EARTHQUAKE RESILIENCE OF THE WESTERN POWERGRID:

DELINEATION OF ELECTRICITY POLES WITHIN POWERGRID SYSTEM (EUGENE, OR)

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INTRODUCTION

A catastrophic subduction zone earthquake and tsunami strikes the west coast of the United States every 300-500 years, and there is an approximately 30% of such an earthquake and tsunami occurring within the next 50 years [1]. A Cascadia Subduction Zone (CSZ) earthquake and tsunami would destroy infrastructure and electrical power systems in communities all along the west coast of the United States.

Estimating the performance of the entire western grid under the widespread damage from a CSZ earthquake and the hazards that follow (e.g., tsunami, fire, subsidence, and floods) is extremely challenging. No single method or tool is adequate to tackle this problem: an interdisciplinary understanding of power system operation, power system protection, power system analysis, geotechnics, earthquake engineering, mapping, and geospatial analytics is required in addition to informed methods of automating assumptions and complications of the power flow analysis of such a large electrical system.

BACKGROUND INFROMATION

This project is funded by the western electrical grid interconnect – commonly referred to as the WECC (Western Electricity Coordinating Council). This group encompasses the states of Oregon, Washington, Idaho, Montana, Wyoming, California, Nevada, Utah, Arizona, Colorado, and New Mexico (aka Western US Cities in the Western Power Grid).

The WECC will be adversely affected by a CSZ earthquake and subsequent tsunami, resulting in widespread damage along the coast. The webGIS tool: O-HELP Oregon Hazard Explorer for Lifelines Program, shows that along the west coast shaking severity could be VIII or higher on the Modified Mercalli Intensity scale for a CSZ event of magnitude 9.3, which corresponds to expected wide-scale destruction. In addition to the shaking threat, there are numerous subsidence, liquefaction, and landslide hazards all along the coast. Approximately 20 minutes after the CSZ event, the entire coast will likely be struck by a very large tsunami, which will completely devastate the coast and threaten the lives of up to 70,000 residents in addition to scores of tourists and seasonal visitors [1].

Approximately 70 to 100 miles off of the US west coast lies the 600 mile long Cascadia Subduction Zone (CSZ), formed where the Juan de Fuca plate dives under the North American plate at the rate of a few inches per year. But how frequently do CSZ events occur? Fig. 1 shows a time recurrence of magnitude 9 CSZ earthquakes. It is estimated that there is an approximately 10% chance of a magnitude 9 CSZ earthquake within the next 50 years, and an approximately 35% chance of a magnitude 8 earthquake within the next 50 years [1].

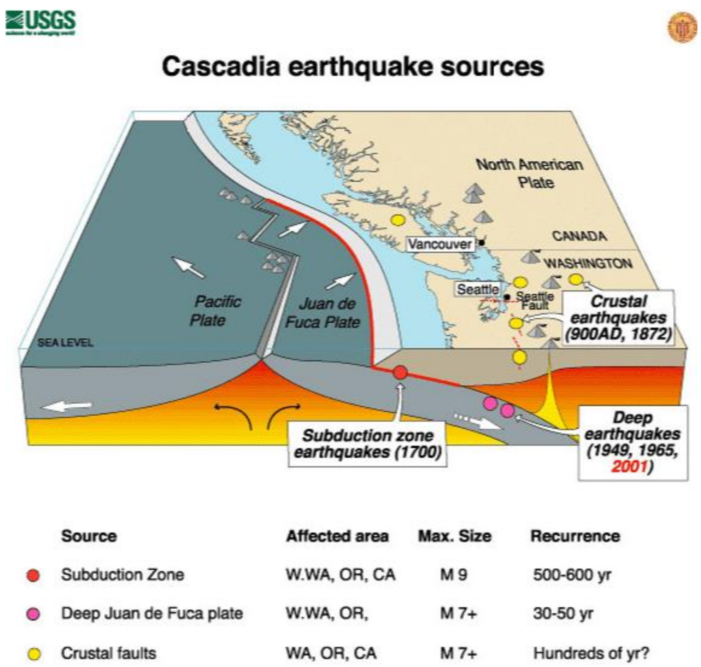

Figure 1.*Areas affected by a Cascadia Subduction Zone Earthquake* [2]

There is a lack of detailed research on the performance of electrical grids during and shortly after an earthquake, particularly from the perspective of electrical power flow and dynamic stability. Existing research focuses mostly on impacts to electrical equipment and studies of recovery time. The Oregon Resilience Plan estimates that recovery of the electrical system could take anywhere from 1 to 6 months, depending on the distance from the fault [1]. Nevertheless, these estimates are based on expert opinion and not – to date – on rigorous power flow studies, as power flow models and tools typically are not suited for incorporating damage and failure information. The existing Western Powergrid system in the

United States is extremely complicated therefore a simplified version of the grid system was used in this analysis specifically the WECC model, a 20,000 bus model.

OBJECTIVE

The objective of this project is to produce a python script that can be used to estimate the location of existing utility pole within the western powergrid system. The GIS project results should model the existing power grid system (bus and branch information) with new points that represent the estimated locations of power poles. For the purpose of this course, the poles will only be estimated for the Eugene area. This will be conducted by densifying the existing information provided in the buses and branches attribute tables constructed from information provided by the utility companies who are funding this research. The positioning of the power poles will be determined based on the voltage associated with buses and branches. In the end, the power poles points should linked back to an existing bus then a branch and ultimately a power station.

This portion of the project is a part of a larger project. The overarching goal of the *Earthquake Resilience of the Western Power Grid* project is to develop more advance power system performance estimating methods and tools to improve earthquake resilience by estimating the electrical power system lifeline impacts in the western electrical grid due to a Cascadia Subduction Zone earthquake.

The primary objectives of the research is to:

- Understand how CSZ earthquakes will impact the extent, distribution, and duration of the western electrical grid failure as a function of earthquake intensity and possible aftershocks.
- Develop a framework for the identification of critical grid locations and components that will aid decision makers and planners, and also be broadly applicable to any seismic zone in the US.
- Estimate expected initial load loss and load recovery time due to a major CSZ event.
- Explore impacts of Remedial Action Schemes (RAS) on grid performance and recovery.

Although this portion of the project does not encompass the whole process, it is important to understand the scope of the overall project and how this information will be used. The location of the poles will be used to gather the soil properties and peak ground acceleration values. This information will then be used to determine how the pole sites will react during an earthquake. Since the poles are linked to specific buses, the conditions of the poles sites after the earthquake could be used to determine if the branch remains functional after the event, therefore specific bus stations.

SITE DESCRIPTION

The site of interest in this investigation is Eugene, Oregon. Eugene is a city in Oregon, located on the Willamette River. As of the 2010 census, Eugene had a population of 156,185. It is located in Lane County and is the state's third most populous city. The area of Eugene is 40.54 mi².

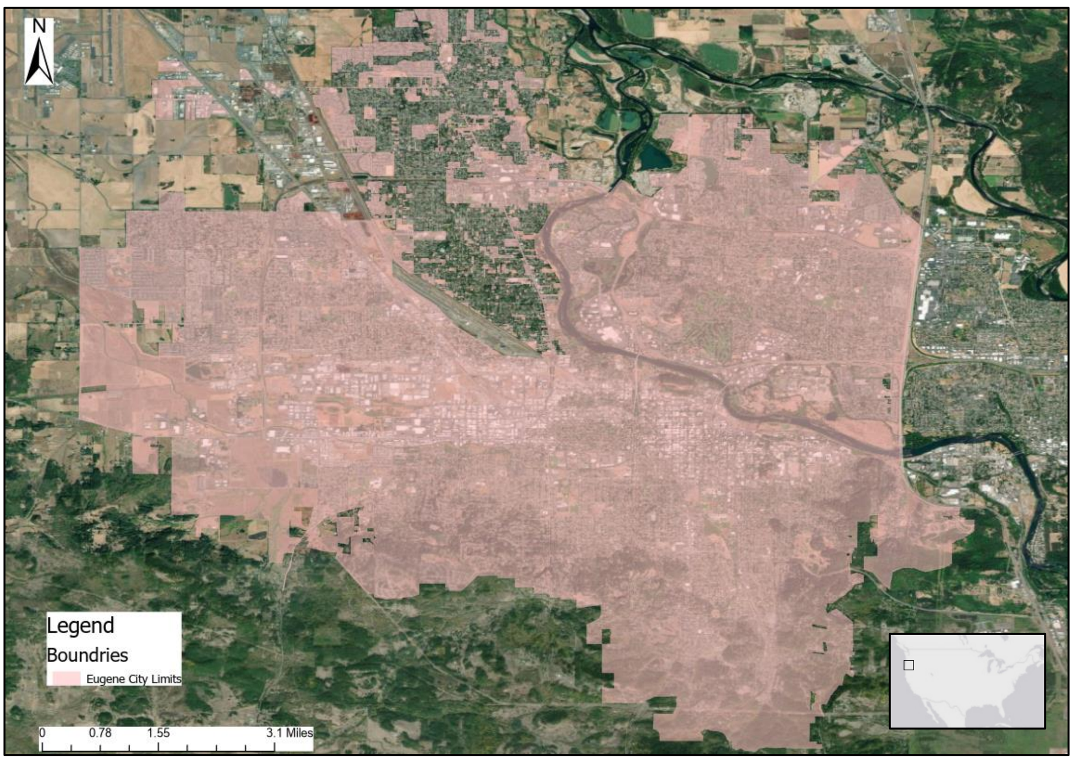

Figure 2. City of Eugene, Area of Interest

DATA RESOURCES

The geographical coordinate system used in this project was USA Contiguous Albers Equal Area Conic USGS version because it covers a large portion of the United States. This conic projection uses two standard parallels to reduce some of the distortion of a projection with one standard parallel. Although neither shape nor linear scale is truly correct, the distortion of these properties is minimized in the region between the standard parallels. This geographical coordinate system is the best option for this project because it ensure land masses that are extending in an east-to-west orientation is less distorted rather than those lying north to south direction.

Bus and branch data source

The bus and branch data used in this project was a synthetic grid. This synthetic grid is composed of a synthetic network, even though it is entirely fictitious, it is realistic and has many potential benefits for aiding power systems research and development. An important requirement in building synthetic power system models is that they match the size, complexity, and characteristics of actual grids [3]. The Western Electricity Coordinating Council (WECC) model (dataset used) is composed of roughly 20,000 bus model of the existing wester power grid system (Map 1). This model was produced using a similar method as shown in Figure 3. After the model was produced, a basic map showing the transmission line voltage and a voltage magnitude contour, shown in Figure 4.

The branch dataset tables consists of the following information: Number, Name, AreaName, NomkV, Vpu, kV, Vangle, SubLatitude, SubLongitude, LoadMW, LoadMvar, GenMW, GenMvar, ShuntMvar, ActG, ActB, AreaNumber and ZoneNumber Each of these perimeters will allow us to link the point to a branch and then to a specific power station. It also provided information about the voltage each unit experiences. The bus dataset tables consists of the following information: ObjectID, BusNumFrom, BusNameFrom, BusNumTo, BusNameTo, Circuit Status, BranchDeviceTypes, IsXF, R, X, B, LimitMVAA, LimitMVAB, and LimitMVAC. Each of these perimeters will allow us to link the branches to a specific power station.

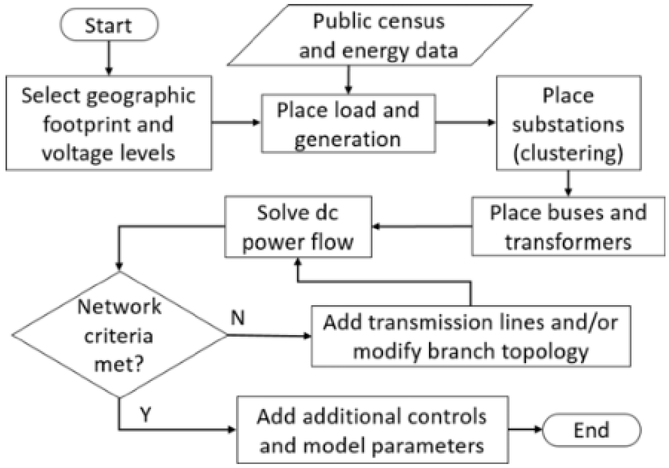

Figure 3. Procedure used to produce the WECC dataset, showing the transmission line voltage and a voltage magnitude contour

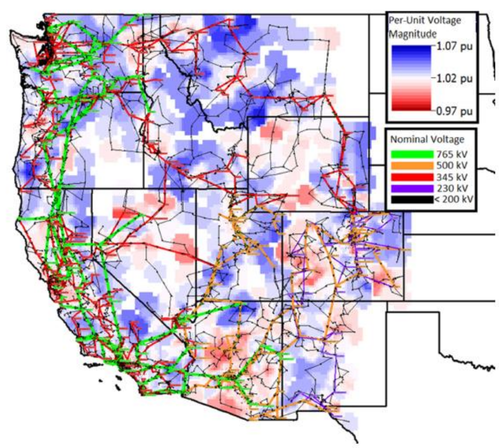

Figure 4. Oneline diagram for the synthetic 10 k grid, showing the transmission line voltage and a voltage magnitude contour

The geographical coordinate system for the bus and branches data was GCS WGS 1984. For the purposes of this project, it was reprojected into the USA Contiguous Albers Equal Area Conic USGS version because this project covers a large portion of the United States.

Peak Ground Acceleration (PGA) for Cascadia Subduction Zone

The peak ground acceleration for the Cascadia subduction zone was obtained from the USGS M9.3 Scenario Earthquake - Cascadia Megathrust - whole CSZ Characteristic largest M branch. The scenario was created May 2017 [4]. “Megathrust” earthquakes result from rupture of the principal interface between the subducting Juan de Fuca plate and the overriding North America plate. The geographical coordinate system for the PGA data was GCS WGS 1984. For the purposes of this project, it was reprojected into the USA Contiguous Albers Equal Area Conic USGS version because this project covers a large portion of the United States.

Geology of USA

The geological data used in this analysis was the *Generalized Geologic Map of the Conterminous United States*. This data set contains boundaries and tags for major geologic units in the conterminous United States. In addition to the polygons representing the areal extent of geologic units. It also identifies boundaries of metamorphic provinces, major faults, calderas, impact structures, and generalized limits of continental glaciation. This data depicts the geology of the bedrock that lies at or near the land surface, however it does not show the distribution of surficial materials such as soils, alluvium, and glacial deposits [5].

Voltage Spacing Information

The voltage information was gathered from professionals in the power utility industry, shown in Table 1. Based on the max value of each branch value, the spacing of the poles was determined.

Table 1. Voltage values used to determine the spacing of the branches to determine placement of power poles

Voltage Range (kV)	Type	Spacing (ft.)
1	Wood	300
13.8	Wood	300
18	Wood	300
20	Wood	300
24	Wood	300
115	Steel	500
138	Steel	500
161	Steel	500
230	Steel	800
345	Steel	1000
500	Steel	1000
765	Steel	1000

METHODOLOGY

This project was broken into three parts. Before anything could be completed, the various coordinate projections for all the layers were projected into the USA Contiguous Albers Equal Area Conic USGS version. Part one focuses specifically on recompiling the data and extracting the correct information from the branch and bus datasets. Part two focuses specifically on using the voltage information and delineating the branch lines to produce power pole locations. Part three focuses specifically on using the determined pole locations to find the soil type and pga values for the sites, therefore it can be used to determine how the sites would react to a 9.0 earthquake.

Part 1

This section of the project focused on using the existing bus and branch information. In the city of Eugene, there are 47 branches and 42 buses according to the WECC model. This process consists of linking the branch and bus datasets based on their *From* and *To* bus numbers, therefore the nominal voltages associated with each branch end is known. Once that was completed, the max nominal voltage was determined and applied to the specific branch. This values was used in part two to determine the spacing of the power poles along the branch. The process of producing this nominal voltage value is shown in Figure 5. After the max nominal voltage value was determined for each branch, the delineation of the pole powers was determined for each branch. This process consists of creating a new field and using a formula to determine the spacing based on voltage, shown in Figure 6. For all branches with a nominal voltage value ranging from 0 to 24 kV would be spaced at 300ft. from each other. For all branches with a nominal voltage value ranging from 24 to 161 kV would be spaced at 500ft. from each other. For all branches with a nominal voltage value ranging from 161 to 230 kV would be spaced at 800ft. from each other. For all branches with a nominal voltage value greater than230kV would be spaced at 1000ft. The script constructed for this section is provided in the Appendix.

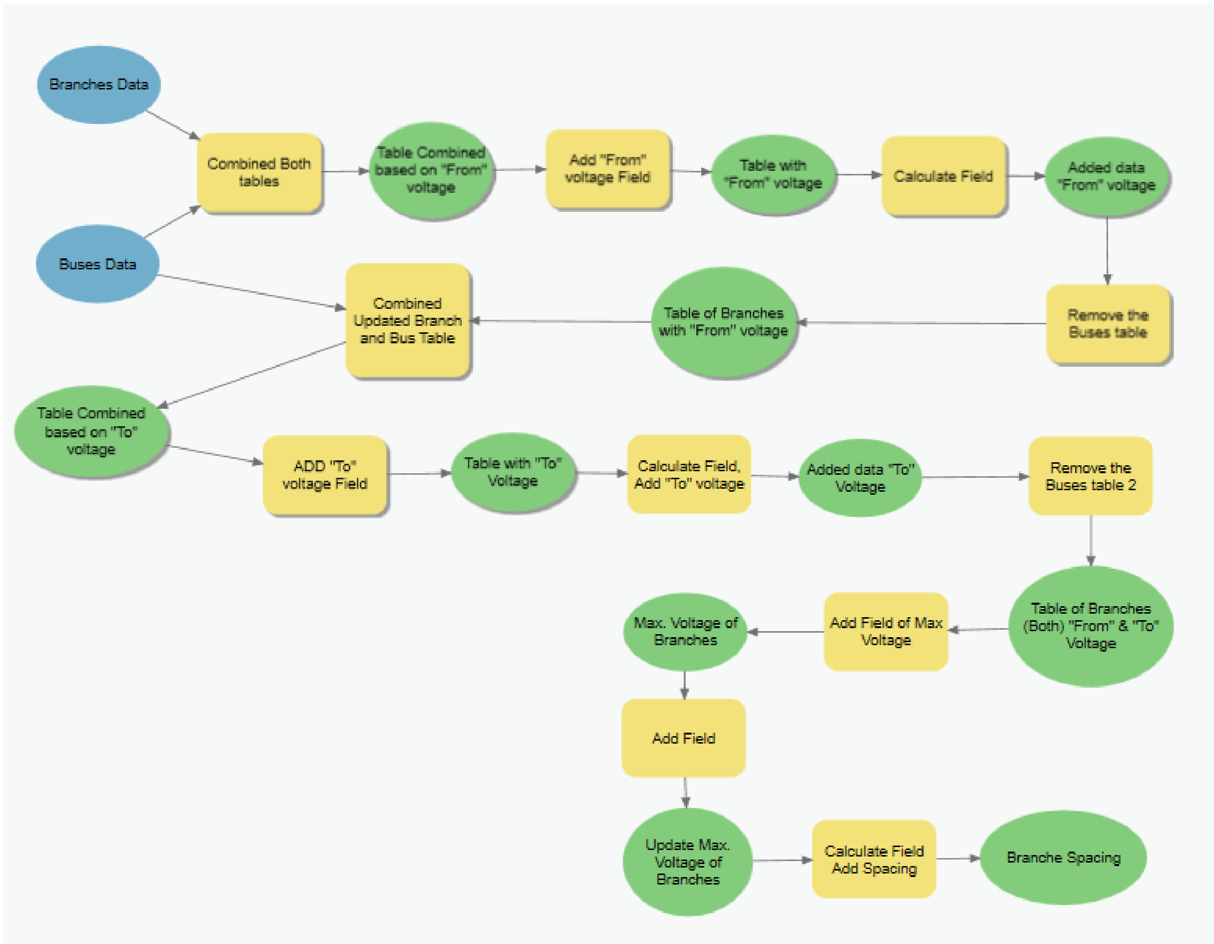

Figure 5. Model Builder of all the steps conducted in Part 1

```
Calspacing(!Max_Voltage!)
def Calspacing (Volt):
if Volt <= 24:
return 300
elif Volt <= 161:
return 500
elif Volt <= 230:
return 800
elif Volt > 230:
return 1000
```

Figure 6. Equation used to determine the spacing of the branches based on max nominal voltage

Part 2

This section of the project focused on using the determined spacing for each branch and generating specific points along the branch. The *generate points along a line* was used to produce points to represent the locations of the existing power poles. The spacing of the points were produced based on the distance determined in part 1. The script constructed for this section is provided in the Appendix.

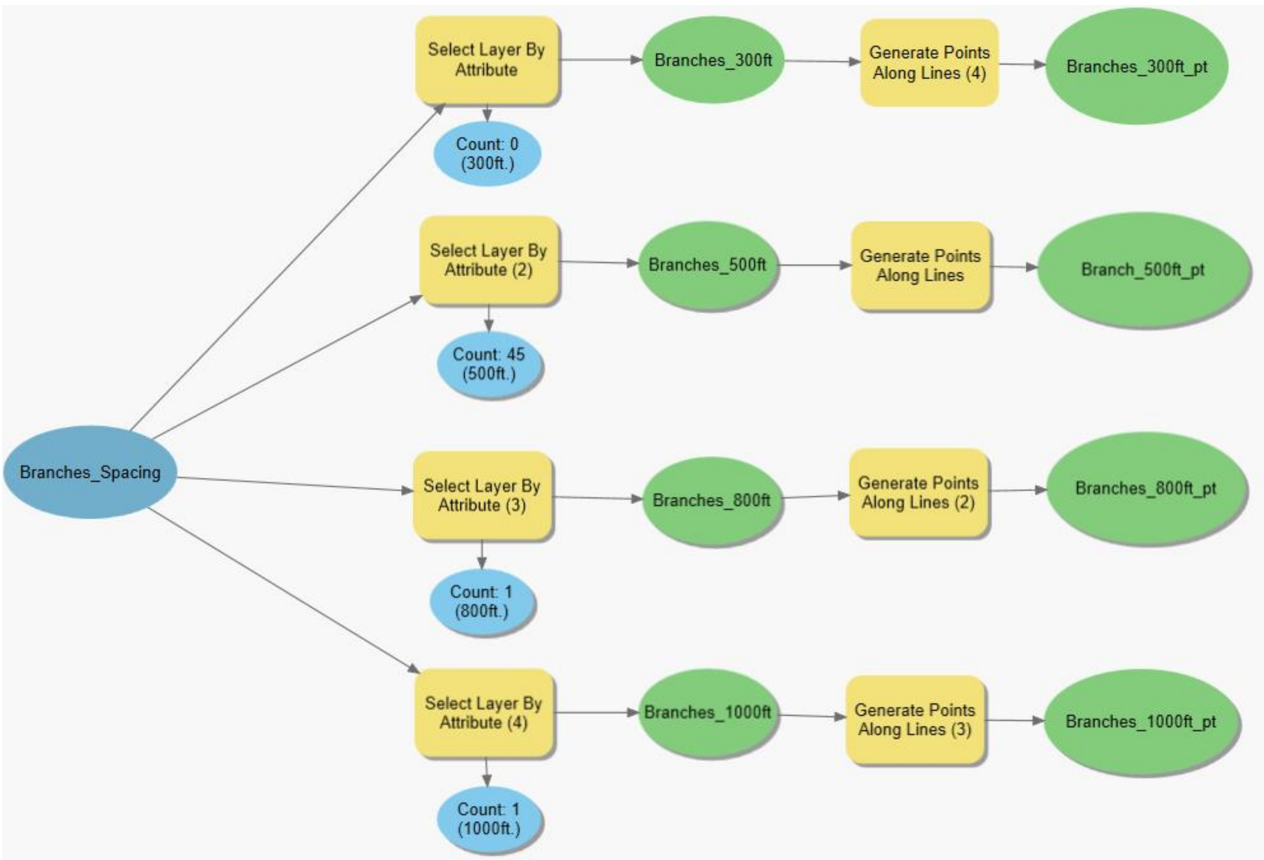

Figure 7. Model Builder of all the steps conducted in Part 2

Part 3

After the location of the power poles were determined, the pga and geology of the site was extracted from the *pga* raster and the *geology of the US* raster. This was done by using the *Extract values to Table* tool to determine the geology type and the *Extract Values to Points* tool to determine the respective pga value at the pole location.

RESULTS

For the City of Eugene, there is a total of 47 branches located inside the city, 45 branches were spaced at 500 ft., 1 branch was spaced at 800ft., and 1 branch was spaced at 1000ft. There was 1170 number of poles generated along the 47 branches, shown on Map 3. There was a total of 72 poles constructed for the 800 ft. spacing, a total of 860 poles constructed for the 500 ft. spacing and a total of 238 poles constructed for the 1000ft. spacing, shown on Map 4. The peak ground acceleration of the area ranged from 0.29 g to 0.44g (Shown in Percentage). The geology of Eugene is shown in Map 2.

FUTURE STEPS

After this step is completed, the next thing to do is collect DEM for the whole area. The DEM will then be used to determine the existing topography of the site. Information regarding frugality curves will be collected and used to compare how bus and power stations are impacted from PGA values and existing soil conditions. Considerations regarding liquefactions will also be considered and a liquefaction map will be imported to determine at risk areas. The end goal of this project is to create a visual for all this information gathered and found, similar to the OHELP map.

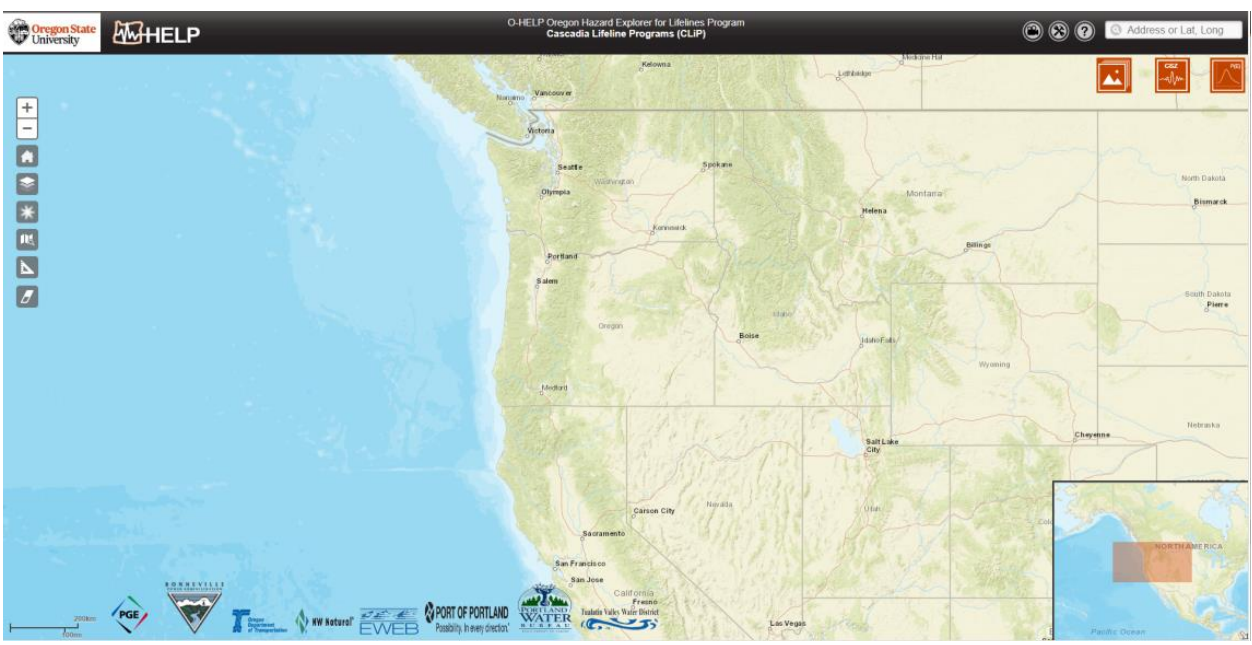

Figure 8. OHELP map created by OSU Geomatics Group

REFERENCES

[1] “The Oregon Resilience Plan,” Oregon Seismic Safety Policy Advisory Commission, Feb. 2013

[2] “Cascadia Subduction Zone.” Pacific Northwest Seismic Network, University of Washington, University of Oregon, USGS, ANNS, pnsn.org/outreach/earthquakesources/csz.

[3] Birchfield, Adam B., Ti Xu, and Thomas J. Overbye. "Power flow convergence and reactive power planning in the creation of large synthetic grids." IEEE Transactions on Power Systems 33.6 (2018): 6667-6674.

[4] “M 9.3 Scenario Earthquake - Cascadia Megathrust - Whole CSZ Characteristic Largest M Branch.” USGS Earthquake Hazards Program, 5 May 2017, earthquake.usgs.gov/scenarios/eventpage/bssc2014cascadia_sub0_m9p34_se/executive.

[5] Bush, Charles. “Generalized Geologic Map of the Conterminous United States.” ScienceBase, USGS, 27 Sept. 2011, www.sciencebase.gov/catalog/item/4f4e48dee4b07f02db54aa15.

APPENDICS

Part 1 Script

```python
import arcpy

# To allow overwriting the outputs change the overwrite option to true.
arcpy.env.overwriteOutput = False

# Local variables:
Branches_Data = "WECCApr2013_13hs2ap_branches_Lines"
Table_Combined_based_on__From__voltage = Branches_Data
Buses_Data = "WECCApr2013_13hs2ap_buses_Points"
Table_Combined__based_on__To__voltage = Buses_Data
Table_with__From__voltage = Table_Combined_based_on__From__voltage
Added_data__From__voltage = Table_with__From__voltage
Table_of_Branches_with__From__voltage = Added_data__From__voltage
Table_with__To__Voltage = Table_Combined__based_on__To__voltage
Added_data__To__Voltage = Table_with__To__Voltage
Table_of_Branches__Both___From_____To__Voltage = Added_data__To__Voltage
Max__Voltage_of_Branches = Table_of_Branches__Both___From_____To__Voltage
Update_Max__Voltage_of_Branches = Max__Voltage_of_Branches
Branche_Spacing = Update_Max__Voltage_of_Branches

# Process: Combined Both tables
arcpy.AddJoin_management(in_layer_or_view=Branches_Data, in_field="FromNumber", join_table=Buses_Data, join_field="Number", join_type="KEEP_ALL")

# Process: Add "From" voltage Field
arcpy.AddField_management(in_table=Table_Combined_based_on__From__voltage, field_name="From_Voltage", field_type="DOUBLE", field_precision="", field_scale="", field_length="", field_alias="", field_is_nullable="NULLABLE", field_is_required="NON_REQUIRED", field_domain="")

# Process: Calculate Field
arcpy.CalculateField_management(in_table=Table_with__From__voltage, field="WECCApr2013_13hs2ap_branches_Lines.From_Voltage", expression="!WECCApr2013_13hs2ap_buses_Points.Nom_kV!", expression_type="PYTHON3", code_block="")

# Process: Remove the Buses table
arcpy.RemoveJoin_management(in_layer_or_view=Added_data__From__voltage, join_name="WECCApr2013_13hs2ap_buses_Points")

# Process: Combined Updated Branch and Bus Table
```

```
arcpy.AddJoin_management(in_layer_or_view=Table_of_Branches_with__From__voltage,
in_field="ToNumber", join_table=Buses_Data, join_field="Number", join_type="KEEP_
ALL")

# Process: ADD "To" voltage Field
arcpy.AddField_management(in_table=Table_Combined__based_on__To__voltage, field_n
ame=""To" voltage", field_type="DOUBLE", field_precision="", field_scale="", fiel
d_length="", field_alias="", field_is_nullable="NULLABLE", field_is_required="NON
_REQUIRED", field_domain="")

# Process: Calculate Field, Add "To" voltage
arcpy.CalculateField_management(in_table=Table_with__To__Voltage, field=""To" vol
tage", expression="!To_voltage!", expression_type="PYTHON3", code_block="")

# Process: Remove the Buses table 2
arcpy.RemoveJoin_management(in_layer_or_view=Added_data__To__Voltage, join_name="
WECCApr2013_13hs2ap_buses_Points")

# Process: Add Field of Max Voltage
arcpy.AddField_management(in_table=Table_of_Branches__Both___From_____To__Voltage
, field_name="Max_Voltage", field_type="FLOAT", field_precision="", field_scale="
", field_length="", field_alias="", field_is_nullable="NULLABLE", field_is_requir
ed="NON_REQUIRED", field_domain="")

# Process: Add Field
arcpy.AddField_management(in_table=Max__Voltage_of_Branches, field_name="Spacing"
, field_type="DOUBLE", field_precision="", field_scale="", field_length="", field
_alias="", field_is_nullable="NULLABLE", field_is_required="NON_REQUIRED", field_
domain="")

# Process: Calculate Field Add Spacing
arcpy.CalculateField_management(in_table=Update_Max__Voltage_of_Branches, field="
Spacing", expression="CalSpacing(!Max_Voltage!)", expression_type="PYTHON3", code
_block="def Calspacing(Volt):

 if Volt <= 24:
    return 300.0
 elif (161 <= Volt and Volt > 24):
    return 500.0
 elif (230 <= Volt and Volt > 161):
    return 800.0
 else:
    return 1000.0")
```

Part 2 Script

```python
import arcpy

# To allow overwriting the outputs change the overwrite option to true.
arcpy.env.overwriteOutput = False

# Local variables:
Branches_Spacing = "WECCApr2013_13hs2ap_branches_Lines"
Branches_300ft = Branches_Spacing
Branches_500ft = Branches_Spacing
Branches_800ft = Branches_Spacing
Branches_1000ft = Branches_Spacing
Count__0__300ft__ = "0"
Count__45__500ft__ = "45"
Branch_500ft_pt = r"D:\ARCGIS_PRO\2019_NSF_WesternPowerGrid\04_Data\WesternUS\99_CurrentMap\Final_Arc_Project\Final_Arc_Project.gdb\WECCApr2013_13hs2ap_branches_Lines_GeneratePointsAlongLines2"
Count__1__800ft__ = "1"
Branches_800ft_pt = r"D:\ARCGIS_PRO\2019_NSF_WesternPowerGrid\04_Data\Branches_800ft_pt.shp"
Branches_1000ft_pt = r"D:\ARCGIS_PRO\2019_NSF_WesternPowerGrid\04_Data\WesternUS\99_CurrentMap\Final_Arc_Project\Final_Arc_Project.gdb\Branches_1000ft_pt"
Count__1__1000ft__ = "1"
Branches_300ft_pt = r"D:\ARCGIS_PRO\2019_NSF_WesternPowerGrid\04_Data\Branches_300ft_pt.shp"

# Process: Select Layer By Attribute
arcpy.SelectLayerByAttribute_management(in_layer_or_view=Branches_Spacing, selection_type="SUBSET_SELECTION", where_clause="Spacing = 300", invert_where_clause=""
)

# Process: Select Layer By Attribute (2)
arcpy.SelectLayerByAttribute_management(in_layer_or_view=Branches_Spacing, selection_type="SUBSET_SELECTION", where_clause="Spacing = 500", invert_where_clause=""
)

# Process: Generate Points Along Lines
arcpy.GeneratePointsAlongLines_management(Input_Features=Branches_500ft, Output_Feature_Class=Branch_500ft_pt, Point_Placement="DISTANCE", Distance="500 Feet", Percentage="", Include_End_Points="")

# Process: Select Layer By Attribute (3)
arcpy.SelectLayerByAttribute_management(in_layer_or_view=Branches_Spacing, selection_type="SUBSET_SELECTION", where_clause="Spacing = 800", invert_where_clause=""
)
```

```
# Process: Generate Points Along Lines (2)
arcpy.GeneratePointsAlongLines_management(Input_Features=Branches_800ft, Output_F
eature_Class=Branches_800ft_pt, Point_Placement="DISTANCE", Distance="800 Feet",
Percentage="", Include_End_Points="")

# Process: Select Layer By Attribute (4)
arcpy.SelectLayerByAttribute_management(in_layer_or_view=Branches_Spacing, select
ion_type="SUBSET_SELECTION", where_clause="Spacing = 1000", invert_where_clause="
")

# Process: Generate Points Along Lines (3)
arcpy.GeneratePointsAlongLines_management(Input_Features=Branches_1000ft, Output_
Feature_Class=Branches_1000ft_pt, Point_Placement="DISTANCE", Distance="1000 Feet
", Percentage="", Include_End_Points="")

# Process: Generate Points Along Lines (4)
arcpy.GeneratePointsAlongLines_management(Input_Features=Branches_300ft, Output_F
eature_Class=Branches_300ft_pt, Point_Placement="DISTANCE", Distance="300 Feet",
Percentage="", Include_End_Points="")
```