values (Sharifi-Mood et al. 2020).

Instead of creating a relationship class between the point layer and each individual sample table, the *Merge* tool was deployed. The input datasets are the borehole sample tables, the output dataset is the merged master sample table saved into the GOSEP database. The output fields are the headers of each column in the sample table. When the datasets are imported to the map, ArcPro will read the type of data that each column contains. One can change the data type as well in the output field properties. The available types include a variety of number types, text types, date types, binary large objects (BLOBs), or globally unique identifiers (GUIDs). ArcPro will attempt to select the correct data type based on the contents of the tables, but this must be manually confirmed for correctly storing data and facilitating analysis and data management. If data stored in a field does not match the data type, the merge will fail. So before importing datasets, it is important to check the data fields and make sure, for example, there is no text in a number field.

After the merge is completed, a relationship class must be created between the sample data and the borehole feature class. The structure of how layers were merged and what relationship classes were created is detailed in the schematic in Figure 10. In the geoprocessing pane, in toolbox, data

management tools, find *Create Relationship Class*. Entering the parameters, the Origin Table is the feature class that will be associated with the destination table. In this case the borehole point location layer is the origin table. The origin table is associated with the destination table, creating a relationship. The destination table is the master sample table with the sample data. Layers and tables are labeled purposefully in order to keep the data and paths organized. The sample table was labeled "Region#_SampleTable". The Output Relationship Class was labeled "Region#_SampleData". The relationship type is composite, meaning that there is a relationship between dependent objects where the lifetime of one object controls the lifetime of the related object (parent to child). So if the point layer is deleted, the relationship class will be as well. It is important when selecting the cardinality to choose a one to many relationship. Since multiple lines of data are attached to a single point, choosing the one to many cardinality allows each row in the origin table to be related to several rows or features in the destination table. The key, as previously stated, is the PointID. This makes sure that the correct data is attached to each boring. After running the *Create Relationship Class* tool, the properties of the soil with depth are added to each point. The same process was repeated for all five ODOT regions and for all other data collected. Relationship classes were also created for the other sheets exported to Excel from the gINT logs so that all the data from the logs was attached to each point.

3.2.4   Database in Practice

The data for each point can be viewed by selecting that point. In ArcGIS Pro, a pop up appears and the user can click through the soil layers and their engineering properties via the related tables. Figure 11 shows a typical pop up box when a point is selected. Along with the ability to view the soil properties and test results, the user is able to download an Excel or text file with pertinent

engineering properties and boring log information. In some cases, the data for a point also includes

a PDF borehole log. The ability to download the data is useful for analysis, developing charts, and

quality control.

Attributed relationship class
Region1_SampleData_Relationship

Type	*Composite*
Cardinality	*One to many*
Notification	*None*

Forward label	*Region1_SampleTable*
Backward label	*SampleTable_Region1*

Origin table		Destination table	
Name	*Region1_Points*	Name	*Region1_SampleTable*
Primary key	*PointID*	Primary key	*PointID*
Foreign key	*PointID*	Foreign key	*PointID*

No relationship rules defined.

Left layer list (box 1):
- R1_columbiariverE
- R1_gresham
- R1_portland
- R1_stateplane27N
- R1_stateplaneN
- R1_stateplaneNmeters
- R1_utm

Left layer list (box 2):
- R2_columbiariverwest
- R2_Eugene
- R2_oregoncoast
- R2_portland
- R2_salem
- R2_salem2
- R2_stateplane27
- R2_stateplaneN
- R2_stateplaneNmeters
- R2_stateplaneS
- R2_stateplaneSmeters

Left layer list (box 3):
- R3_grantspass
- R3_oregoncoast
- R3_siskiyou
- R3_siskyoupass
- R3_stateplaneS
- R3_stateplaneSmeters

Left layer list (box 4):
- R45_baker
- R45_bendklamathfalls
- R45_bendredmond
- R45_bendredmond2
- R45_bendredmond3
- R45_columbiariverE
- R45_corrected
- R45_lagrande
- R45_lagrande2
- R45_pendletonlagrande
- R45_stateplane27N
- R45_stateplane27S
- R45_stateplaneN
- R45_stateplaneNmeters
- R45_stateplaneS
- R45_stateplaneSmeters
- R45_utm
- R45_wallowalla
- R45ll

Simple Feature Class		Geometry	*Point*
Region 1 Points		Contains Z values	*Yes*

Field Name	Data Type	Allow Nulls	Optional
OBJECTID	OBJECTID	FALSE	Required
PointID	Text	TRUE	Required
North	Double	TRUE	Required
East	Double	TRUE	Required
Equipment	Text	TRUE	Optional
Start_Date	Text	TRUE	Optional
End_Date	Text	TRUE	Optional
Purpose	Text	TRUE	Optional
Driller	Text	TRUE	Optional
Recorder	Text	TRUE	Optional
HoleDepth	Double	TRUE	Optional
Key_No	Double	TRUE	Optional
Start_Card_No	Text	TRUE	Optional
Bridge_No	Text	TRUE	Optional
Elevation	Double	TRUE	Optional
Depth_Log_Page	Double	TRUE	Optional
Tube_Height	Text	TRUE	Optional
Plunge	Text	TRUE	Optional

Table			*Standalone table*
Region 1 Sample Table			

Field Name	Data Type	Allow Nulls	Optional
OBJECTID	OBJECTID	FALSE	Required
PointID	Text	TRUE	Required
Depth	Double	TRUE	Optional
Bottom	Double	TRUE	Optional
Type	Text	TRUE	Optional
Recovery	Text	TRUE	Optional
Driving_Resist	Text	TRUE	Optional
N_Value	Text	TRUE	Optional
Discontinuities	Text	TRUE	Optional
RQD	Text	TRUE	Optional
Moisture	Text	TRUE	Optional
Description	Text	TRUE	Optional
Percent_Moist	Text	TRUE	Optional
Soil_Name	Text	TRUE	Optional
USCS	Text	TRUE	Optional
Soil_Color	Text	TRUE	Optional
Plasticity	Text	TRUE	Optional
Consistency	Text	TRUE	Optional
Soil_Texture	Text	TRUE	Optional
Soil_Structure	Text	TRUE	Optional
Soil_Other	Text	TRUE	Optional
Soil_Origin	Text	TRUE	Optional
Rock_Name	Text	TRUE	Optional
Rock_Color	Text	TRUE	Optional
Weathering	Text	TRUE	Optional
Hardness	Text	TRUE	Optional
Rock_Structure	Text	TRUE	Optional
Formation	Text	TRUE	Optional
Blow	Text	TRUE	Optional
Graphic	Text	TRUE	Optional
Name	Text	TRUE	Optional
Highway	Text	TRUE	Optional
Geologist	Text	TRUE	Optional
County	Text	TRUE	Optional

Simple Feature Class		Geometry	*Point*
Region 2 Points		Contains Z values	*Yes*

Simple Feature Class		Geometry	*Point*
Region 3 Points		Contains Z values	*Yes*

Simple Feature Class		Geometry	*Point*
Region 4&5 Points		Contains Z values	*Yes*

Simple Feature Class		Geometry	*Point*
BODO		Contains Z values	*No*

Simple Feature Class		Geometry	*Point*
Geotech2		Contains Z values	*No*

Simple Feature Class		Geometry	*Point*
Buck Creek Research		Contains Z values	*Yes*

Table	*Standalone table*
Region 2 Sample Table	

Table	*Standalone Table*
Region 3 Sample Table	

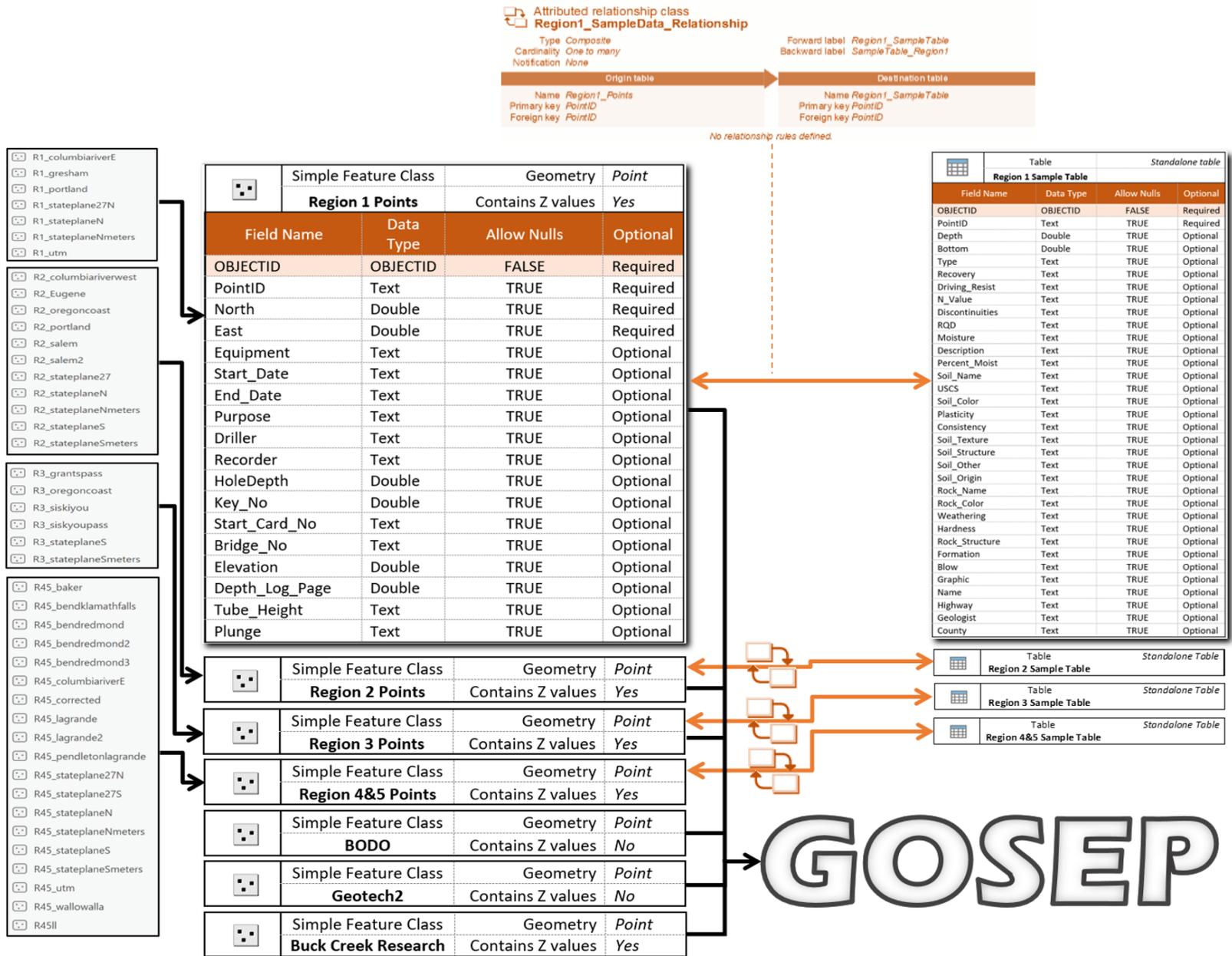| Table	*Standalone Table*
Region 4&5 Sample Table	

GOSEP

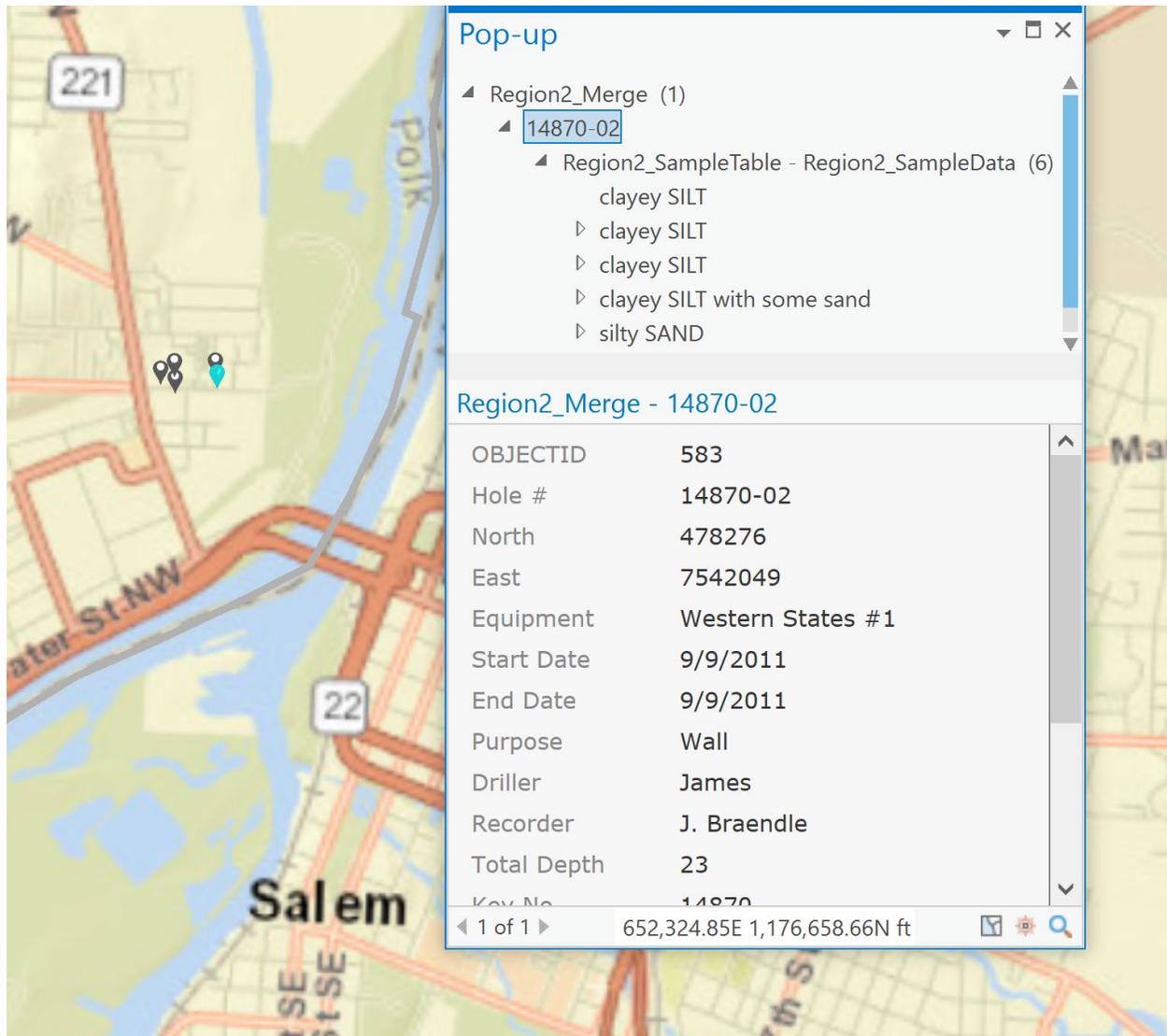Figure 10: Layers and relationship classes built into the GOSEP database.

Figure 11: Typical pop up box when a point is selected in ArcPro

Features cannot store file attachments in ArcGIS Pro by default. To enable file attachments, the *Enable Attachments* tool in the Geoprocessing Pane is employed for each feature class to which files are attached. Once attachments are enabled, in the Attributes pane, click the Attachments tab to add, update, open, or remove file attachments. Selecting the feature that corresponds to the PDF or Excel file that is being attached will open the tab since each feature class is now enabled to store attachments. File attachments are files stored in a geodatabase feature class attachment table and linked to individual features. Attachments, similar to creating relationship classes, allow

nongeographic data to be associated with geographic information. Figure 12 shows file links in a feature pop up after they have been attached to the borehole point. Attaching tables and PDF images to each individual point was done manually, and was facilitated by well-organized data. By first selecting the attachment, then finding the corresponding borehole ID in the attribute table for the working feature class, the attribute tab will show the attributes for the point selected and the attachment will be linked through the attachment tab.

After all files have been successfully attached to the borehole point feature classes, all of the feature classes must be merged to one layer. The *Merge* tool can merge the features with the attachments in the hosted feature layers into one hosted feature layer. Making sure the environment setting for "Maintain Attachments" is enabled ensures that attachments are copied from input features to output features. The input datasets are all the feature classes with borehole data and the output dataset will be the final merged layer with all the borehole data that has been collected. The database points shown on the map of Oregon in ArcGIS Pro are shown in Figure 13.
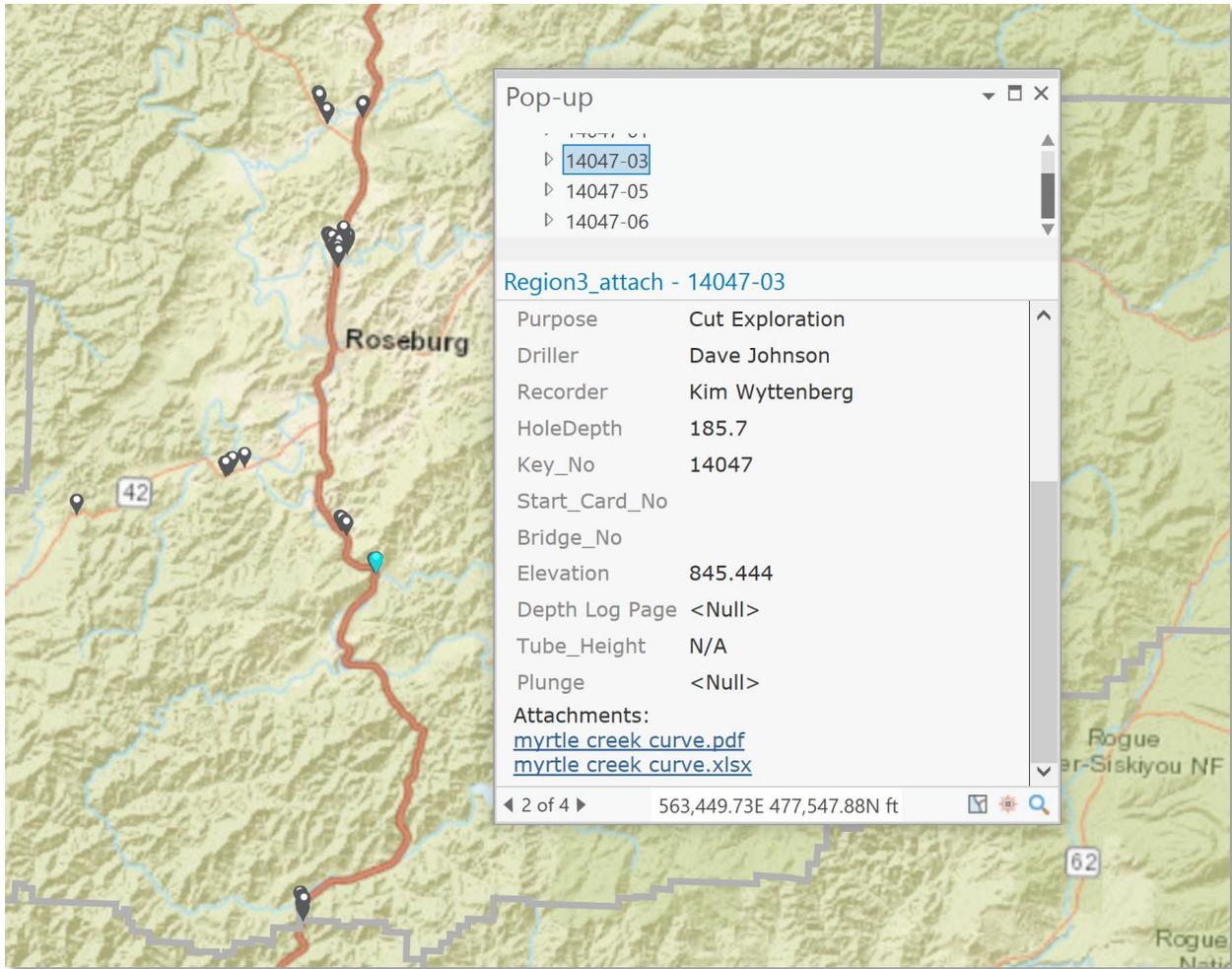
Figure 12: The raw data files and pdf borehole logs are attached to the geographical points. File links in a feature are shown in the pop up for the feature class and can be downloaded when selected.
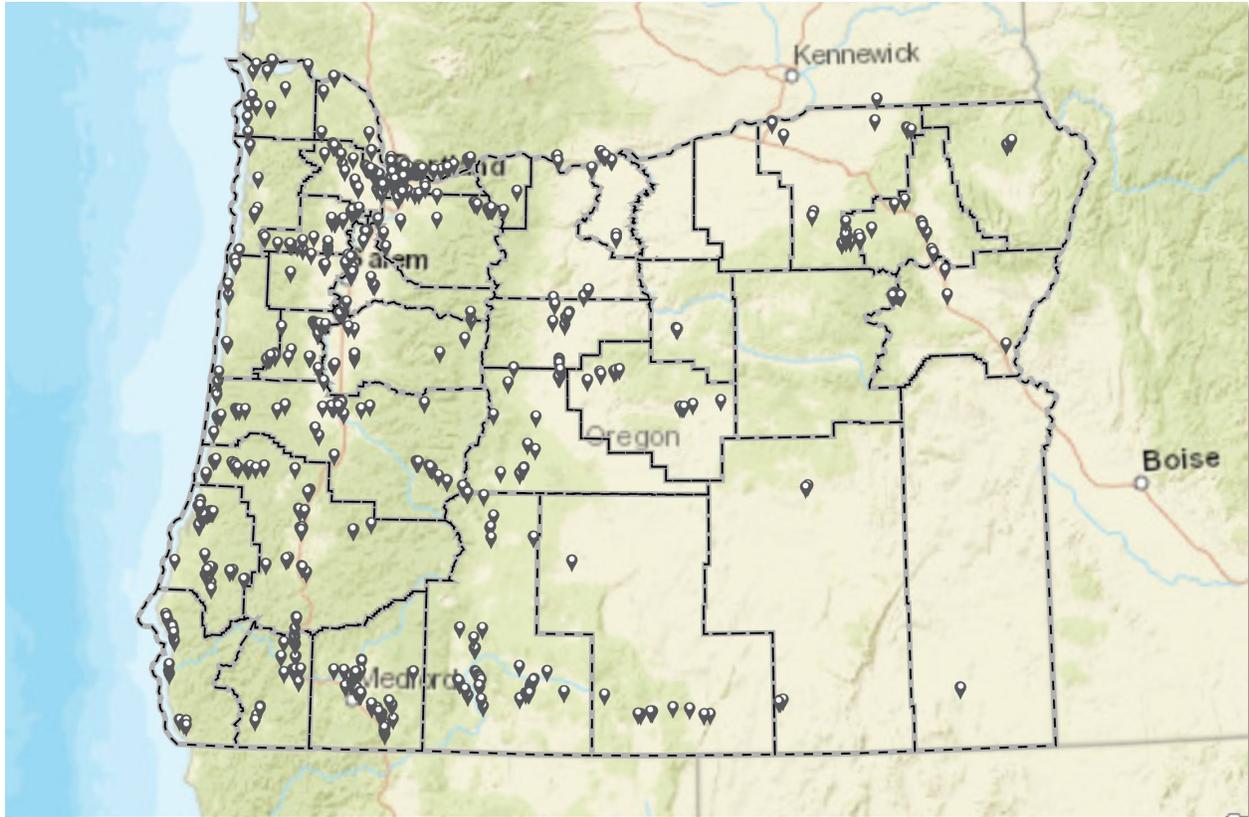
Figure 13: GOSEP Database shown in ArcPro.

3.3   Development of Publishing Tool

Once the database was developed, the goal was to make it open source and accessible to the public. The original scope and plan for this project was integration with OHELP. The GOSEP database would be created to eventually become a layer on the OHELP website. However, as the GOSEP database grew more robust, it was decided that GOSEP would be housed in a stand-alone website. Since GOSEP is its own website, the purpose and how to navigate the database is clearer. Still connected to OHELP so that stakeholders can easily access GOSEP through OHELP, GOSEP has the domain "ohelp.oregonstate.edu\GOSEP\". There is also a link to the GOSEP website on the OHELP interface. The website is housed on the Oregon State University server.

The completed database with all data from ODOT, Oregon State researchers, Oregon State Facilities, BODO, and other sources was published on Arcweld. a GIS Server hosting a variety of hazard map layers for the Cascadia Lifelines Program, housed in the School of Civil and Construction Engineering at Oregon State University. Publishing the database to Arcweld ensures the data layers can be available within an open source website, that the data layers can be opened in Esri ArcGIS or other applications, and that there will be continuity of the database and feature layers as more people become involved in the GOSEP project in the future.

Code was developed using ArcGIS API for JavaScript 4.15 to create the GOSEP WebViewer. The website aims to be clear and to visually represent the data in a way that is easy for the user to navigate and interact with. Styles and functions from the code used to publish the OHELP website were used for continuity. Other sample codes from the ArcGIS For Developers archive were used to create the website interface. Sample code tutorials were employed to create a map scene within the website, to add data layers to the map, to create a local scene and represent boreholes three dimensionally, and to add widgets for simple navigation like a search bar, a basemap toggle, and home button. Code was also written to configure the pop ups for each data point and to make sure all data was displayed upon clicking on the points of interest. The code that was developed is in .html format and can be referenced in Appendix A. The starting screen of the GOSEP website is shown in Figure 14. Each data point is represented by a black "X". The boreholes in the GOSEP database are rendered on the surface as well as below the surface of the scene. Figure 15 shows the visualization of boreholes beneath the surface.

There is a link to the user manual embedded in the website that aids the user in navigating the database and using the different tools within the website. The user manual is enclosed in this report

in Appendix B. The user manual also details how to access and use the data in ArcGIS desktop applications and elsewhere.
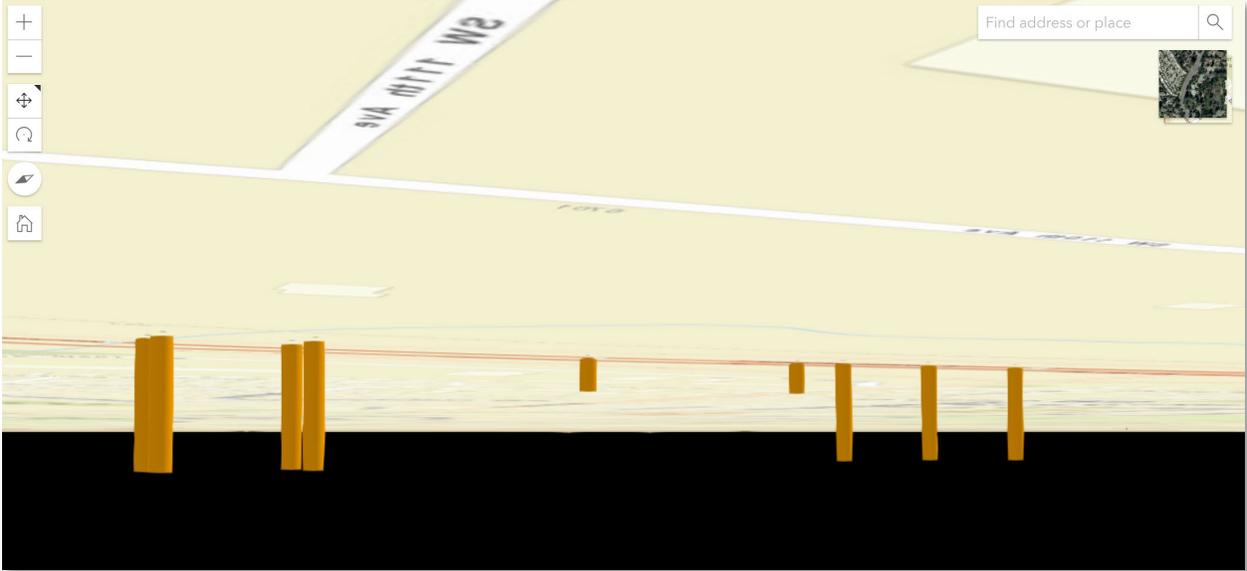

Figure 14: The starting screen of GOSEP.

Figure 15: Boreholes along a portion of the Tigard-Beaverton Highway represented beneath the surface.

3.4   Quality Control Methods

GOSEP should not be the sole geotechnical data source for an engineering project and should be accompanied by a geotechnical site investigation. Nonetheless, the data herein has been subject to quality control methods and efforts have been made to ensure that the boring logs and information is as accurate as possible. The first step was to exclude data which did not have any recorded geographic location, that referenced landmarks or mile markers instead of referencing a coordinate system, and data with inaccurate coordinates or that could not be matched to any of the coordinate systems in the Reconciling Coordinate Systems section of this report. Attachments of the original borehole data, in electronic table format as well PDF format in some cases, were added to each point as a quality control measure. If some of the data was not transferred properly or was recorded in the inappropriate section, the user will have the original boring logs as a reference to view and correct errors. Additionally, an Oregon State University email address was created for the GOSEP database, gosep.help@oregonstate.edu, where users can email database creators and managers detailing problems and inaccuracies that they come across when interacting with the data.

4   RESULTS AND DISCUSSION

4.1   Overall Evaluation of Database Efficacy

GOSEP stores geotechnical data in an organized, useful way by tagging each borehole and data point to its correct location spatially. It is easy to search and download subsurface data. The data is, for the most part, electronic and can be analyzed and used for planning purposes. Additionally, many of Oregon's lifeline providers, such as public and private entities responsible for transportation, electric and gas utilities, water and wastewater, fuel, airports, and harbors face an aging infrastructure that was built prior to a full understanding of this extreme seismic risk. Before GOSEP, the state of Oregon did not have a comprehensive record of the testing that has gone on beneath the surface. Subsurface data provides valuable insight to engineers, geologists and planners to guide decisions about infrastructure hardening, protection, and post-disaster redeployment. GOSEP compiles existing data across projects from all over the state, including monotonic strength, laboratory characterization data, borehole logs, and in-situ test results. The database is world viewable and searchable. GOSEP was constructed because, ultimately, more complete data sets facilitate better decision making. With this data now available through an online interface, and minimal knowledge of GIS needed to work with the web-GIS tool, more informed decision making and planning for subsurface investigations is possible. Overall, the web-GIS interface is user friendly, easy and familiar to navigate, and most importantly, is a single location where geotechnical data can be stored and can be found.

4.2   Summary of Results and Lessons Learned

When working with a database of this size, organization is paramount. When importing data to ArcGIS, data must be organized with clear column headings and into purposeful tables. While working in ArcGIS Pro, having consistent naming conventions that convey information about the data layer is important to geodatabase organization. When creating and manipulating layers and

relationship classes, keeping track of the forward and backward paths through naming also helps with geodatabase organization. When merging layers, data organization and also making sure data in similar columns is the same format will help to merge the layers successfully and ultimately analyze the data spatially.

The database succeeded in compiling and visualizing borehole locations across the state, as well as displaying borehole data and attached information. The web application is capable of displaying boreholes beneath the surface as three-dimensional cylinders based on the recorded hole depth. However, the database does not currently display the soil type varying with depth in three dimensions. Using MATLAB or Python to automatically change data format and condense some of the sheets from the ODOT .gINT files so that soil type was in a table that had coordinates attached, instead of relating the lithology data with a relationship class, would have made it easier to change the color of the cylinders for different soil types. It may also decrease redundancy. Overall, the resulting database is organized, functions well, and is designed to be updated and improved.

5 CONCLUSIONS

5.1 Summary of Work Performed

The work performed to create a functional database included collection of geotechnical data and working closely with stakeholders, learning GIS and JavaScript, data management and organization, and displaying data in a GIS and online framework. The beginning phases of this project covered becoming familiar with Esri and Bentley products and systems and learning how to use ArcGIS Pro to display and analyze spatial data. Data procurement was also in the beginning phase. Strategic decisions were made on how to procure the most amount of usable data. Then geologists, organizations, and researchers were persistently contacted and agreements were made for data transfer. A great deal of work for this project went into organizing the data that was received. The data was organized and formatted for upload to ArcGIS Pro in prepared layers and tables. Since there many disparities within the data and the recordings, an effort was made to standardize the data format as well as the coordinate system that was used to project the data onto the map. Attaching pertinent soil engineering properties to each point was crucial to the success of the database, and attaching raw data to each point aided in quality and database efficacy. Throughout this process, steps were taken to make sure that the data was easy to follow and the steps and formatting were methodical so that the database could be improved upon in the future and so that data could be added. The final stages of the project involved learning ArcGIS API for JavaScript and gaining a basic knowledge of HTML, CSS and JavaScript. ArcGIS API for JavaScript allowed for the creation of a web app to visualize the GOSEP database in 2D and 3D.

5.2 Future Applications and Improvements

GOSEP will continue to be updated and expand as more subsurface investigations and research are conducted. CLiP members and other agencies and organizations who have geotechnical data and would like to see their data added to the GOSEP database can email gosep.help@oregonstate.edu.

Additionally, more layers should also be added to the GOSEP WebViewer to aid in analysis. The general geology GIS raster layer by the Oregon Department of Geology and Mineral Industries (DOGAMI) should be added as an optional layer to turn off and on so that users can view the boreholes and explorations in relation to general geology. BLAMO, Borehole Logging Application Made for Oregon, is a mobile application that has also been developed at Oregon State University. The mobile application is designed to log boreholes in the field electronically, conveniently, and consistently using smart phones. Via BLAMO, engineers and geologists will be able to log borehole information in the field, return to the office and transfer the digital information to a computer to generate electronic borehole logs. When creating BLAMO, the structure of the GOSEP database was considered so that in the future, quantitative data can be automatically extracted from the borehole logs and used to populate the georeferenced database. The future goal for this work is full GOSEP-BLAMO integration to allow near-real-time database updating. Figure 16 shows the current BLAMO interface and workflow for logging boreholes and exporting logs. BLAMO has the potential to solve many issues that were encountered when building the GOSEP database due to data age, format, and recording gaps and disparities. For example, many of the boreholes included in the GOSEP database so far did not have a standard coordinate system that was used for recording the location of the boreholes. Often a local datum was used, then not recorded making it difficult to reference the borehole's correct location. BLAMO will be able to use the GPS capabilities of the user's smartphone to correctly locate the borehole automatically and report the location in a standardized way.
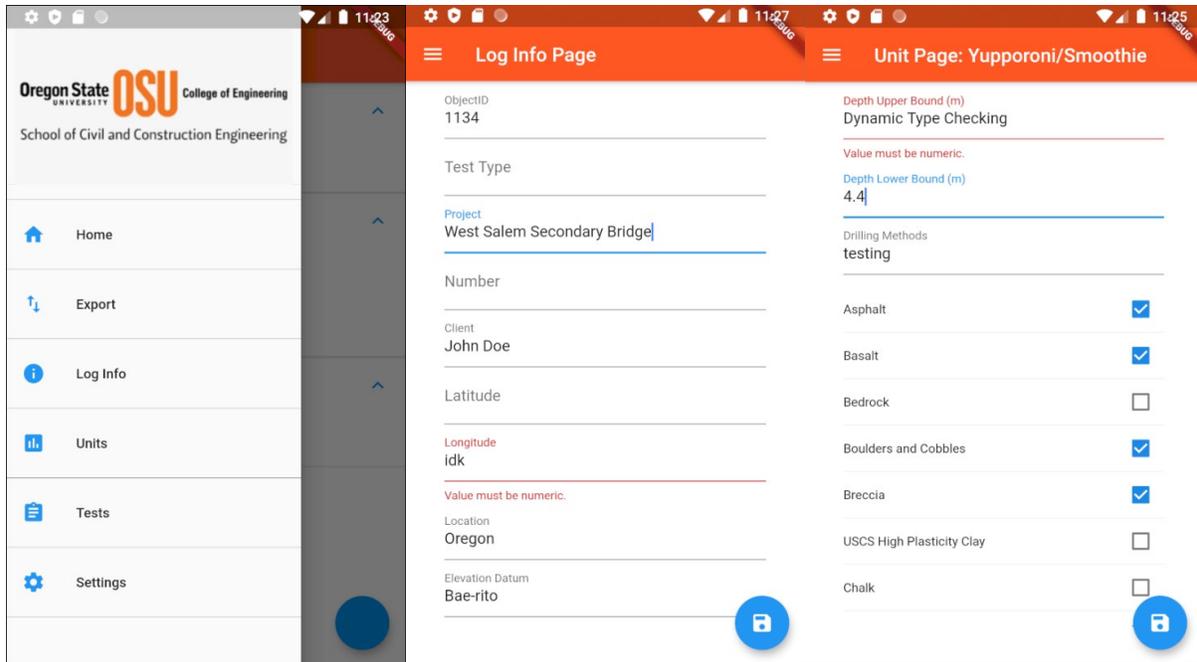
Figure 16: BLAMO mobile application; sample screens menu, log info page, and unit page.

BLAMO supports standardizing geotechnical data, and a movement away from geotechnical information being stored primarily as PDF borehole logs. These efforts to standardize geotechnical data formatting, interchange and storage by both BLAMO and GOSEP also support the DIGGS project. DIGGS involves development of a geospatial standard schema for the transfer and dissemination of geotechnical data and addresses many of the problems stated herein with regards to geotechnical data disparities. A future goal of GOSEP is to build a tool to map GOSEP/BLAMO data directly to DIGGS and vice-versa.

As the database expands, more high-quality data will be included (via BLAMO and other electronic applications) and more PDF borehole logs will be digitized and incorporated. Data quality indicators have been implemented in previous geotechnical databases such as the Geotechnical Database for Utah (Sharifi-Mood et al. 2020) to aid in the analysis of subsurface data and in the degree of confidence in results. The quality of the data in the GOSEP database should be documented in the future as more data is added and as more comprehensive analysis becomes available like

interpolation between boreholes. In the GeoDU database, data that came directly from a report or boring log was assigned a rank of "1" to indicate the highest quality data. Data estimated from other samples in the boring or from nearby boreholes were assigned a quality rank of "2" indicating lower confidence in the data (Sharifi-Mood et al. 2020).

Querying soil surrounding existing boreholes is another future application for GOSEP. The capabilities of the database should be increased to where nearby boreholes can be used to estimate soil properties. Where borehole points are dense, interpolating between drillings can be reasonably accurate. In areas where there is less data or boreholes are farther spread out, estimating soil properties from the existing nearby boreholes can help to fill data gaps. Interpolated data will have a lower quality or confidence, but it will be helpful in initial site reconnaissance, planning subsurface investigations and alerting planners and engineers of possible threats such as potentially liquefiable soils. Allowing for estimation of surrounding soil properties based on existing boreholes and for interpolation between boreholes will let the user to create subsurface profiles for sites of interest. Interpolating over larger areas can show trends in soil behavior and potential hazardous zones. As an example, spatial trends in subsurface engineering properties and lithology can be compared to other map layers and data such as past earthquakes, earthquake damage, and earthquake effects like lateral spreading and liquefaction, to make decisions and assess infrastructure. Subsurface profiles and surficial sediment classification can also be useful in groundwater analysis. Information in the GOSEP database can help estimate soil runoff coefficients and absorption and infiltration rates and can be combined with water quality and flow data for hydrological and groundwater modeling.

Further future capabilities of the database include real-time generation of charts from borehole data in addition and displaying pictures and videos from the field or of soil samples. The database should also include more advanced laboratory data as it expands. Oregon State University provided some

lab data from graduate research projects, and we should work towards archiving as much advanced testing results as possible. The website can also be further developed so that the user is able to search for a specific laboratory testing technique or only show points on the map where lab testing has been completed by a specific entity.

GOSEP has the potential to be used for every geotechnical project in the state of Oregon. Since it is easily available to the public online, it can be accessed and used by anyone; from researchers to state and private agencies, geologists, engineers, planners, and students. GOSEP can be used in the classroom so civil engineering students can become familiar with the types of *in-situ* tests and laboratory tests that are conducted in practice. Data from the GOSEP database can be used in projects so students will see real data and how it is used for design and soil remediation. Instead of instructors simply providing students with data to work with, students will be able to become familiar with this tool, find data for themselves, then bring their working knowledge of the database to their future place of employment, and hopefully continue to contribute to the database. GOSEP offers CLiP members and other entities the opportunity to store geotechnical data in an organized way that is searchable and where data are available to download. It has the potential to result in significant cost savings by preventing lost records and unnecessary repeated borings. The full user manual detailing exactly how to use and interact with the GOSEP user interface is included in Appendix B. Moreover, the database's designed application is to help in planning a geotechnical investigation campaign more efficiently and economically. The *in-situ* and laboratory data contained in GOSEP can help engineers and geologists develop soil sampling strategies, find data gaps and areas with limited prior testing, and become aware that an area may have dangerous or variable soil conditions. It is important to note that this database does not intend to replace site investigations, but to be a tool in planning and supplementing them.

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APPENDIX A: ARCGIS API FOR JAVASCRIPT CODE

```
<!DOCTYPE html>
<html lang="en" >
<head>
  <meta charset="UTF-8">
  <title>GOSEP</title>
  <link rel="stylesheet" href="./style.css">

</head>
<body>
<!-- partial:index.partial.html -->
<head>
  <meta charset="utf-8">
  <meta name="viewport" content="initial-scale=1, maximum-scale=1, user-scalable=no">
  <title>GOSEP</title>
  <style>
      html,
      body,
      #viewDiv {
        padding: 0;
        margin: 0;
        height: 100%;
        width: 100%;
      }

      #infoDiv {
        position: absolute;
        top: 15px;
        left: 60px;
      }

      #infoDiv input {
        border: none;
        box-shadow: rgba(0, 0, 0, 0.3) 0px 1px 2px;
      }

    #clearButton {
        margin-top: 5px;
        display: none;
      }
      .dgrid {
        height: auto !important;
      }
      .dgrid .dgrid-scroller {
        position: relative;
        max-height: 200px;
        overflow: auto;
      }
```

```
  </style>

  <link rel="stylesheet" href="https://js.arcgis.com/4.15/esri/themes/light/main.css">
 <script src="https://js.arcgis.com/4.15/"></script>

<h5>
  <a     id="OSULogo"      href="http://oregonstate.edu"      target="_blank">      <img
src="http://communications.oregonstate.edu/sites/communications.oregonstate.edu/files/osu-
primarylogo-2-compressor.jpg" alt='OSU_Logo' height="60" width = "150" /></a>
  <a    id="GOSEPLogo"    href="http://ohelp.oregonstate.edu"    target="_blank">    <img
src='http://ohelp.oregonstate.edu/GOSEP/Logo/GOSEP.PNG'      alt='GOSEP'      height="50"
width="200"/></a>
  <a         id="read-me"         href="http://ohelp.oregonstate.edu/GOSEP/User_Manual.pdf"
target="_blank">    <img    src="http://ohelp.oregonstate.edu/images/help-icon5.png"    alt='User-
Manual' height="40" width = "40" /></a>
  <a id="test" href="http://cascadia.oregonstate.edu/"
  style="text-decoration: none; color:white;">
  GOSEP Georeferenced Oregon Soil Engineering Properties Database </br> Cascadia Lifeline
Programs (CLiP) </a>
 </h5>
</script>

  <script>
   require([
     "esri/Map",
     "esri/views/SceneView",
     "esri/layers/FeatureLayer",
     "esri/widgets/Home",
     "esri/PopupTemplate",
     "esri/popup/content/AttachmentsContent",
     "esri/widgets/BasemapToggle",
    "esri/widgets/Search",
     "esri/WebScene"
   ], function (Map, SceneView, FeatureLayer, Home, PopupTemplate, AttachmentsContent,
BasemapToggle, Search, WebScene) {

     var scene = new WebScene({
      portalItem: {
       // autocasts as new PortalItem()
       id: "1791539c0bf34fe38515f02b962843ce"
      }

     });

     var Region1Url =
```

```
"https://arcweld.engineering.oregonstate.edu:6443/arcgis/rest/services/GOSEP/GOSEP/MapServer
/3";

    var Region2Url =

"https://arcweld.engineering.oregonstate.edu:6443/arcgis/rest/services/GOSEP/GOSEP/MapServer
/2";
    var Region3Url =

"https://arcweld.engineering.oregonstate.edu:6443/arcgis/rest/services/GOSEP/GOSEP/MapServer
/1";
    var Region45Url =

"https://arcweld.engineering.oregonstate.edu:6443/arcgis/rest/services/GOSEP/GOSEP/MapServer
/0";

    var OSUGeotechUrl =

"https://services1.arcgis.com/dePSdaG71BplHMCO/arcgis/rest/services/Sit_Geotech/FeatureServe
r/0";

    var BODOUrl =

"https://arcweld.engineering.oregonstate.edu:6443/arcgis/rest/services/BODO/BODO_20181018/
MapServer/0";


    // The clipping extent for the scene
    var OregonExtent = {
     // autocasts as new Extent()
     xmax: -12400000,
   xmin: -14400000,
   ymax: 5960000,
   ymin: 4900000,
   spatialReference: { // == autocasts as new SpatialReference()
    wkid: 3857
     }
    };


    /*****************************************************
     * The popupTemplate that will populate the content of the
     * popup when a well feature is selected
     *****************************************************/
    let attachmentsElement = new AttachmentsContent({
     displayType: "list"
```

```javascript
});

// Create the PopupTemplate
let template = new PopupTemplate({
  title: "{PointID}<br>"+
  "Point ID: {PointID}<br>"+
  "Equipment: {Equipiment}<br>" +
   "Start Date: {Start_Date}<br>" +
   "End Date: {End_Date}<br>" +
   "Driller: {Driller}<br>" +
   "Purpose: {Purpose}<br>" +
   "Hole Depth: {HoleDepth} feet<br>"+
  "Recorder: {Recorder}<br>"+
  "Key Number: {Key_No}<br>"+
  "Elevation: {Elevation}<br>",
  outFields: ["*"],
  content: [attachmentsElement]

});

var boreholesTemplate = {
 // autocasts as new PopupTemplate()
 title: "{PointID}",
 content:
   "<b>PointID:</b> {PointID}<br>" +
   "<b>Equipment: </b> {Equipiment}<br>" +
   "<b>Start Date: </b> {Start_Date}<br>" +
   "<b>End Date: </b> {End_Date}<br>" +
   "<b>Driller: </b> {Driller}<br>" +
   "<b>Purpose: </b> {Purpose}<br>" +
   "<b>Hole Depth: </b> {HoleDepth} feet<br>" +
  "<b>Recorder: </b> {Recorder}<br>" +
   "<b>Key Number: </b> {Key_No}<br>" +
   "<b>Start Card Number: </b> {Start_Card_No}<br>" +
  "<b>Bridge Number: </b> {Bridge_No}<br>" +
   "<b>Tube Height: </b> {Tube_Height}<br>" +
   "<b>Elevation: </b> {Elevation}<br>",
 fieldInfos: [
   {
    fieldName: "Start_Date",
    format: {
      dateFormat: "short-date"
    }
   },
   {
    fieldName: "End_Date",
    format: {
```

```javascript
        dateFormat: "short-date"
      }
    },
    {
      fieldName: "HoleDepth",
      format: {
        places: 0,
        digitSeparator: true
      }
    },
  ]


};

// Create the PopupTemplate
let geotech2template = new PopupTemplate({
  title: "Project ID: {proj_ID}<br>"+
  "Type: {type}<br>"+
  "Ref: {ref}<br>"+
  "Firm: {firm}<br>"+
  "Title: {title}<br>"+
  "Date: {date}<br>"+
  "Boring Data Location: {bore_data}<br>",

  outFields: ["*"],
  content: [attachmentsElement]

});

var geotechinfoTemplate = {
  // autocasts as new PopupTemplate()
  title: "{proj_ID}",
  outFields: ["*"],
  content:
    "<b>Project ID:</b> {proj_ID}<br>" +
    "<b>Type: </b> {type}<br>" +
    "<b>Ref: </b> {ref}<br>" +
    "<b>Firm: </b> {firm}<br>" +
    "<b>Title: </b> {title}<br>" +
    "<b>Date: </b> {date}<br>" +
    "<b>Boring Data Location: </b> {bore_data}<br>" +
  "<b>Notes: </b> {Notes}<br>" +
    "<b>uID_1: </b> {uID_1}<br>",


};
```

```javascript
var BODOTemplate = {
 // autocasts as new PopupTemplate()
 title: "{Boring}",
 outFields: ["*"],
 content:
  "<b>File Name:</b> {FileName }<br>" +
  "<b>Boring: </b> {Boring}<br>" +
  "<b>Page: </b> {Page}<br>" +
  "<b>Elevation: </b> {BoreElev}<br>" +
  "<b>Drilling Method: </b> {DrillMeth}<br>" +
  "<b>Rig Type: </b> {RigType}<br>" +
  "<b>Borehole Diameter: </b> {BoreDiam}<br>" +
 "<b>Hammer Type: </b> {HammerType}<br>" +
  "<b>Location: </b> {Location}<br>"+
 "<b>Driller:</b> {Driller}<br>" +
  "<b>Link: </b>" + "<a href = '{Link}'> view </a>" + " <br>" +
  "<b>FillStatus: </b> {FillStatus}<br>" +
  "<b>File Name: </b> {FILE_NAME}<br>" +
  "<b>Boring Depth: </b> {BORINGDEPTH}<br>" +
  "<b>Drill Comp: </b> {Drill_Comp}<br>" +
  "<b>Rod Type: </b> {ROD_TYPE}<br>" +
 "<b>Hammer Type: </b> {HAMMER_TYPE}<br>" +
  "<b>Hammer Drop: </b> {HAMMER_DROP}<br>"+
 "<b>Vertical Datum: </b> {VERT_DATUM}<br>" +
  "<b>Horizontal Datum: </b> {HORIZ_DATUM}<br>" +
  "<b>Date: </b> {DATE_}<br>" +
  "<b>Notes: </b> {NOTES}<br>" +
  "<b>Site Name: </b> {SITENAME}<br>" +
 "<b>Start Date: </b> {START_DATE}<br>" +
  "<b>End Date: </b> {END_DATE}<br>",


};



/*******************************************************
 * Renderer properties for symbolizing wells on the surface
 ********************************************************/

var boreholesSurfaceRenderer = {
 type: "simple", // autocasts as new SimpleRenderer()
 symbol: {
  type: "point-3d", // autocasts as new PointSymbol3D()
```

```
    symbolLayers: [
     {
      type: "icon", // autocasts as new IconSymbol3DLayer()
      outline: {
        color: "black"
      },
      resource: {
        primitive: "cross"
      },
      size: 6
     }
    ]
   }
};

/***********************************************
 * Renderer for symbolizing wells below the surface
 ***********************************************/

var startDate = new Date("Thu Jul 25 2013 00:00:00 GMT-0700 (PDT)");
var endDate = new Date("Mon Nov 09 2015 00:01:40 GMT-0800 (PST)");

var BODODepthRenderer = {
  type: "simple", // autocasts as new SimpleRenderer()
  symbol: {
    type: "point-3d", // autocasts as new PointSymbol3D()
    symbolLayers: [
     {
      type: "object", // autocasts as new ObjectSymbol3DLayer()
      resource: {
        primitive: "cylinder"
      },
      anchor: "top",
      width: 7
     }
    ]
  },
  visualVariables: [
   {
    type: "size",
    field: "BORINGDEPTH",
    axis: "height",
    valueUnit: "feet"
   },
   {
    type: "size",
    axis: "width",
```

```
    useSymbolValue: true // sets the width to 50m
   },
   {
    type: "color",
    field: "BORINGDEPTH",
    stops: [
      {
       // From mid-2013
       value: startDate.valueOf(),
       color: "orange"
      },
      {
       // to Nov 2015
       value: endDate.valueOf(),
       color: "red"
      }
    ]
   }
  ]
};

var boreholesDepthRenderer = {
 type: "simple", // autocasts as new SimpleRenderer()
 symbol: {
  type: "point-3d", // autocasts as new PointSymbol3D()
  symbolLayers: [
    {
     type: "object", // autocasts as new ObjectSymbol3DLayer()
     resource: {
      primitive: "cylinder"
     },
     anchor: "top",
     width: 7
    }
  ]
 },
 visualVariables: [
   {
    type: "size",
    field: "HoleDepth",
    axis: "height",
    valueUnit: "feet"
   },
   {
    type: "size",
    axis: "width",
    useSymbolValue: true // sets the width to 50m
```

```
      },
      {
       type: "color",
       field: "HoleDepth",
       stops: [
         {
          // From mid-2013
          value: startDate.valueOf(),
          color: "orange"
         },
         {
          // to Nov 2015
          value: endDate.valueOf(),
          color: "red"
         }
       ]
      }
     ]
    };


    /**************************************************
     * Layers depicting boreholes in ODOT Region 1
     **************************************************/

    // Layer for depicting wells below the surface
    var Region1 = new FeatureLayer({
     url: Region1Url,
     //definitionExpression:
       //"Status = 'CBM' OR Status = 'EOR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
     outFields: ["*"],
     popupTemplate: template,
     renderer: boreholesDepthRenderer,
     // This keeps the cylinders from poking above the ground
     elevationInfo: {
       mode: "relative-to-ground",
       offset: -1
     }
    });

    // Layer for depicting well locations on the surface
    var Region1SurfaceLayer = new FeatureLayer({
     url: Region1Url,
     //definitionExpression:
       //"Status = 'CBM' OR Status = 'EDR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
     outFields: ["*"],
```

```
    popupTemplate: template,
     renderer: boreholesSurfaceRenderer,
     elevationInfo: {
       mode: "on-the-ground"
     }
   });
   /************************************************
    * Layers depicting boreholes in ODOT Region 2
    ************************************************/


   // Layer for depicting wells below the surface
   var Region2 = new FeatureLayer({
     url: Region2Url,
     //definitionExpression:
       //"Status = 'CBM' OR Status = 'EOR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
     outFields: ["*"],
     popupTemplate: template,
     renderer: boreholesDepthRenderer,
     // This keeps the cylinders from poking above the ground
     elevationInfo: {
       mode: "relative-to-ground",
       offset: -1
     }
   });


   // Layer for depicting well locations on the surface
   var Region2SurfaceLayer = new FeatureLayer({
     url: Region2Url,
     //definitionExpression:
       //"Status = 'CBM' OR Status = 'EDR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
     outFields: ["*"],
     popupTemplate: template,
     renderer: boreholesSurfaceRenderer,
     elevationInfo: {
       mode: "on-the-ground"
     }
   });


   /************************************************
    * Layers depicting boreholes in ODOT Region 3
    ************************************************/


   // Layer for depicting wells below the surface
   var Region3 = new FeatureLayer({
     url: Region3Url,
```

```
        //definitionExpression:
          //"Status = 'CBM' OR Status = 'EOR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
        outFields: ["*"],
        popupTemplate: template,
        renderer: boreholesDepthRenderer,
        // This keeps the cylinders from poking above the ground
        elevationInfo: {
          mode: "relative-to-ground",
          offset: -1
        }
      });

      // Layer for depicting well locations on the surface
      var Region3SurfaceLayer = new FeatureLayer({
        url: Region3Url,
        //definitionExpression:
          //"Status = 'CBM' OR Status = 'EDR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
        outFields: ["*"],
        popupTemplate: template,
        renderer: boreholesSurfaceRenderer,
        elevationInfo: {
          mode: "on-the-ground"
        }
      });

      /***********************************************
       * Layers depicting boreholes in ODOT Region 4 & 5
       ***********************************************/

      // Layer for depicting wells below the surface
      var Region45 = new FeatureLayer({
        url: Region45Url,
        //definitionExpression:
          //"Status = 'CBM' OR Status = 'EOR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
        outFields: ["*"],
        popupTemplate: template,
        renderer: boreholesDepthRenderer,
        // This keeps the cylinders from poking above the ground
        elevationInfo: {
          mode: "relative-to-ground",
          offset: -1
        }
      });
```

```javascript
    // Layer for depicting well locations on the surface
    var Region45SurfaceLayer = new FeatureLayer({
     url: Region45Url,
     //definitionExpression:
       //"Status = 'CBM' OR Status = 'EDR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
     outFields: ["*"],
     popupTemplate: template,
     renderer: boreholesSurfaceRenderer,
     elevationInfo: {
       mode: "on-the-ground"
     }
    });


    /*************************************************
  * Layers depicting boreholes from OSU facilities
     *************************************************/

    // Layer for depicting wells below the surface
    var OSUGeotech = new FeatureLayer({
     url: OSUGeotechUrl,
     //definitionExpression:
       //"Status = 'CBM' OR Status = 'EOR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
     outFields: ["*"],
     popupTemplate: geotech2template,
     renderer: boreholesDepthRenderer,
     // This keeps the cylinders from poking above the ground
     elevationInfo: {
       mode: "relative-to-ground",
       offset: -1
     }
    });

    // Layer for depicting well locations on the surface
    var OSUGeotechSurfaceLayer = new FeatureLayer({
     url: OSUGeotechUrl,
     //definitionExpression:
       //"Status = 'CBM' OR Status = 'EDR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
     outFields: ["*"],
     popupTemplate: geotech2template,
     renderer: boreholesSurfaceRenderer,
     elevationInfo: {
       mode: "on-the-ground"
     }
```

```
    });

    /*************************************************
     * Layers depicting boreholes from BODO database
     **************************************************/

    // Layer for depicting wells below the surface
    var BODO = new FeatureLayer({
      url: BODOUrl,
      //definitionExpression:
        //"Status = 'CBM' OR Status = 'EOR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
      outFields: ["*"],
      popupTemplate: BODOTemplate,
      renderer: boreholesDepthRenderer,
      // This keeps the cylinders from poking above the ground
      elevationInfo: {
        mode: "relative-to-ground",
        offset: -1
      }
    });

    // Layer for depicting well locations on the surface
    var BODOSurfaceLayer = new FeatureLayer({
      url: BODOUrl,
      //definitionExpression:
        //"Status = 'CBM' OR Status = 'EDR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'",
      outFields: ["*"],
      popupTemplate: BODOTemplate,
      renderer: boreholesSurfaceRenderer,
      elevationInfo: {
        mode: "on-the-ground"
      }
    });
    /****************************************************************
     * Create a map with the above defined layers and a topographic
     * basemap. Setting the navigationConstraint on the ground to be of
     * type "none" will allow the user to navigate the view's camera
     * below the surface.
     ****************************************************************/
    var map = new Map({
      basemap: "streets",
      layers: [
        Region1,
        Region1SurfaceLayer,
        Region2,
```

```
      Region2SurfaceLayer,
      Region3,
      Region3SurfaceLayer,
      Region45,
      Region45SurfaceLayer,
      OSUGeotech,
      OSUGeotechSurfaceLayer,
      BODO,
      BODOSurfaceLayer
    ],
   ground: {
    navigationConstraint: {
      type: "none"
     }
   }
 });

 /*****************************************************************
  * Create a local scene in south central Kansas
  *
  * To create a local scene, you must set the viewingMode to "local".
  * To define a small, localized area for the view, set
  * the clippingArea property.
  *****************************************************************/
 var view = new SceneView({
  container: "viewDiv",
  map: map,
  // Indicates to create a local scene
  viewingMode: "local",
  // Use the extent defined in clippingArea to define the bounds of the scene
  clippingArea: OregonExtent,
  extent: OregonExtent,
  // Turns off atmosphere and stars settings
  environment: {
   atmosphere: null,
   starsEnabled: false
  }
 });

 /************************************************************
  * Set up action for returning the number of wells within
  * 10km of the earthquake.
  ************************************************************/

 // Default parameters for selecting wells within 10km of click
 var boreholesBufferParams = {
  spatialRelationship: "esriSpatialRelIntersects",
```

```
       distance: 10,
       units: "kilometers",
       where:
         "Status = 'CBM' OR Status = 'EDR' OR Status = 'GAS' OR Status = 'INJ' OR Status = 'O&G'
OR Status = 'OIL' OR Status = 'SWD'"
     };

   view.popup.on("trigger-action", function (event) {
    if (event.action.id === "find-wells") {
     boreholesBufferParams.geometry = view.popup.selectedFeature.geometry;
     Region1
       .queryFeatureCount(boreholesBufferParams)
       .then(function (response) {
        var results =
          "<b>" +
          response +
          "</b> active wells are within 10 km of this earthquake.";
        view.popup.content = results;
       })
       .catch(function (error) {
        console.log("action failed: ", error);
       });
    } else {
     return;
    }
   });

   // Set up a home button and add to the ui top-left
   var homeBtn = new Home({ view: view });
   view.ui.add(homeBtn, "top-left");

   // Search widget
  var search = new Search({
   view: view
  });

  view.ui.add(search, "top-right");
   var basemapToggle = new BasemapToggle({
   view: view,
   nextBasemap: "topo"
  });


   view.ui.add(basemapToggle, "top-right");
```

```
    });
   </script>
 </head>

 <body>
  <div id="viewDiv"></div>
  <div id='sponsorBottom'>
   <a    id="PGELogo"    href="https://www.portlandgeneral.com/"    target="_blank">   <img
src='http://ohelp.oregonstate.edu/images/Logo/PGE_logo.png'    alt='PGE_Logo'    height="60"
width="90"/></a>
   <a   id="BPALogo"   href="https://www.bpa.gov/Pages/home.aspx"   target="_blank">   <img
src='http://ohelp.oregonstate.edu/images/Logo/BPA_logo.png' height="80" width="90"/></a>
   <a id="ODOTLogo" href="http://www.oregon.gov/ODOT/Pages/index.aspx" target="_blank">
<img    src='http://ohelp.oregonstate.edu/images/Logo/ODOT_logo.png'    alt='ODOT_Logo'
height="40" width="90"/></a>
   <a    id="NWLogo"    href="https://www.nwnatural.com/"    target="_blank">    <img
src='http://ohelp.oregonstate.edu/images/Logo/nwnatural_logo.png' alt='NW_Logo' height="40"
width="90"/></a>
   <a   id="PortlandLogo"   href="http://www2.portofportland.com/"   target="_blank">   <img
src='http://ohelp.oregonstate.edu/images/Logo/port_logo.png'    alt='Portland_Logo'    height="50"
width="130"/></a>
   <a    id="EWEBLogo"    href="http://www.eweb.org/"    target="_blank">    <img
src='http://ohelp.oregonstate.edu/images/Logo/EWEB_logo.png' height="40" width="90"/></a>
   <a   id="PortlandWaterLogo"   href="https://www.portlandoregon.gov/water/"   target="_blank">
<img                src='http://ohelp.oregonstate.edu/images/Logo/portlandwater_logo.png'
alt='Portlandwater_Logo' height="80" width="90"/></a>
   <a    id="tualatinLogo"    href="https://www.tvwd.org/"    target="_blank">    <img
src='http://ohelp.oregonstate.edu/images/Logo/tualatin_logo.png'  alt='tualatin_Logo'  height="50"
width="120"/></a>

     <div id="manual-rep" class="read-me" title="User Manual">
   <a href="User_Manual_V8_20200604.pdf" target="_blank"> <img src='images/help-icon5.png'
/></a>
  </div>

     <section id="Disclaimer" style="display: none;" title="Disclaimer Information">
  <p                        style='font-size:125%;'                        align='center'><img
src='http://ohelp.oregonstate.edu/GOSEP/Logo/GOSEP.PNG' alt='HTML5 Icon'><br>
  <p  style='font-size:150%;'><strong> Georeferenced  Oregon  Soil  Engineering  Properties
</strong></p>
  <p  style='font-size:112%;'><strong>  The  preferred  browser  for  GOSEP  is  <a  href =
'https://www.google.com/chrome/' target='_blank'>Google Chrome</a>.</strong></p>
  <p style='font-size:112%; color:#B26200;'><strong> Please enable hardware acceleration and
disable pop-up blockers.</strong></p>
  <p  align='left'>The  <a  href=  "https://cascadia.oregonstate.edu/"  target="_blank">  Cascadia
Lifeline Program (CLiP) </a> and the <a href= 'https://research.engr.oregonstate.edu/geomatics/'
target='_blank'> Geotechnical Research Group </a>
```

in School of Civil and Construction Engineering at the

 Oregon State University works to ensure that the information provided on this website is accurate, timely, and useful.

<b style='font-size:112%; color:#B26200;'> The information provided herein is for reference only and is not suitable as the sole source in engineering design and site-specific analysis; instead, it provides a starting point to identify and understand subsurface conditions and approximate locations where previous investigations have been conducted.

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Corrections, additions, and updates to this website will be made when necessary or as time permits. </p>

<p style='font-size:112%;'>For questions or comments, please send an email to help.gosep@oregonstate.edu.</p>

</section>

  </body>

</html>

<!-- partial -->

</body>

</html>

APPENDIX B: GOSEP USER MANUAL

GOSEP

GOSEP: Georeferenced Oregon Soil Engineering Properties
USER MANUAL

Release v 1.0
July 28, 2020

Development Team: Victoria Dutille, T. Matthew Evans, Jaehoon Jung, Michael J. Olsen
School of Civil and Construction Engineering, College of Engineering

Table of Contents

INTRODUCTION:

This is a user manual for the GOSEP (Georeferenced Oregon Soil Engineering Properties) 3D website, which is a user-friendly, web-based 3D geographic information system (GIS) tool to assess Oregon soil engineering properties and geotechnical site investigations, developed with support from the Cascadia Lifelines Program (CLiP, https://cascadia.oregonstate.edu/). The website contains previous boreholes, in situ and laboratory tests of Oregon soils in a powerful 3D web-based interface, which does not require the user to have extensive knowledge of GIS.

BACKGROUND:

The Cascadia Subduction Zone (CSZ) is capable of generating a M9.0 earthquake that could greatly damage the built environment in Oregon. Such a powerful and long-lasting earthquake can generate severe ground shaking, landslides, liquefaction-induced ground deformations, fault rupture vertical displacement, tsunamis, etc. These seismic deformations will likely be considerably damaging to foundations, bridges, roadways, pipelines, and other lifelines.

Many of Oregon's lifeline providers, such as public and private entities responsible for transportation, electric and gas utilities, water and wastewater, fuel, airports, and harbors face an aging infrastructure that was built prior to a full understanding of this extreme seismic risk. Before GOSEP, the state of Oregon did not have a comprehensive record of subsurface site explorations that have been performed in the state. Subsurface data provides valuable insight to engineers, geologists and planners to guide decisions about infrastructure hardening, protection, and post-disaster redeployment. GOSEP compiles existing data across projects from all over the state, including monotonic strength, laboratory characterization data, borehole logs, and *in-situ* test results. The database is world viewable and searchable. GOSEP was constructed because, ultimately, more complete data sets facilitate better decision making.

INTENDED AUDIENCE:

This tool is designed for engineers, planners, geologists, and others who need this information to help make appropriate decisions. It is assumed that the users have enough knowledge of geotechnical subsurface investigations to understand what the data means and how to use it appropriately. Minimal knowledge of GIS will be needed to work with this web-GIS tool.

Participants in the Project:

Participating organizations in CLiP include: the Oregon Department of Transportation (ODOT), Portland General Electric (PGE), Northwest Natural Gas (NWN), Portland Water Bureau (PWB), Port of Portland (PDX), Eugene Water and Electric Board (EWEB), Bonneville Power Administration (BPA) and Tualatin Valley Water District (TVWD).

The Geotechnical research group in the School of Civil and Construction Engineering at Oregon State University manages this website under the direction of CLiP. Specifically the following persons from OSU (unless directed otherwise) have worked directly on this project since its inception:

- **Project management**: T. Matthew Evans, Michael Olsen, Armin Stuedlein.
- **WebGIS Version 1.0** (current) development and maintenance: Victoria Dutille, Tifong Chin, Jaehoon Jung and Michael Olsen

- **Server support**, maintenance, and administration: Paul Montagne
- **Creation of data layers contained in GOSEP:**
    - **ODOT Region 1 Boreholes, ODOT Region 2 Boreholes, ODOT Region 3 Boreholes, ODOT Region 4 and 5 Boreholes**: Victoria Dutille, Tifong Chin
    - **Borehole Database of Oregon (BODO)**: May Shin Lyan, Nicholas Matthews, Ben Leshchinsky, and Michael Olsen.
    - **Geotech2**: Oregon State Facilities
    - **Buck Creek**: Victoria Dutille, Jiayao Wang, Ehsan Yazdani

DISCLAIMER:

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Corrections, additions, and updates to this website will be made when necessary or as time permits.

PLATFORM

The web-GIS framework for GOSEP has been designed in ESRI's ArcGIS for Server (i.e., ArcServer) platform. ArcServer enables the use of several of ESRI's base layers, including aerial imagery, topographic maps, and road networks. While the primary interface is the GOSEP webGIS, the data layers may be streamed directly in GIS software. The Appendix contains instructions on how to access the layers.

TOOL FEATURES

Several features and tools in GOSEP (numbered in Figure 1) are defined individually below. GOSEP can simply be accessed via a web browser. (Although please note that some compatibility versions will occur with different browsers. Chrome is currently the preferred browser).
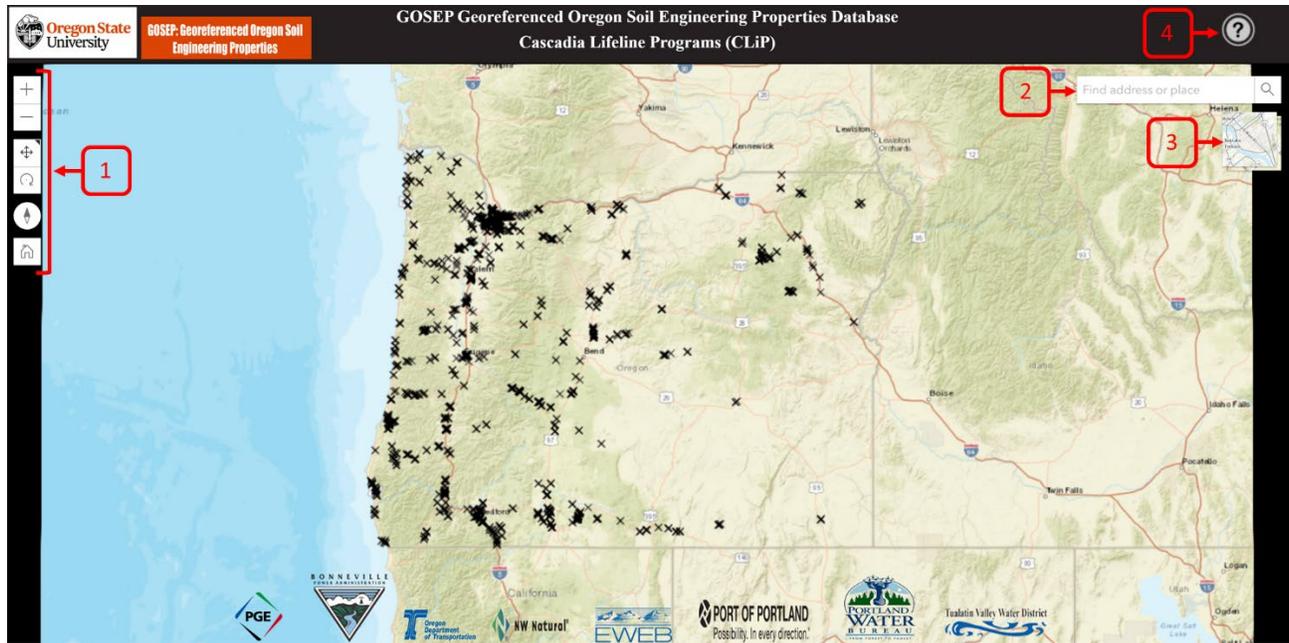
Figure 1. Outline view of the GOSEP website with various feature tools and their screen location.

1. Navigation widgets

The user can zoom in and out with the buttons $\boxed{+}\boxed{-}$ or by using the mouse wheel.

The default navigation mode is always pan $\boxed{\oplus}$. The alternate navigation mode to toggle to is rotate $\boxed{\circlearrowleft}$. This allows the user to rotate the view with a mouse drag and pan the view with a right-click and drag gesture.

The Compass widget $\boxed{\diamond}$ indicates where north is in relation to the current view rotation or camera heading. Clicking the Compass widget rotates the view to face north (heading = 0).

The Home Widget $\boxed{\text{⌂}}$ Quickly return to the map's default starting viewpoint using the Home button widget. The initial default view is the entire State of Oregon.

2. Address Locator

$\boxed{\text{Find address or place} \quad \text{Q}}$

This tool enables the user to search for a specific location by entering either geographic coordinates in longitude, latitude format, or by entering the address for a location of interest. Once the user inputs the search information, the locator will show the place by dropping a black point on the map. A window will then pop up in the map with the latitude and longitude information for that site (see Figure 2).
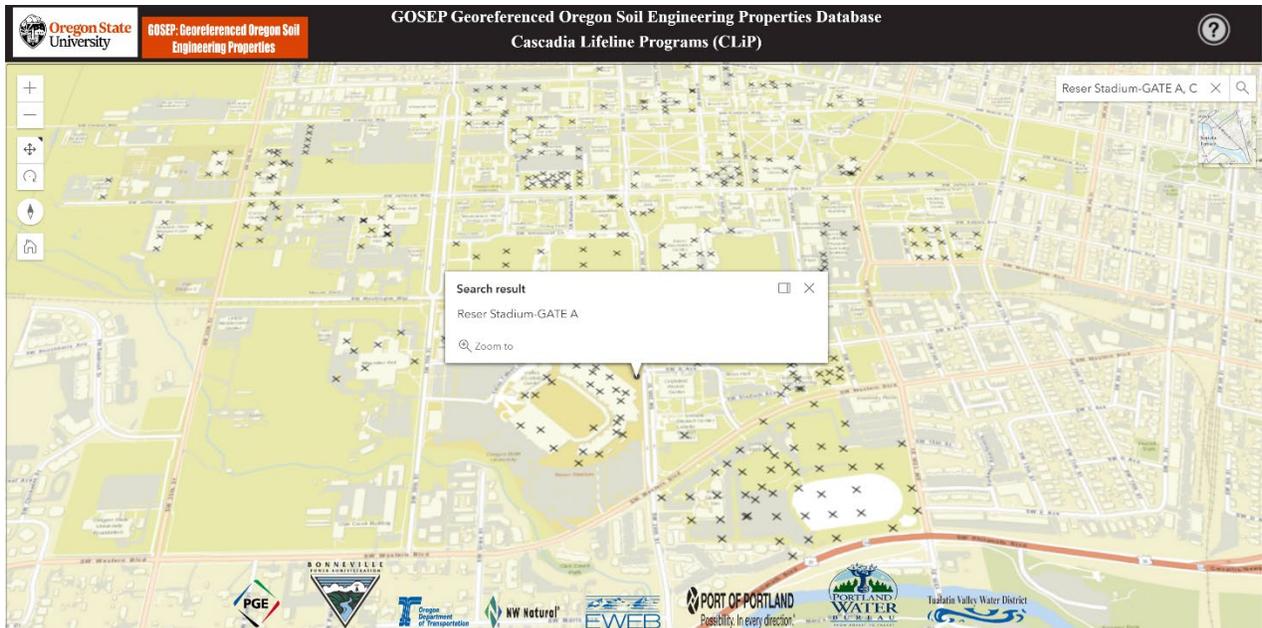
Figure 2: Pop up window representing the selected address, location, or latitude, longitude on the interactive map.

3. **Base Map Toggle**

After selecting this icon, the base map will change to show topography (Figure 3). Current available base map layers are ESRI Streets and ESRI Topography. The user can click on the same icon to change the base map back to the default, ESRI Streets.

Figure 3: GOSEP database displayed with the ESRI World Topography base map after clicking the base map toggle icon.

4. User Manual ⓘ

Clicking on ⓘ provides a link to the GOSEP user manual document.

BOREHOLE VISUALIZATION

Each borehole or test site is represented on the ground surface by a black "X". Clicking on a point will display information related to that point (Figure 4). Information for the borehole or site may be viewed and downloaded by clicking on the "Attachments" link.

The boreholes in the GOSEP database are rendered on the surface as well as below the surface of the scene. You may navigate underneath the basemap to view the exact location and depths of drilled boreholes and other *insitu* tests. To explore features below the surface, you must tilt the view. To tilt below the surface, use the navigation tools, or right click the view and drag the mouse up. Right click and drag the mouse downward to tilt back above the surface. Figure 5 shows the visualization of boreholes beneath the surface. Clicking on a cylinder representing a borehole will display a similar pop-up as on the surface where depth information and other data from the particular exploration can be viewed and then downloaded in PDF or spreadsheet format.
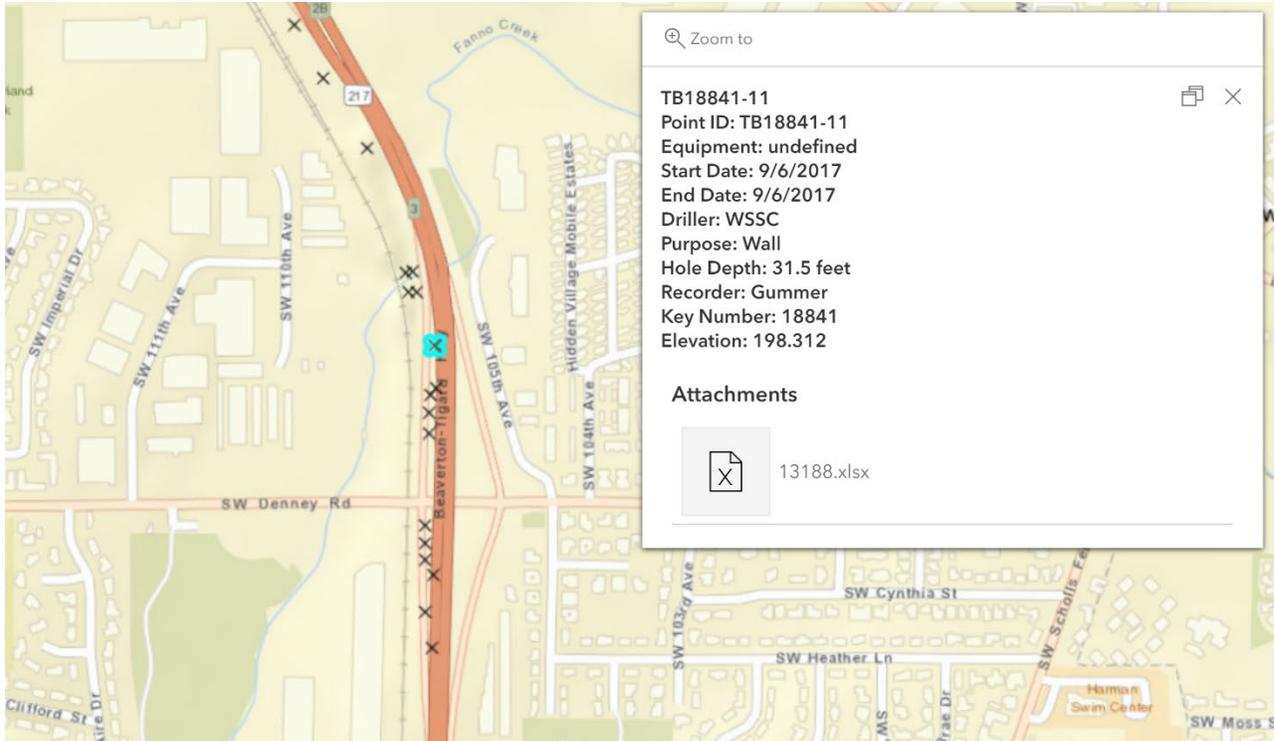
Figure 4. A typical pop-up when a point is selected displaying key information about the borehole
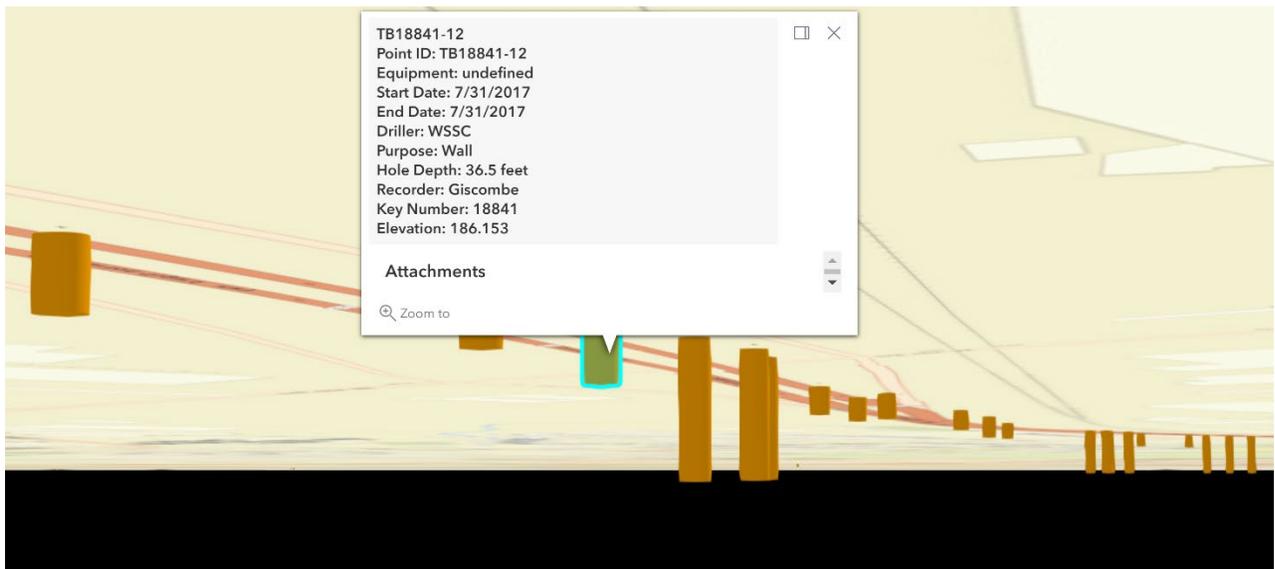
Figure 5. Boreholes along a portion of the Tigard-Beaverton Highway represented beneath the surface.

MOBILE DEVICE SUPPORT

GOSEP is available in mobile devices (Figure 6). Note that some features (title, sponsor list.) are not available in a mobile phone due to the limited display space available, so the experience will ordinarily be better in a web browser on a desktop.
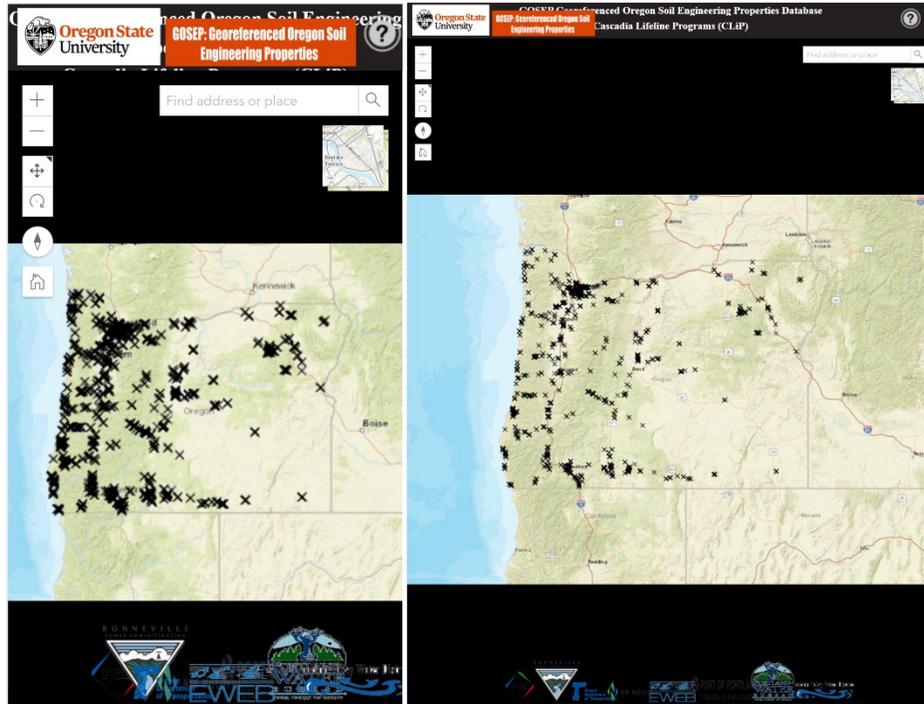
Figure 6. The starting screen of GOSEP in mobile phone (left) and tablet device (right)

FUTURE WORK

GOSEP will continue to be updated and expand as more subsurface investigations and research are conducted. BLAMO, Borehole Logging Application Made for Oregon, is a mobile application that has been developed by Oregon State University computer science students. The mobile application is designed to log boreholes in the field electronically, conveniently, and consistently using smart phones. Via BLAMO, engineers and geologists will be able to log borehole information in the field, return to the office and transfer the digital information to a computer to generate electronic borehole logs. The future goal for this work is full GOSEP-BLAMO integration to allow near-real-time database updating. Querying soil surrounding existing boreholes is another future application for GOSEP. The capabilities of the database should be increased to where nearby boreholes can be used to estimate soil properties. Allowing for estimation of surrounding soil properties based on existing boreholes and for interpolation between boreholes will let the user to create subsurface profiles for sites of interest. Interpolating over larger areas can show trends in soil behavior and potential hazardous zones. Real-time generation of charts from borehole data in addition and displaying pictures and videos from the field or of soil samples may be included in the future. The database should also include more advanced laboratory data as it expands.

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APPENDIX:

Access to the data:
The data in GOSEP is available for research purposes through the College of Engineering at Oregon State University's ArcGIS web server. To access the mapping data in ESRI's ArcGIS products, follow the steps below to setup the server and to connect to the data:

1. Go to "Arc Catalog".
2. Double-click on "Add ArcGIS Server".
3. In the check box choose "Use GIS services" (Figure 5).
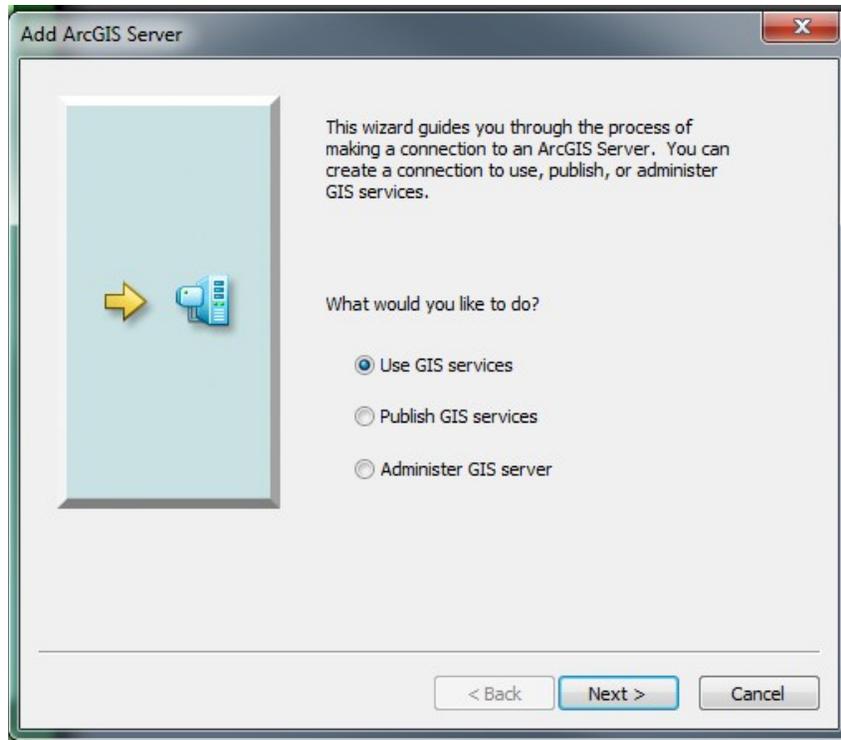
Figure 5: setting up of server step 3

4. Enter the following URL in the server URL box (Figure 15):
   (https://arcweld.engineering.oregonstate.edu:6443/arcgis/rest/)
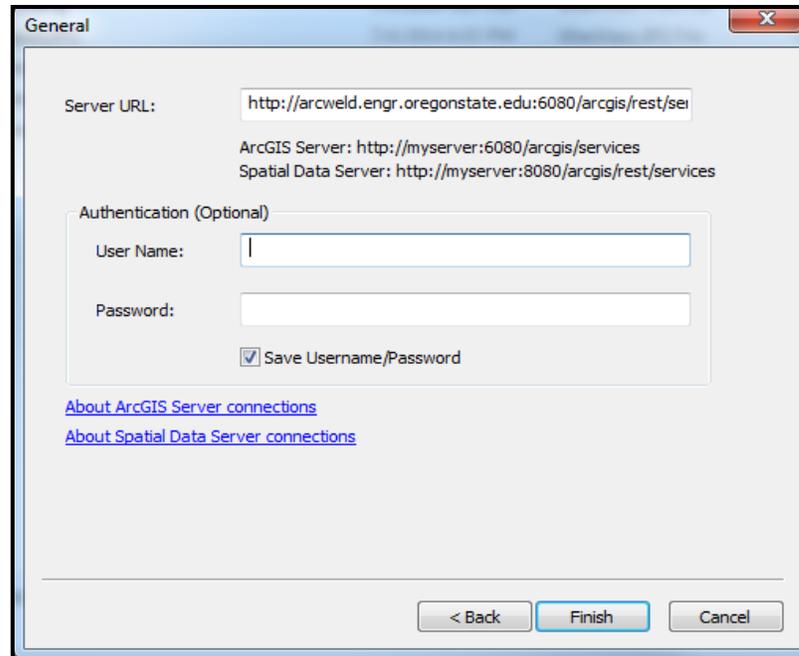
Figure 6: Setting up of server Step 4

5. No authentication credentials are necessary at this time.
6. Once the server setup is completed, the data becomes visible on the catalog window. Data can be added to ArcMap from Arc Catalog by dragging and dropping the files to the table of contents.

Alternatively, type the following URL into the preferred search engine:
https://arcweld.engr.oregonstate.edu:6443/arcgis/rest/services/GOSEP/GOSEPfinal/MapServer.
This will bring you to the GOSEP ArcGIS REST Service Directory. From here the GOSEP data layers can be opened in ArcGIS JavaScript, ArcGIS Earth, ArcMap, ArcGIS Explorer, and ArcGIS Online Map Viewer.

The user can click View In: ArcGIS Online Map Viewer to view the data layers in the browser. Once the data has loaded, sign in to your ESRI account, create an account for free, or click "Modify Map" to view the data, enable pop ups, and view related records.
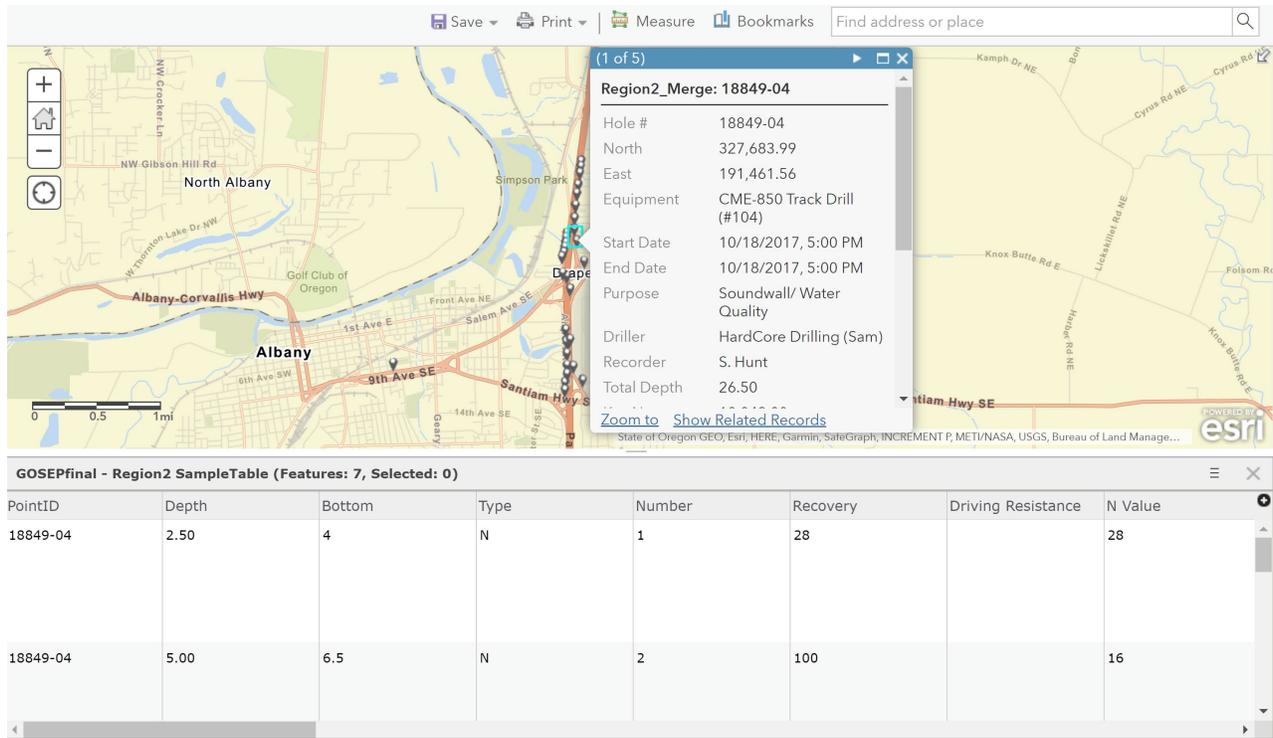
Figure 7: Show Related Records for point data displays soil information with depth of drilling.

Troubleshooting and FAQs:

Please make sure that once you have selected the pin tool on the location of interest, wait for the pop-up window to come up.

Q: The data related to the points is not popping up. What should I do?

A: The preferred browser for GOSEP is GOOGLE CHROME. Try opening the website with the chrome browser and refresh the page. Also, let the page allow pop-ups.

Q: The attachments are not loading. What should I do?

A: If not already using GOOGLE CHROME, try opening the website with the chrome browser and refresh the page. Otherwise, try to right click the attachment link and select "Open link in new tab".

Q: The home button on the left side of the screen is vanished and features are not working properly. What should I do?

A: Go to the Settings for the CHROME browser and try clearing your "Cookies and Cached images and files".