Creation of a Revised Site Specific Liquefaction Potential Map Utilizing Geographic Information Systems (GIS) Technology and ArcGIS® Software

A Senior Project
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the Faculty of the Earth and Soil Sciences Department
California Polytechnic State University, San Luis Obispo

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of the Requirements for the Degree
Bachelor of Science

by

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APPROVAL PAGE

TITLE: Creation of a Revised Site Specific Liquefaction Potential Map Utilizing Geographic Information Systems (GIS) Technology and ArcGIS® Software

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ABSTRACT

The purpose of this project was to make improvements on an existing GIS-based liquefaction susceptibility map that was published in 2007 by the County of San Luis Obispo. Upon analysis, we concluded that the County liquefaction map was based entirely on the County's geology data for the region and did not take into account any other factors such as; proximity to fault lines, soil properties or the presence of water. We are of the opinion that both proximity to water and soil morphology should be taken into account when devising a liquefaction potential map, as liquefaction will not occur without the presence of water and, will not occur in the presence of certain soil conditions (for this project's site specific map, the proximity to active fault lines is assumed). One guiding parameter of the project was to only obtain and edit layers of GIS map information found free of charge on the World Wide Web. The "free download" rule limited the amount of GIS information available; however we were successful in finding all of the information we needed to make a GIS-based liquefaction potential map. After downloading the information into our desktop, we employed ArcCatalog, ArcMap and the Tools in the ArcGIS® ArcEditor 9.2 Desktop software published by ESRI Inc. to complete the map, carefully choosing the layers of information deemed necessary by research into the property of soils and geology and how they relate to the liquefaction phenomenon. Online training and an Evaluation Edition of the software were available through Cal Poly, free of charge, to students interested in the technology.

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INTRODUCTION

Liquefaction has been the cause of countless millions of dollars of damage to buildings and infrastructure throughout the history of the civilized world. It is an issue that has come to the forefront in recent years as scientists and engineers strive to understand the “what”, “why” and “where” of soils liquefaction so better efforts could be made towards mitigation.

For this project we have gained a basic knowledge of map making technology utilizing the GIS-based software, ArcGIS® ArcEditor 9.2, by ESRI Inc. Concurrently, we pursued the latest available information on the soil liquefaction phenomenon so we would know what data to look for in the data selection process. We will go into more detail about the selection processes within the “Literature Review” and “Materials and Methods” chapters.

Liquefaction

What is liquefaction? Liquefaction is a phenomenon where a saturated soil suddenly behaves as a liquid when a force is applied to it. Have you ever been to the beach and slammed your hand on the saturated sand at the tide line and the sand appears to liquefy under the pressure? Or your foot sinks into the sand as you run along the shoreline? You have just witnessed a mini-liquefaction event. Take that same concept, but this time the force exerted is the force of an earthquake in the magnitude of a 6+ on the Richter

Scale; an entire geographic area may liquefy. When the soil loses its cohesiveness and thus loses its war against gravity, it can flow, causing settlement, lateral spreads and/or sand boils as shown in figures 1 through 4 on pages 3 through 6.

Why does liquefaction occur? Liquefaction can only occur in a saturated soil; a soil that has every pore within the soil structure filled with water. When gravity is the only force exerted on a soil at rest, the water pressure between the soil pores is low and the natural structure of the soil is maintained. An earthquake event applies force to a geographic area causing the pore pressure between the soil particles in that area to increase to the point that the soil looses its natural cohesion and every soil particle becomes suspended in fluid causing the soil to act as a fluid. When this phenomenon occurs the soil can flow out in all directions due to the combined forces of gravity and earthquake shaking velocity. (Arias, A., 1970, Kayen and Mitchell, 1997)

Where does liquefaction occur? Liquefaction only occurs in saturated soils and only occurs where certain soil conditions and soil structures are present. We chose Oceano, California to be the subject of the revised liquefaction potential map because of a history of liquefaction in the area and a report done in 2004 about the liquefaction phenomenon that occurred during the 6.5M, San Simeon, California earthquake of December 22, 2003. The report was titled: *Liquefaction-Induced Lateral Spreading in Oceano, California, During the 2003 San Simeon Earthquake, Thomas L. Holzer et al(2004).* Specific guidelines for determining a liquefaction hazard zone as described by the California Geological Survey (CGS), will be covered in more detail in the “Literature Review” chapter.

Figure 1. Overturned apartment complex buildings in Niigata, Japan (1964). Photo from the University of Washington Liquefaction web site: http://www.ce.washington.edu/~liquefaction/html/quakes/niigata/niigata.html

Figure 2. Liquefaction settlement damage caused by Loma Prieta Earthquake, San Francisco, California (1989). Photo downloaded from USGS web site - Liquefaction Hazards Program, Liquefaction Hazard Maps, San Francisco Bay area: http://earthquake.usgs.gov/regional/nca/qmap/

Figure 3. Lateral spread damage caused by Nisqually Earthquake (2001). Damage located at the Capitol Interpretive Center, Deschutes Parkway, Olympia, Washington. Photo downloaded from the PEER Report "*Some Observations of Geotechnical Aspects of the February 28, 2001, Nisqually Earthquake in Olympia, South Seattle, and Tacoma, Washington*":

http://peer.berkeley.edu/publications/nisqually/geotech/liquefaction/lateralspread/index.html

Figure 4. Liquefaction sand boil damage caused by the Loma Prieta Earthquake at the Oakland Airport, Oakland, California (1989). Photo from the University of Washington Liquefaction web site: http://www.ce.washington.edu/~liquefaction/selectpiclique/lomaprieta89/sandboil3.jpg

GIS-Based Mapping Technique

GIS-based maps of today represent a huge technological jump in map making application. A big difference is that GIS maps are dynamic. While you can look at a standard wall map, navigation map or globe and see where features are located and even measure approximate distances between them, you can not do much more than that. With a GIS map however, you are in charge, you can "tell" the map what you want to see. With the help of your browser or GIS software application you can zoom in and out to see different areas with more or less detail, you can decide what features you want to see, quantify them, decide how they are to be symbolized and, most importantly, you can access a database of information about all the features shown on the map by a click of your mouse. Everyday more and more maps are created by professional map makers, private and public organizations, and everyday people; many of the maps being posted and shared for everyone to see, use, and in the case of some maps, modify. The GIS-based map making technique involves three processes: Defining a problem, choosing the data for analysis to build your map, and then deciding on the GIS-based application to use to build and display your map.

Defining the problem to be analyzed. The "problem" we are defining here is the topic of our project: To Create a Revised Site Specific Liquefaction Potential Map utilizing Geographic Information Systems (GIS) Technology and ArcGIS® Software.

Choosing the data for the project analysis. A GIS map consists of one or more Data Frames with each Data Frame representing a complete map. For instance, a map with an inset would have two Data Frames; one for the main map and one for the inset. A Data Frame contains a collection of thematic layers that represent real world objects such as topography, streets, elevations, demographics, etc.; the list is extensive and gets longer every day. On a GIS map, features have a location, shape, and a symbol. Location is the where on the map. Shapes consist of lines (rivers, streets, contours, map grids), points (cities, XY map coordinates) and polygons (areas, counties, states, countries) as shown in Figure 5 on page 9. Symbols are used to represent features such as road signs and attributes. To make a GIS map, you can add as many layers as you want. The extent of the layers we added to create the map will be discussed further in the "Materials and Methods" chapter.

Choosing the GIS-based application to use to build the map. For this project we chose to create the site specific GIS-based liquefaction potential map of Oceano, California using ArcGIS® ArcEditor 9.2 by ESRI Inc.

Figure 5. In this GIS map of South America, as copied from the online course - *Learning* ArcGIS® *Desktop by ESRI*; countries are represented as polygons, rivers and grids are represented as lines and cities are represented as points.

LITERATURE REVIEW

The literature review entailed a twofold process: 1. Establish a basic foundation of knowledge about map making with GIS-based operational software and processes.
2. Establish a strong understanding of the liquefaction phenomenon by review of free online data consisting of published studies, reports, articles, books and journals.

GIS-Based Operational Software Literature Review

The original intent of the project was to explore and compare the functionality of the ArcGIS® Editor Desktop software, ESRI Explorer Online browser and ESRI Explorer Desktop for creation of a GIS-based, site specific liquefaction potential map. It was imperative that the maps we created with each method included all of the information and relationships we determined were necessary to sufficiently display the information we needed to convey. The literature review for the GIS-based operational software portion of the project included over 35 hours of instruction to complete the following courses online: Introduction to ArcGIS® Explorer Online, Learning ArcGIS® Desktop, Creating, Editing and Managing Geodatabases for ArcGIS® Desktop, and Creating and Editing Geodatabase Topology for ArcGIS® Desktop.

Liquefaction Literature Review

In preparation for this project we reviewed many recent articles, periodicals, reports and scientific studies on the causes of liquefaction, the mechanics of liquefaction and the prediction methods used to predict liquefaction hazards. The prediction tools include several formula and graph based tools utilizing earthquake magnitude, peak velocity, distance to fault lines, depth to water table, acceleration, intensity at depth and site-specific soils investigations of soil characteristics to depth. A complete list of references is available at the back of this report.

Liquefaction potential prediction tools. The first tool for predicting liquefaction potential was proposed by Seed and Idriss (1971) in their "Simplified Procedure". This procedure compared size of the force (earthquake magnitude or loading) as a Cyclic Stress Ratio(CSR), with the ability of the soil to resist liquefaction expressed as the Cyclic Resistance Ratio(CRR). The Cyclic Resistance Ratio is determined from lab tests using the equivalent clean sand standard penetration resistance of the soil or the equivalent clean sand normalized cone tip resistance of the soil to arrive at a Factor of Safety (FS) used to predict the possibility of free-field liquefaction. The Factor of Safety is expressed by the following equation: FS = CRR / CSR. In this equation a Factor of Safety (FS) greater than 1 indicates that the liquefaction resistance of the soil exceeds the earthquake loading, and therefore liquefaction would not be expected. A soil with an FS less than 1 would have liquefaction potential ranging from low to high as the factor gets smaller. A soil with an FS of 0 would have the highest liquefaction potential. According to Holzer et al. (2004), the Simplified Procedure is based on the nature of the property of a soil and is the standard method used in the United States for predicting liquefaction potential to this date.

The liquefaction resistance of a soil is directly related to its age and structure. The majority of liquefaction hazards are associated with saturated sandy and silty soils of low plasticity and density that have been deposited in recent geologic history; soils such as unconsolidated alluvial and fluvial deposits of the Holocene to late Pleistocene age in the Quaternary Period. According to Walker et al (2009), the Pleistocene-Holocene boundary is dated at 11,700 calendar years (+/- 90 years) before A.D. 2000, the boundary being based on the retreat of the last ice age. Liquefaction typically occurs in these cohesionless sands, silts, and fine-grained gravel deposits left over from the retreating ice age and/or deposits of lakes, rivers, streams and sloughs (and/or artificially placed uncompacted fills) of recent history. The low density soils have not had the necessary time to consolidate and become more cohesive. Their pore spaces are larger, can hold more water, and have less resistance to seismic force, making their soil structure prone to failure when seismic stress is applied. Soils with a clay content (particle size < 0.005mm) greater than 15% are generally not considered susceptible to soil liquefaction. In rare cases, some gravelly soils are vulnerable to liquefaction if encapsulation by impervious soils prevents rapid dissipation of seismically induced pore pressure.

The second tool proposed for predicting liquefaction potential was the Liquefaction Potential Index (LPI), proposed by Iwasaki et al. (1978). They assumed that the severity of liquefaction is proportional to the thickness of the liquefiable layer, proximity of the liquefiable layer to the surface, and the amount by which the FS is less than 1.0. Because surface effects from liquefaction at depths greater than 20 meters are rarely reported, they limited the computation of LPI to depths ranging from 0 to 20 meters. According to Holzer et al. (2004), this method is not widely used in the United States compared to the Simplified Procedure. In their opinion, however, the LPI has major advantages over the Simplified Procedure. With the LPI, a whole geographic area can be analyzed to 20 meters in depth, an advantage, as liquefaction events can and do occur in soil layers at depths exceeding 15 meters. It should be noted that to implement this method, site specific soil testing is required to conduct the standard penetration tests (SPT) and the cone penetration tests (CPT) necessary to create a ratio with the soil properties to a depth of 20 meters, earthquake loading probability and the FS for the area. As expressed by David Kun Li et al. (2006), liquefaction risk is low if the LPI is less than 5, high if the LPI is greater that 5 and very high if the LPI is greater than 15, with 100 being the maximum.

Since 1982, there have been several other liquefaction potential formulas that have been proposed by scientists in this field of study, however the FS derived from the Simplified Procedure and the LPI remain as the two tools most widely used be researchers and scientists for predicting liquefaction potential. It should be noted that both of these prediction tools require site specific soil testing which is not a part of this project.

Criteria for mapping liquefaction hazard zones. California is far ahead of the curve in seismic hazard mapping in the United States having passed The Seismic Hazards Mapping Act of 1990. The act was passed shortly after the 1989 Loma Prieta Earthquake of San Francisco caused millions of dollars of damage due to soil liquefaction and structural failure. One part of the act required the State Geologist, Chief of the Department of Conservation's California Geological Survey (CGS), to designate seismic hazard zones. The following is a paraphrased summary of the Liquefaction Hazard Zone guidelines published by the CGS in the *"Special Publication 118 – Recommended Criteria for Delineating Seismic Hazard Zones in California*, *dated May 1992, Revised April 2004" – Pages 3-5:*

1. Any areas known to have experienced liquefaction during historical earthquakes.

2. Any areas of known uncompacted fills that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where soil testing has been done and the data indicates that the soils are potentially liquefiable. The following are four key types of information that are generally available: a) Geologic information for the area. b) Recorded ground water depths less than 40 feet from surface. c) Existing borehole data with the FS and/or LPI already computed indicating a potential for liquefaction. d) Existing seismic data that indicates the ground motion parameters for the area are met for liquefaction to occur.

4. Areas where existing subsurface data is not sufficient for quantitative evaluation of the liquefaction hazard. In these areas the CGS recommends that a secondary liquefaction risk assessment be required through the application of the following geologic criteria as quoted:

> "(a) Areas containing soil deposits of late Holocene age (current river channels and their historical floodplains, marshes and estuaries) where the M7.5-weighted peak acceleration"(estimated weighted average of PGA) "that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the anticipated depth to saturated soil is less than 40 feet; or

> (b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the anticipated depth to saturated soil is less than 30 feet; or
> (c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the anticipated depth to saturated soil is less than 20 feet.

As previously stated, saturated soil is an essential ingredient in the phenomenon of liquefaction occurrence. The other essential ingredient of liquefaction occurrence is the composition of the soil layers that lie under the surface. Extensive studies have been conducted on this subject with reference here being made to a report done by Moss et al.(2006). In this report, published by the Pacific Earthquake Engineering Research Center (PEER), a collection of over 500 case histories covering the last three decades of earthquake events were reviewed and analyzed, with 188 case histories ultimately being inputted in their data base for their study. There are many factors addressed in their report besides presence of saturated soil and the properties of underlying soils; factors such as plasticity, liquefiable layer thickness, soil cavity expansion properties, cyclic stress ratios, earthquake magnitude, etc., all factors that require field and laboratory testing, which is not a part of this report. We did however utilize the liquefaction data contained in their report to arrive at cutoff points for determining very high to high liquefaction potentials for the map. We did this to supplement the criteria as specified by the CGS in their Special Publication 118 used by the team to arrive at the cutoff points for moderate to low liquefaction potential. This process will be discussed further in the “Discussion” portion of this report.

MATERIALS AND METHODS

This purpose of this project was to take the knowledge we gained in our studies of soil science and the knowledge gained by research of the phenomenon of liquefaction to create a site specific liquefaction potential map on a desktop computer with free GIS-based information and GIS software.

Project materials utilized by team. The software we used was ArcGIS® 9.2 ArcEditor Desktop by ESRI Inc. We were informed by ESRI that, if we were to buy this software, the cost would be $7,000. However, when we enrolled in the "*Learning ArcGIS Desktop for ArcGIS 9.2-9.3* (offered free of charge to Cal Poly students), we accepted a free 60-day Evaluation Edition of the software that was immediately sent to us for download on the project computer. The project computer we used was an HP with a Pentium 4 processor, Windows 2002 XP Professional platform with 1GB of RAM. When the software arrived, we completed over 35 hours of online training to be able to use the software necessary to make the maps for this project.

We explored using ArcGIS® Explorer Online and ArcGIS® Explorer Desktop to make the required maps, but ran into issues with both programs. The issues with ArcGIS® Explorer Desktop were twofold; the software required an upgraded graphics card for the desktop computer being used for this project and would have involved an expense that we did not budget for. Secondly, the software did not have the tools required to make the quality of map that we wanted to represent our project. The issues with

ArcGIS® Explorer Online were twofold also; the program did not have the tools we needed to complete and present the maps in the level of professionalism we required, and secondly we were limited by the extent of map layers available, as the software does not allow the user to download their own map information into a layer.

General map making methods utilized by the team. The general map making method implemented by the team consisted of the following steps:

- Defining the problem. What is the purpose of the map?
- Researching online data assumed by the team to be of use to create the maps required.
- Downloading the map data layers into the project desktop then moving the files into ArcCatalog (the map storage platform of the software) for use with ArcMap (the map making platform of the software). A full description and jpg copy of all downloaded maps for this project are located in the Appendices.
- Applying our knowledge of soil properties and liquefaction to quantify and/or categorize the data into groups that met the needs of the project; colorizing then categorizing data to help with viewing, creating new names for all the groups, categories, Data Frames and layers for ease of understanding and readability.
- Layering the data in the Data Frame for determination of the optimal presentation qualities, adjusting aspect and zoom to the desired presentation level then locking the aspect ratio in place.
- Editing the data using the ArcEditor Tools to Buffer, Combine, Clip, etc.
- Adjusting transparency of layers to allow information to "bleed" through to other layers for optimal presentation qualities.
- Adding and adjusting annotation as required or choosing to display embedded map annotation or both.
- Deciding on layout templates to use and executing transfer of data to layout of choice.
- Adding a secondary Data Frame with the layer information for utilization of an inset map or a comparison map as required by project.

- Applying all the previous steps for map creation to the second Data Frame for compilation of the inset or comparison map.

- Determining location and style of legends, north arrows and map scales - changing scale and extent of units to be used in scale icon, then resizing all icons to fit the map, adding heading names to legend and colorizing units as required for readability.

- Adding title to map, including font and color adjustments.

- Adjusting color of Data Frame backgrounds for optimal viewing.

- Saving map to desktop Geodatabase while making a TIFF copy for inclusion in the senior project report documents.

Materials and Methods Utilized in Creation of All Project Maps

Site specific liquefaction potential map for Oceano, California. There were two limiting factors for creation of the revised site specific liquefaction potential map. First, we were limited to the GIS-compatible files we could find free of charge on the internet. Second, we were limited by the fact that soil testing was not a part of this project. That being said, we are of the opinion the map we created displays the areas of higher potential for liquefaction in Oceano, California more accurately than the existing geology driven, GIS-based, liquefaction susceptibility map produced by the County of San Luis Obispo Planning and Building Department in 2007. Hours were spent researching available data, downloading the data into the project desktop, and then applying our knowledge of liquefaction, soils properties, geology and physics to "edit" the information for the ultimate presentation of the revised map.

The following are the layers and attributes we chose for map inclusion to create the revised liquefaction potential map for Oceano, California:

1. USA Topographic map – We added the USA Topographic Map available from ESRI to serve as the base map to build all of the upcoming map layers upon. The topographical map was added for map enhancement purposes only.

2. Locations of sand boils and lateral spreads in Oceano – We plotted the historic locations of the 2003 liquefaction event points and lines on both maps, the 2007 map and the revised map, per the event locations as referenced in the U.S. Geological Survey study conducted by Holzer et al. (2004). On the 2007 map the locations of the sand boils and lateral spreads were all shown to be within the "Medium Liquefaction Susceptibility" area. We were of the opinion that the plotted locations of sand boils and lateral spreads should have fallen within the "Very High Liquefaction Susceptibility" area on the map. On the new map, the plotted areas of liquefaction do fall within the revised "Very High Liquefaction Potential" area.

3. Streams and waterbodies – We added streams and waterbodies to the original map and utilized ArcEditor Tools to create a 60-foot buffer zone around them to represent the distance water could migrate in an earthquake event. Saturated soil is a key component of mapping liquefaction hazard zones per Item #2 of Special Publication 118 outlining the CGS criteria. In Special Publication 118, the CGS considers any groundwater within 40 feet of the surface a potential liquefaction hazard component. In the opinion of the team, if the CGS considers that water may migrate up to 40 feet vertically against the forces of gravity during an earthquake then by all means water migration occurring laterally should be taken into account also. We increased the potential migration distance from 40 feet to 60 feet, an arbitrary distance for mapping purposes, due to lateral migration horizontally out from a water source not having to fight the forces of gravity to flow.

4. Elevation Data – We added two sources of elevation data: Digital Elevation Modeling (DEM) Raster files and 5 meter contour line shapefiles. Raster files and shapefiles are differing types of files that can be "read" by the ArcMap mapping platform used in ArcEditor. Plotting elevation of an area was critical to extrapolate the surface distance to groundwater; the lower the surface elevation, the closer to groundwater. Additionally, soil areas on a slope tend to move down hill with the force of gravity during a liquefaction event. With the elevations inputted, the relative slope of an area could be determined based on elevation change over distance. We obtained the relative groundwater elevation from the data charted in the 2004 USGS report on lateral spreading in Oceano. Knowing distance to groundwater is essential for creating an accurate Soils Liquefaction Potential Map.

5. Arroyo Grande Valley Groundwater Basin – This layer was added to show the extent of the groundwater basin that lies under Oceano. This layer did not contain depth to groundwater elevation information. That information was provided by the report done by the Holzer group in 2004.

6. San Luis Obispo County Geology data – We added the layer of geology data available from San Luis Obispo County to obtain the geology information we needed to compare with the liquefaction susceptibility information on the original map and to highlight the geologic age and makeup of the Oceano area. This data layer contained the age, boundaries, scientific nomenclature and locations of the geologic units for the Oceano area.

7. Soils Data – We added the NRCS soils morphology data for the Oceano area available from the Department of Agriculture. This layer contained the boundaries, locations and names of the soils within the study area. The names of the soil types provided the information we needed to categorize the soils by their vulnerabilities to liquefaction based on the known composition of sands, silts and clays. According to the USGS, the majority of liquefaction hazards are associated with saturated sandy and silty soils of low plasticity and density that have been deposited in recent geologic history. Liquefaction typically occurs in cohesionless sands, silt, and fine-grained gravel deposits. Soils with a clay content (particle size < 0.005 mm) greater than 15% are generally not considered susceptible to soil liquefaction as the clay particles add cohesion to the soil structure while infiltrating the pore spaces between the grains, all serving to resist the free flow of water required for liquefaction to occur. We utilized the soils composition triangle as shown on page 50 to determine which soils types would be prone to liquefaction per the NRCS data.

8. FEMA flood data– We downloaded this layer to understand the extent of recently laid alluvial deposits. Per Perkins and Boatwright (1995), certain factors such as saturated, recently deposited alluvium or un-compacted fill, can amplify earthquake shaking. The USGS also states on their web site, http://earthquake.usgs.gov/regional/nca/qmap/, that shallow alluvial deposits will amplify shaking and increase the possibility of liquefaction occurring.

GIS-based liquefaction/geology comparison map. The data layers for the 2007 Liquefaction Susceptibility Map and Geology Map were downloaded to the project desktop from the SLODataFinder, located at lib.calpoly.edu. We chose a layout in ArcMap with the option for two Data Frames, then moved the shapefiles into the ArcMap program; the liquefaction file to Data Frame #1 and the geology file to Data Frame #2.

After downloading the shapefiles, we added the waterbody data layer to both Data Frames, we chose which attributes to display for both layers, categorized the attributes in both layers; applying separate color themes (choosing colors for the individual attributes that would prove the theory that the 2007 liquefaction map was based on the geologic age attributes of the geology map). To finalize the maps we chose legend templates, added the north arrow, scale and acknowledgement annotation. We then saved our map to our Geodatabase and as a TIFF file that can be viewed in Figure 6 on page 23. Please refer to Table 1 on page 24 to view the accompanying geologic age chart for reference.

Creation of base map and 60-foot buffer zone for water features map. To create the base map we opened the map we had already formatted for the comparison map shown in Figure 6, we enlarged the window for the liquefaction map and shrunk the window for the geology map. With the Tools of ArcMap we added the name "**2007 Liquefaction Susceptibility Map for Oceano, California**" at the top of the main map, creating a rectangular frame with background color. To further enhance the map presentation, we wanted to add a map layer that showed streets with topographic features. We used ArcCatalog and connected to the ESRI GIS server to pick the topographical map we wanted to use, the USA Topographical Map, and added the topographical map data to the Data Frame. We proceeded to add the data layer for streams from the SLODataFinder, first to the desktop, then, with the Add Data Tool, we moved the shapefiles from ArcCatalog to the ArcMap Data Frame we were working with (the transfer method we used on all added map data). We then changed the name of the streams layer from "nhd_streams_sloco" to "Streams", changed the line color of the streams to match the waterbodies, moved streams and waterbodies to the top of the Data

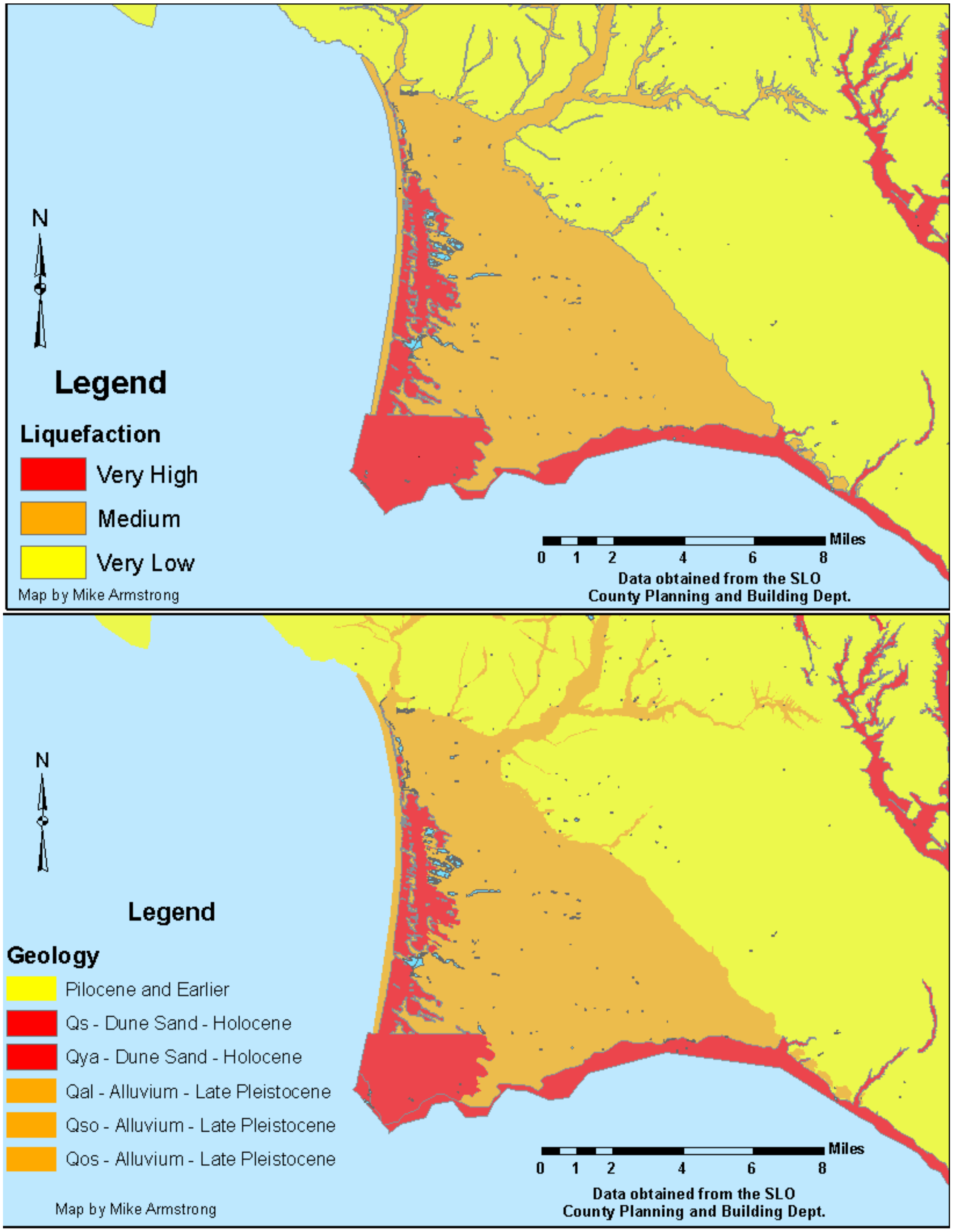
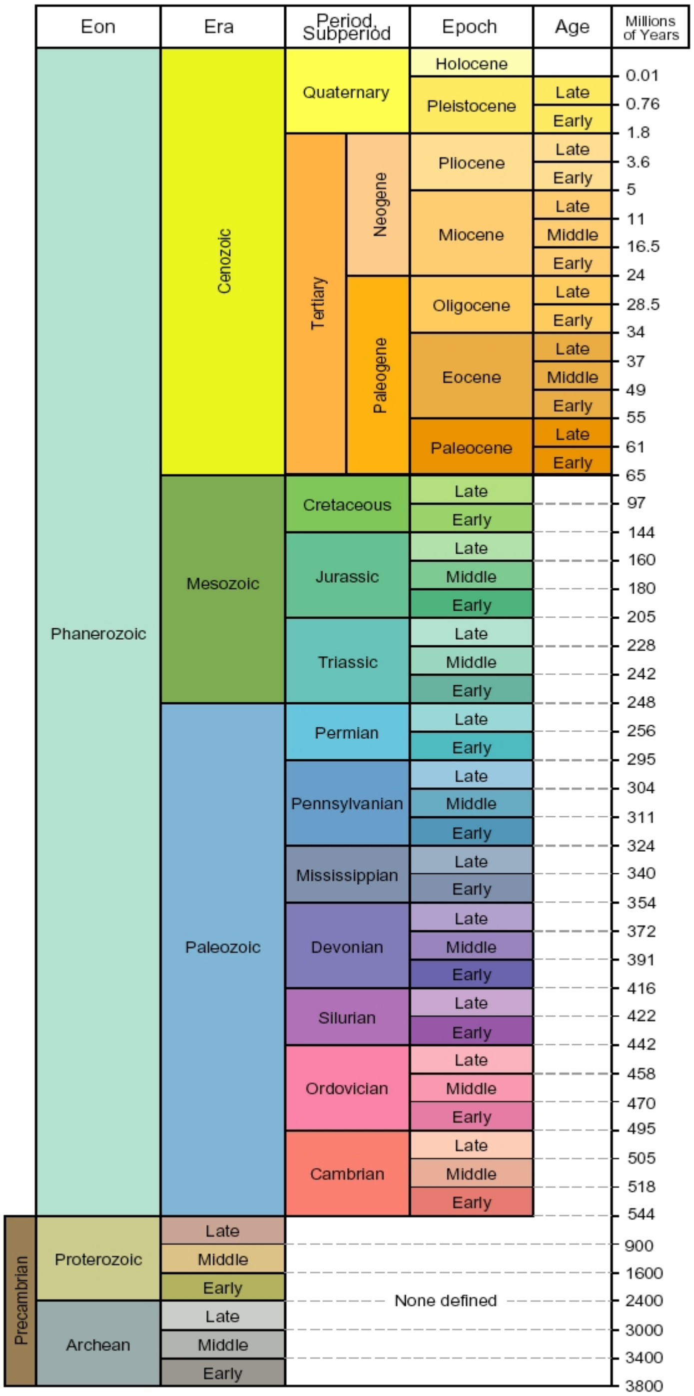


Figure 6. GIS-based comparison maps we created utilizing the data available from the County of San Luis Obispo Planning and Building Department. The geology data as shown in the lower map and the liquefaction data as shown in the upper map are identical. This shows that the data for the liquefaction map was extrapolated from the age of geologic units data contained in the geology map shapefile.

Table 1. Geologic age chart as referenced in the comparison map. The orange on the geology comparison map, coded Qal, Qos and Qso, represents geology from the late Pleistocene period. The red on the geology comparison map, coded Qs and Qya, represents geology from the Holocene period. The yellow represents all earlier periods of geologic history. This graph was downloaded from the Carleton College Science Education Resource Center and was credited by them to the USGS.



	Eon	Era	Period	Subperiod	Epoch	Age	Millions of Years
	Phanerozoic	Cenozoic	Quaternary		Holocene		0.01
					Pleistocene	Late	0.76
						Early	1.8
			Tertiary	Neogene	Pliocene	Late	3.6
						Early	5
					Miocene	Late	11
						Middle	16.5
						Early	24
				Paleogene	Oligocene	Late	28.5
						Early	34
					Eocene	Late	37
						Middle	49
						Early	55
					Paleocene	Late	61
						Early	65
		Mesozoic	Cretaceous		Late		97
					Early		144
			Jurassic		Late		160
					Middle		180
					Early		205
			Triassic		Late		228
					Middle		242
					Early		248
		Paleozoic	Permian		Late		256
					Early		295
			Pennsylvanian		Late		304
					Middle		311
					Early		324
			Mississippian		Late		340
					Early		354
			Devonian		Late		372
					Middle		391
					Early		416
			Silurian		Late		422
					Early		442
			Ordovician		Late		458
					Middle		470
					Early		495
			Cambrian		Late		505
					Middle		518
					Early		544
Precambrian	Proterozoic	Late	None defined				900
		Middle					1600
		Early					2400
	Archean	Late					3000
		Middle					3400
		Early					3800

Frame layers to facilitate the continued visibility of the streams and waterbodies in all instances. We moved the topographical map to the bottom of the layers as this data layer is used for background only. We added points for the sand boils and lines for the lateral spreads then labeled them for reference. We added the annotation “Oceano” then adjusted the scale for the Data Frame, locking the aspect and saving the map.

With Data Frame #1 completed we directed attention to Data Frame #2 containing the geology map. We resized the map to make the Data Frame an inset map. We deleted all the geology data layers in the Data Frame then proceeded to download the San Luis Obispo County boundary layer from the SLODataFinder using the techniques already described above. We downloaded a California County base map shapefile from the State of California website. We added the annotation for Oceano, changed the data frame background color and changed the line and shape color of California and SLO County to match each other. The map, titled **“2007 Liquefaction Susceptibility Map for Oceano, California”** as illustrated in Figure 7 on page 26, was saved at this point to use as a “base map” for all the future maps made for this project.

Taking the base map as shown on page 26, we applied the Buffer Tool in ArcMap to add a 60-foot buffer zone around every water feature. We did this to represent the extent of possible migration of water out from a water feature into liquefiable soils during an earthquake event contributing to liquefaction; a working hypothesis of this project. We completed the map by revising the acknowledgements, name of the map and the legend, saving this reference map as **“60-Foot Buffer Zone at Water Features”** per the processes previously explained. The map can be viewed in Figure 8 on page 27.

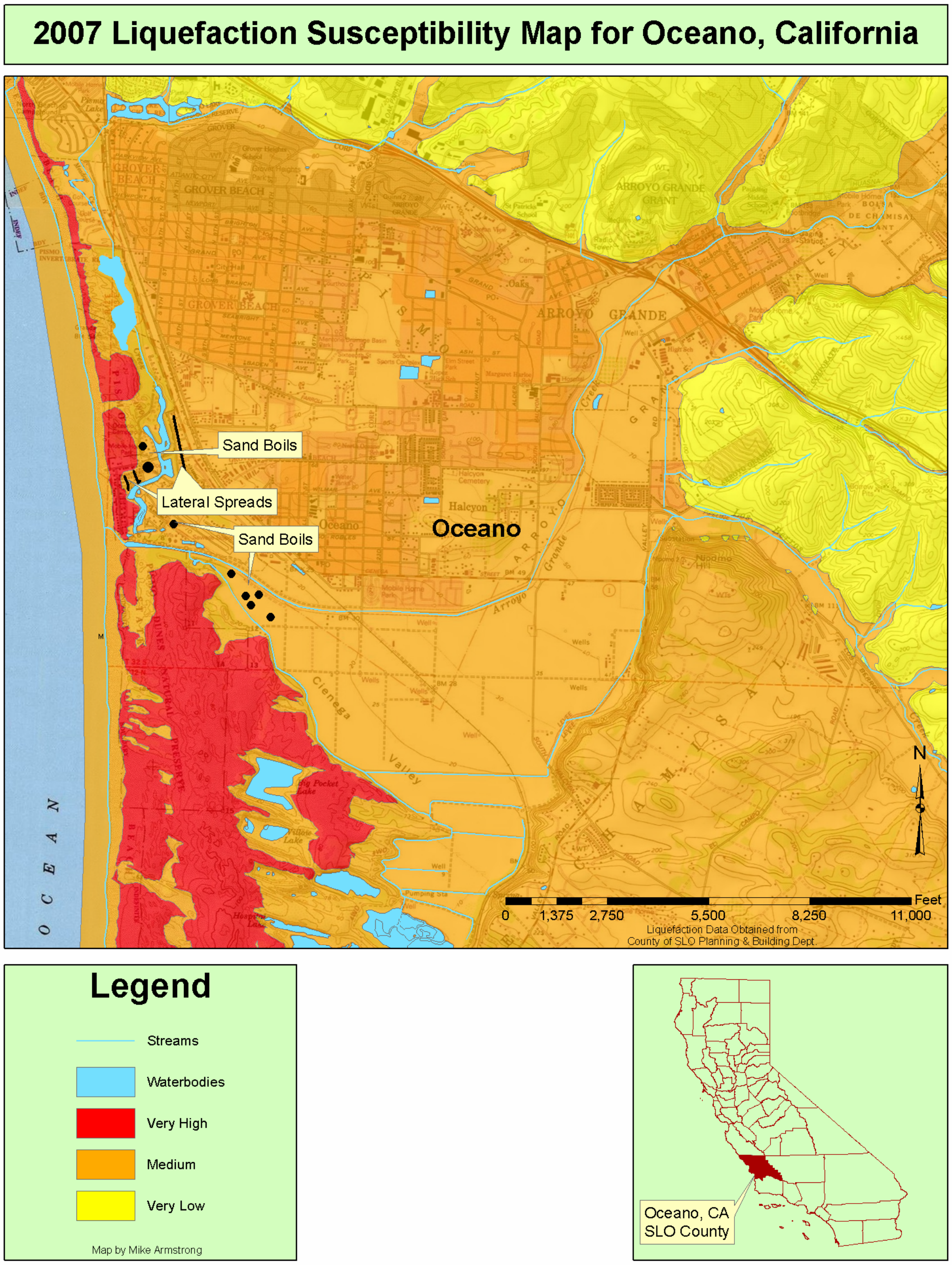


Figure 7. This is the map created for use as the "base map" for all of the future project map creations. We utilized the same County shapefile data as shown in the liquefaction/geology comparison map in Figure 6 on page 23; the difference being we have zoomed in on Oceano specifically, adding a topographical base map and a new Legend.

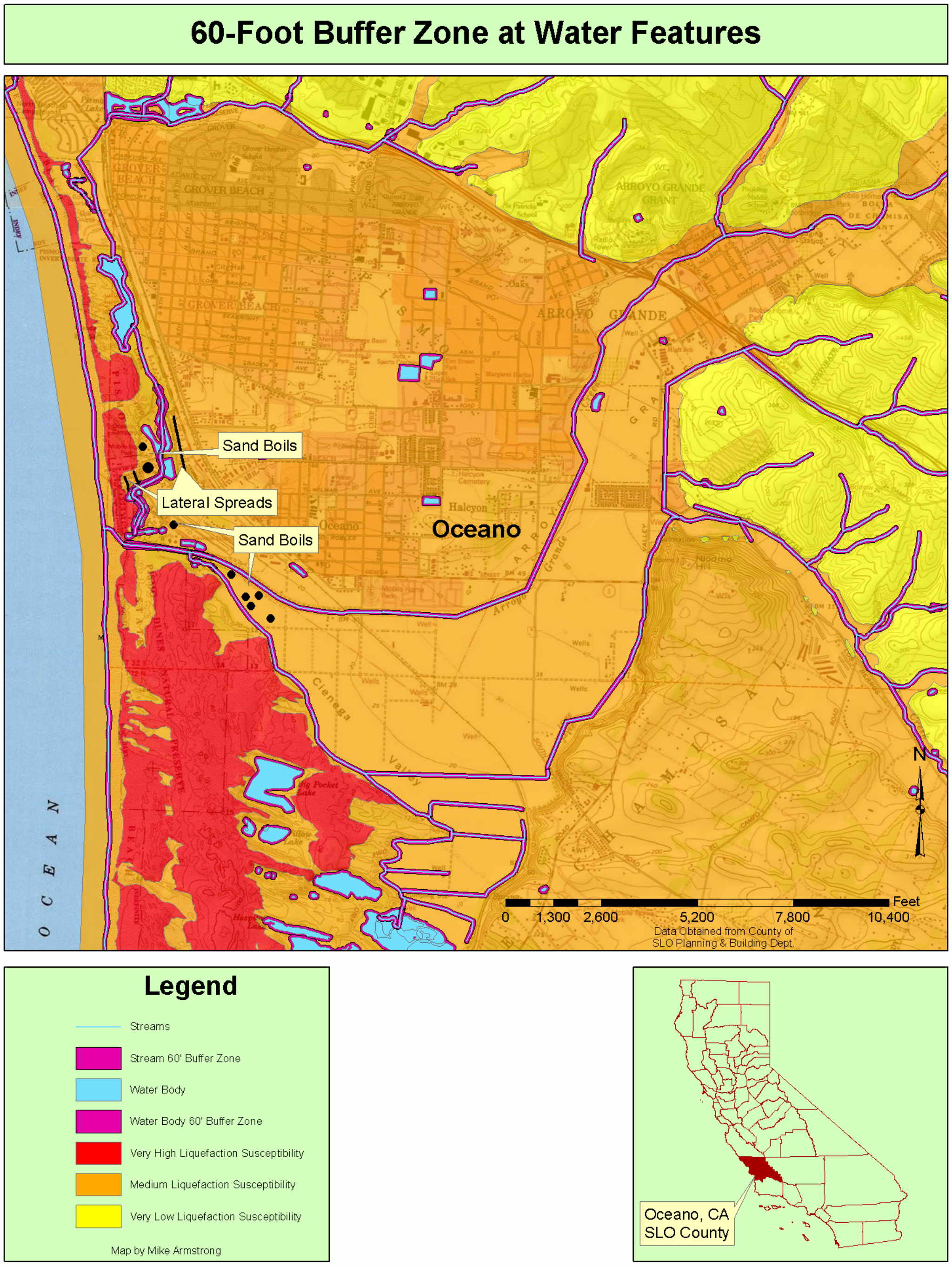


Figure 8. 60-Foot Buffer Zone Map with areas of liquefaction shown. Note that all manifestations of liquefaction occurred outside of the 60-foot buffer zones. An enlarged map of the extent of the buffer zones can be viewed in Figure 13 on page 40.

FEMA flood zone and historic flood zone reference maps. To create the FEMA map we opened the base map developed previously by the team and added the FEMA shapefile obtained from SLODataFinder into Data Frame #1 using all the processes previously described. After turning off the liquefaction potential information in Data Frame #1, we categorized the flood map data according to Flood Zones; Very High Flood Risk to Low flood Risk and Historic Flood Plain. We then assigned colors to the attributes, adjusted the transparency, moved the flood data layer below the water features layers, created a new legend, changed the acknowledgements, named the map **"FEMA Flood Zones and Historic Flood Plain Map"** then saved the map as a reference tool. This map can be viewed in the "Discussion" section; page 51 in Figure 18.

Arroyo Grande Valley groundwater basin map. We downloaded the shapefile for San Luis Obispo County groundwater basins from SLODataFinder to Data Frame #1 of the base map. After turning off all the data layers except the water features and topographical map, we moved the data layer below the water features, categorizing the basins according to name for determination of the basin name under Oceano. After determining the name, we removed all other basins so as to display the basin under Oceano only. We colored the attribute, renamed it, added a blue background, adjusted the transparency, added a new legend, revised the acknowledgments, changed the map name to **"Arroyo Grande Valley Groundwater Basin"** then saved the map as a reference tool. This map can be viewed in the "Discussion" section; page 42 in Figure 14.

<u>**Soil classification maps**</u>. We downloaded the shapefile from SLODataFinder containing the data for San Luis Obispo County NRCS soil classifications to Data Frame #1 of our base map. After turning off all the data layers except the water features and the topographical map, we moved the data layer below the water features. We chose "soil name" to categorize the data. Using the Information Tool we determined all of the soil types within the borders of the map that fell into the medium to very high range of liquefaction potential as illustrated on our previous map. We saved a second copy of the map to illustrate two scenarios, one scenario showing the separate soil types individually colored and one scenario with the soil types color coded by liquefaction susceptibility. After arranging the soil types of Oceano in our legend from sandy to silty clay loam, we colorized each map separately. On the first map, as illustrated in Figure 9 on page 30, the soil types are randomly colored to show the area boundaries of each soil type. On the second map, as illustrated in Figure 10 on page 31, we colorized the soil types as follows: Red for sand and sandy soils including the sandy loams, tan for loams and silty sands, considered to have medium to high liquefaction potential and yellow for all other classifications representing a very low liquefaction potential. We derived the classification criteria from the definition of soils susceptible to liquefaction referenced by the USGS. Noting that the lower sand boils occurred in the Mocho fine sandy loam and the Mocho Variant fine sandy loam, we changed the color of these two classifications from tan to red then adjusted the transparency of the soil data layer, resized the new legend, revised the acknowledgments, changing the map names to **"NRCS Soil**

Classification Map for Oceano, California" and "Liquefaction Susceptibly Map Utilizing NRCS Soil Classifications" respectively, saving the maps as reference tools.

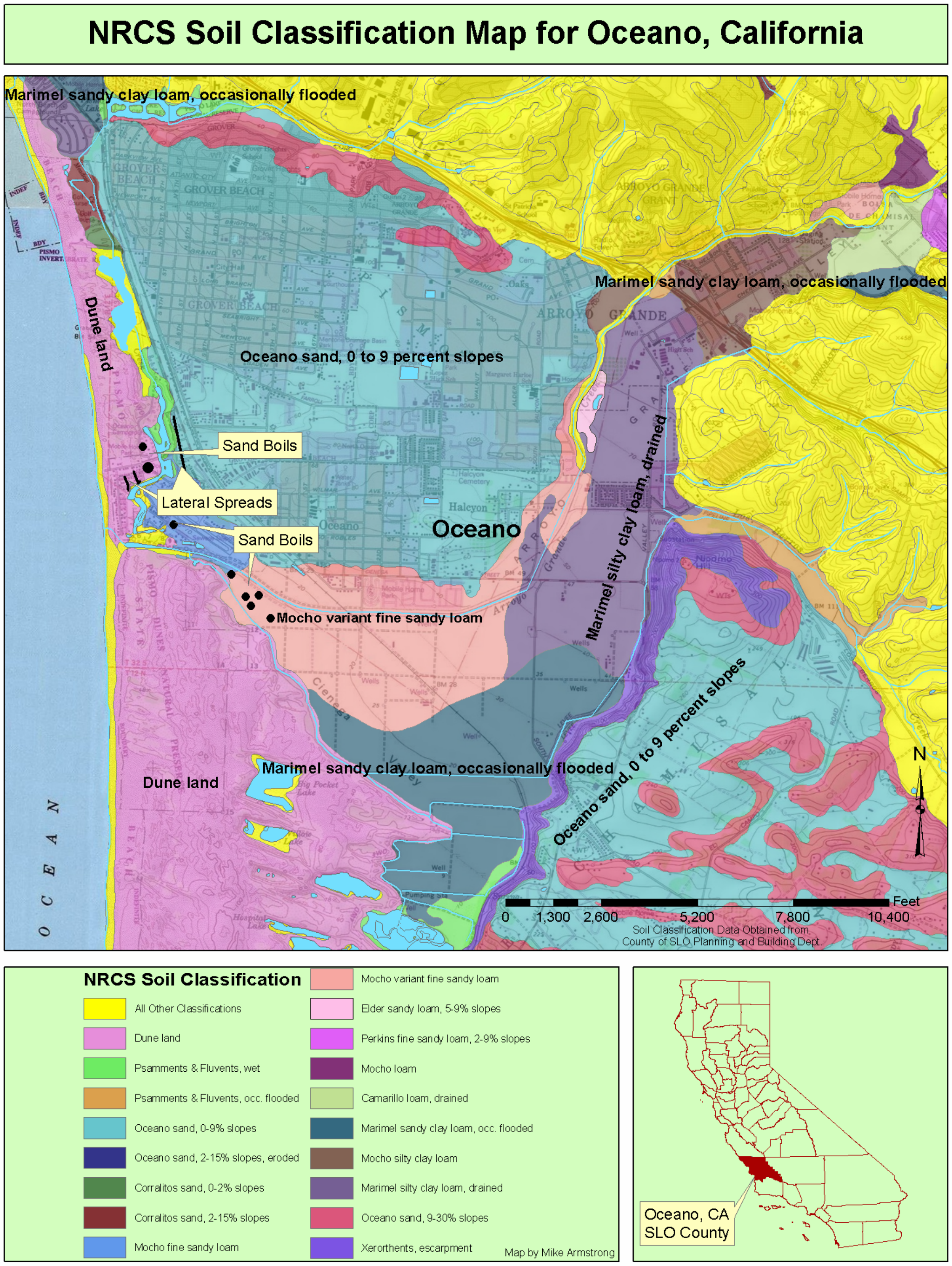


Figure 9. NRCS soil classification map with random colors delineating separate areas of differing soils types in Oceano, California.

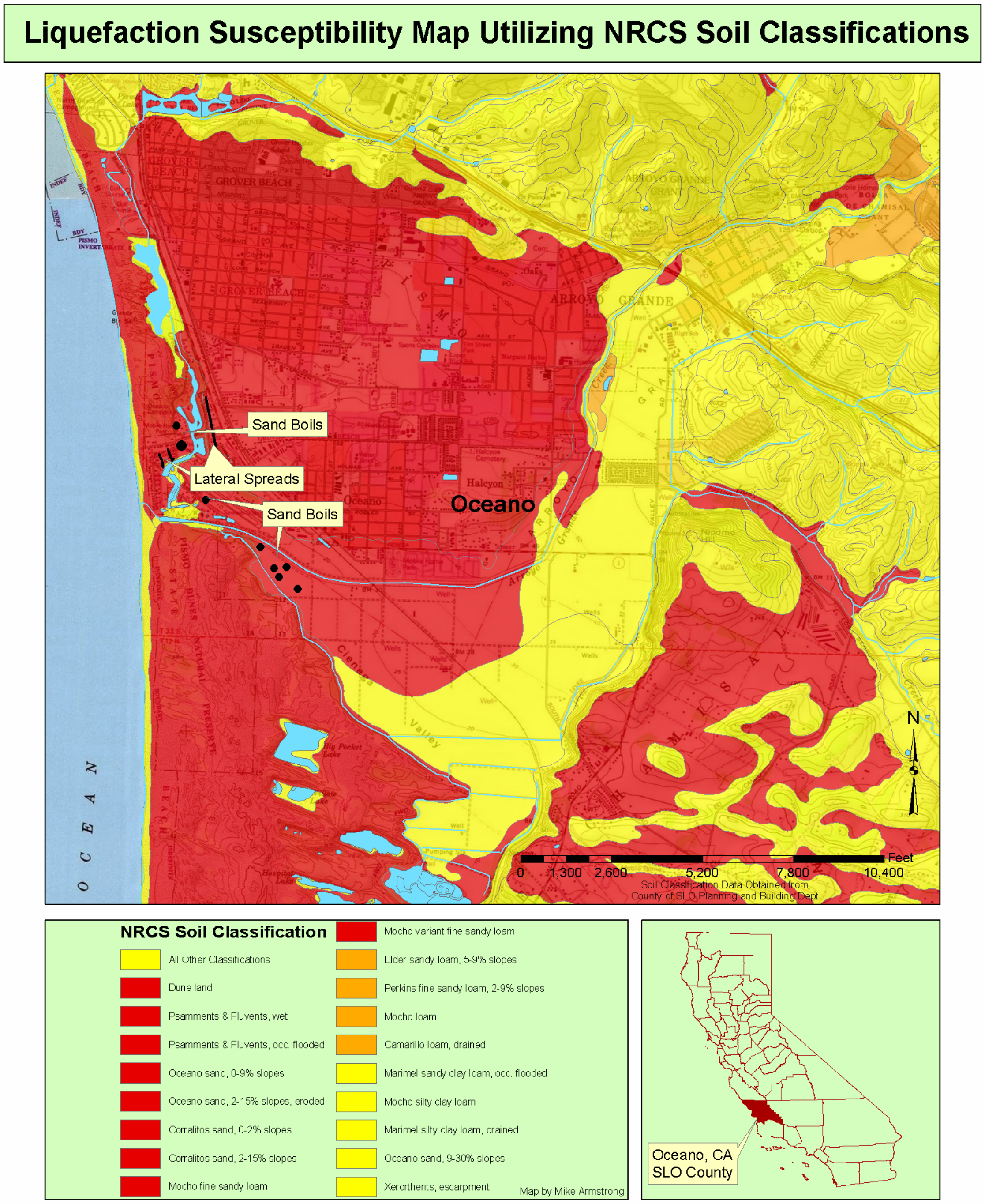


Figure 10. Soil classifications for Oceano, with soil types colorized to help show liquefaction potential based on soil composition: Red for very high liquefaction potential. Orange for moderate to high liquefaction potential. Yellow for low to very low liquefaction potential.

Surface elevations map of Oceano. We downloaded the composite county elevation raster file data from SLODataFinder to add to Data Frame #1 of the base map. After turning off all the data layers except the water features and topographic map, we utilized the ArcMap Properties Tool to switch the classification category from Stretched to Classified in order to display elevation as a unit of feet above sea level. We knew we wanted to show elevation breaks in 3-foot intervals so we counted the number of breaks we needed for the display and manually inputted the classification breakdown to range from 0 feet to 60 feet (Liquefaction is generally thought to occur in the upper 60 feet of soil so we only considered up to 60 feet with 3-foot breaks). We assigned 0 feet to Sea Level for display purposes and made it "hollow" so you could still see the ocean through the layer. We spent some time experimenting with color combinations to determine the most desirable for our map. We then added the attributes, renamed the layer, adjusted the transparency, added a new legend, revised the acknowledgments, changed the map name to **"Surface Elevations Map for Oceano, California"** then saved the map as a reference tool. This map can be viewed in the "Discussion" section; page 44 in Figure 15.

Geology map for Oceano. We downloaded the shapefile from SLODataFinder containing the data for the Geology in San Luis Obispo County to add to Data Frame #1 of the base map. After turning off all the data layers except the water features and Topo map, we moved the data layer below the water features. In the Symbology section of the data layer properties we utilized ArcMap Tools to choose "Add all Values", using the Information Tool to determine all of the geologic names within the borders of our map.

Armed with our list of names we deleted all values then added back the values we wanted to use. We arranged the geologic units in the legend from younger to older deposits, younger deposits being more prone to liquefaction. We colorized the map similar to the map we used in the liquefaction/geology comparison map but gave every unit in the map its own color for display purposes. We then adjusted the transparency of the geology data layer, created a new legend, added annotation, revised the acknowledgments, changed the map name to **"Geology Map for Oceano, CA"** then saved the map as a reference tool. This map can be viewed in the "Discussion" section; page 46 in Figure 16.

Site specific revised liquefaction potential map. Upon completion of each reference maps for this project, we saved a copy of the data layers to one Data Frame for utilization in creation of the revised site specific liquefaction potential map. It was not necessary to add any more layers of data as all the data we anticipated we could possibly need we stored in the Geodatabase for this Data Frame. By turning the various Data Frame layers on and off, we viewed the possible relationships between the different attributes of the geology, soil classification, elevation and flood zones as categorized on the reference maps. Not finding any free GIS data online for depth to groundwater, a critical ingredient in formulating the revised liquefaction potential map for the project, we extrapolated the ground water depth from the liquefaction report completed in 2004 by Holzer et al. For the purposes of the revised map, depth to water table was assumed to be approximately 5 feet above sea level (we discuss our depth assumptions further in the "Discussion" section of this report). For all other data layers we used the ArcMap Tools to explore and view the differing patterns of information available. We used the following Tools: The Conversion Tool to convert the digital raster file layer in the elevation reference map to a point shapefile to view the results for possible use in the revised map. The Join Tool to join the geologic units that had medium to high liquefaction potential to the soil types that had medium to high liquefaction potential. The Clip Tool to clip out the joined geologic units so we could view the combined attributes as a stand alone category and the Information Tool to get point values on elevations. After completely reviewing the options, the team was satisfied with the project assumptions, finalizing the map results by choosing the attributes to display and their extent, coloring the attributes for optimal viewing, adjusting the locations of the layers in the Data Frame for optimal viewing, creating a new legend from scratch, revising the acknowledgments, then naming the map **"Site Specific Liquefaction Potential Map for Oceano, California"** before saving two copies, one map for the "Results" section that can be viewed on page 36 in Figure 11 and one map for comparison purposes.

2007 liquefaction susceptibility/liquefaction potential comparison map. With the data for the revised liquefaction map saved in Data Frame #1 of the second saved copy, we directed attention to Data Frame #2 containing the inset map of California. We resized the map to make Data Frame #2 a comparison map of equal size to Data Frame #1. We copied and pasted the SLO county liquefaction data layer, both water feature layers and the USA topographic map from Data Frame #1 into Data Frame #2. We adjusted the view then locked in the ratio to match the map view in Data Frame #1. We added the annotation for Oceano and map descriptions for both maps, adjusted the north arrow and scale bar, moved and resized the legends and adjusted the layer positions and transparency for optimal viewing; saving the map for discussion. This comparison map can be viewed in the "Results" section; page 37 in Figure 12.

RESULTS

The results, creation of a site specific liquefaction potential map utilizing geographic information systems and ArcGIS® Software, can be viewed in the project title map as illustrated in Figure 11 on page 36 and also the comparison map in Figure 12 on page 37. The comparison map in Figure 12 illustrates the differences between the original 2007 liquefaction susceptibility map data obtained from the County of San Luis Obispo and the liquefaction potential map data created by the project team utilizing information obtained free over the World Wide Web. As you can see by the comparison map, the differing areas of liquefaction potential have changed considerably.

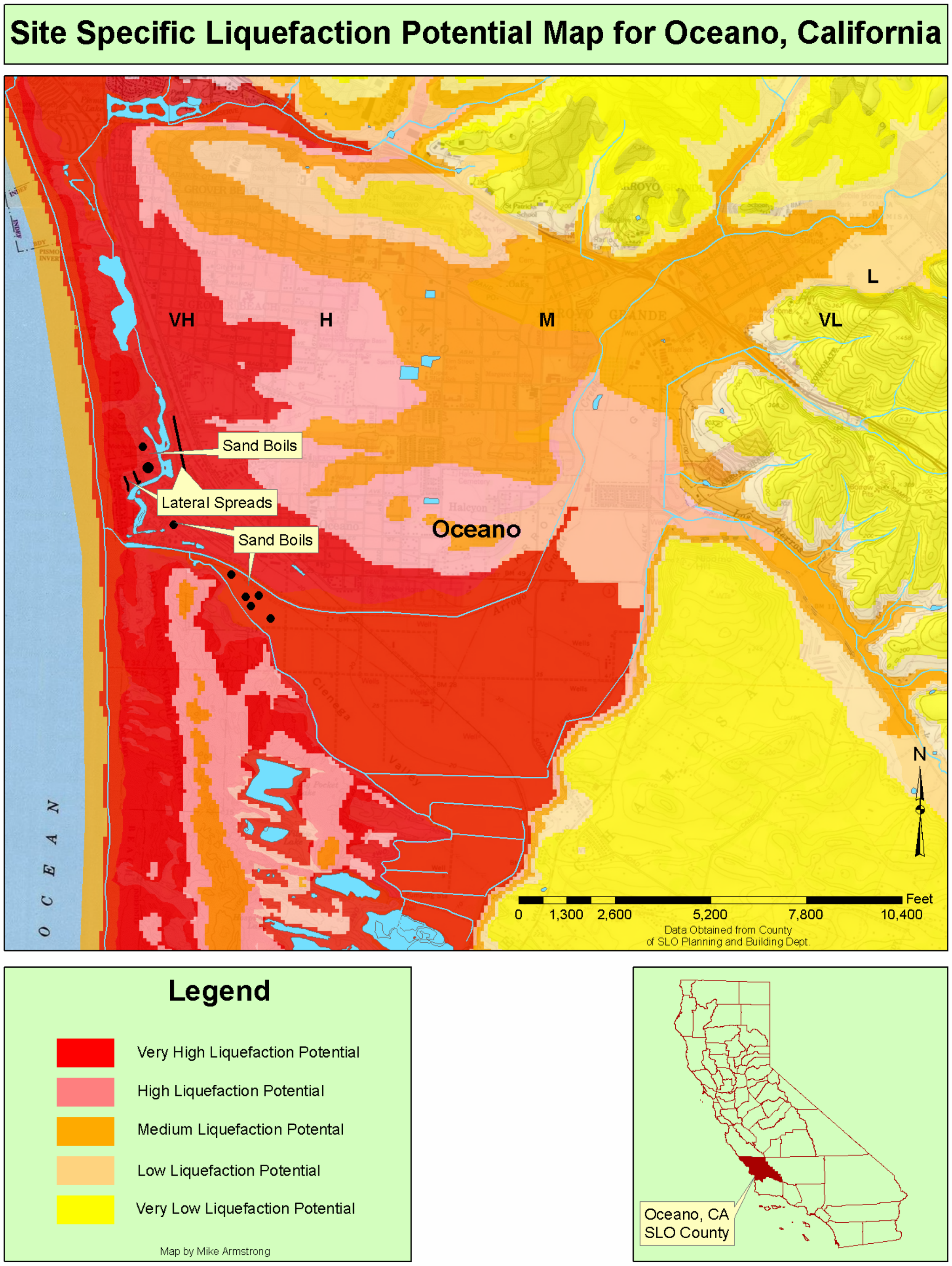


Figure 11. The above map, creation of which was the purpose of this project, shows liquefaction potential for the Oceano, California area. It was developed utilizing GIS technology and ArcGIS® Software. The areas in red represent the areas that have very high liquefaction potential. The pink areas represent the areas of high liquefaction potential. The gold areas represent the areas that have medium liquefaction potential. All the remaining areas represent areas of low to very low liquefaction potential.

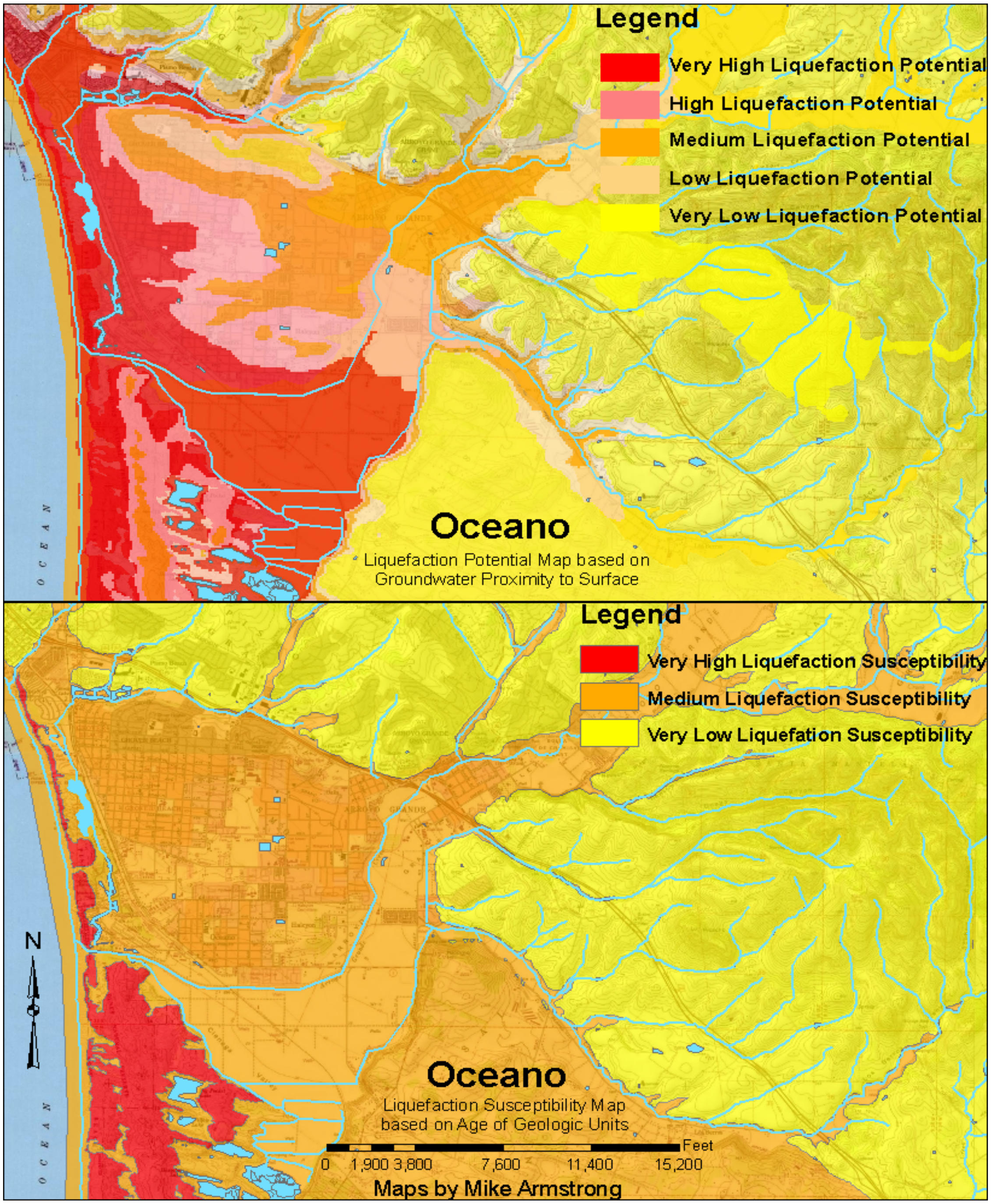


Figure 12. The above comparison map illustrates the differences between the 2007 liquefaction/geology map data provided by the County of San Luis Obispo (lower map) and the information compiled and analyzed by the team to create a revised liquefaction map(upper map). As you can see, the shapes of the areas of liquefaction vulnerability have changed considerably, with the areas of very high liquefaction and very low liquefaction more than doubling in geographic size and the areas of moderate liquefaction shrinking in size considerably.

DISCUSSION

As illustrated in Figure 12 on page 37, the project's revised liquefaction potential map of Oceano is substantially different from the 2007 liquefaction susceptibility map information published by the County of San Luis Obispo. On the revised map the "Very High Liquefaction Potential" areas now cover over one half of Oceano, inclusive of the known areas of liquefaction that occurred during the San Simeon Earthquake as illustrated in Figure 11 of the Results section of this report.

The report premise was to create a revised, hopefully improved, site specific liquefaction potential map utilizing GIS-based technology and free available data downloads from the internet. The direction we took was to include proximity to water and soil morphology in the data layers to form a relationship somehow between soil composition, water proximity and geology. According to Youd and Perkins (1978), as referenced by the CGS on page 13 of their *"2008 Seismic Hazard Zone Report 112 for the Dublin 7.5-Minute Quadrangle, Alameda County, California"*, as paraphrased; a liquefaction susceptibility map only includes the geologic characteristics of an area, that is a geologic area that has a propensity to liquefaction. By introducing the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map (in this case, adding proximity to groundwater to the map), you can produce a liquefaction potential map. Liquefaction susceptibility was defined by Youd and Perkins as a function of the capacity of soil to resist liquefaction. Liquefaction opportunity was defined by them as a function of the potential of seismic ground shaking occurring. As stated previously, and for the purposes of the project liquefaction potential map, the function of seismic ground shaking is assumed for Oceano. The “liquefaction opportunity” outlined in this report is not the intensity of the ground shaking, but the presence of saturated soils. For liquefaction to happen, ground shaking must occur within a saturated, susceptible soil. We have transformed the 2007 liquefaction susceptibility map into a revised liquefaction potential map for this project by adding one crucial ingredient, proximity to water.

At the onset, we held the theory that the water features in and around Oceano may have infused the surrounding areas with water during the San Simeon Earthquake, resulting in the surrounding liquefiable soils becoming saturated and liquefying. To help prove the “water migration” theory, we created a 60-foot buffer zone around every water feature on a reference map to represent the areas and extent of possible water migration. As stated previously in this report, and according to the liquefaction criteria called out by the CGS in Special Publication 118, soils susceptible to liquefaction should be considered to have liquefaction potential if located within 40 feet of groundwater. Using this criteria, we theorized that all liquefiable soils within 60 feet horizontally of a water source should be considered to have liquefaction potential as the possible water migration will not have to fight the forces of gravity to migrate. We plotted and labeled the known areas of liquefaction in Oceano on the map thinking the buffer zones and the liquefaction areas would intersect. As you can see by the zoomed aspect map of the buffer zones and liquefaction areas of Oceano illustrated in Figure 13 on page 40, they did not intersect, however the areas of liquefaction were close to the buffer zones in some instances.

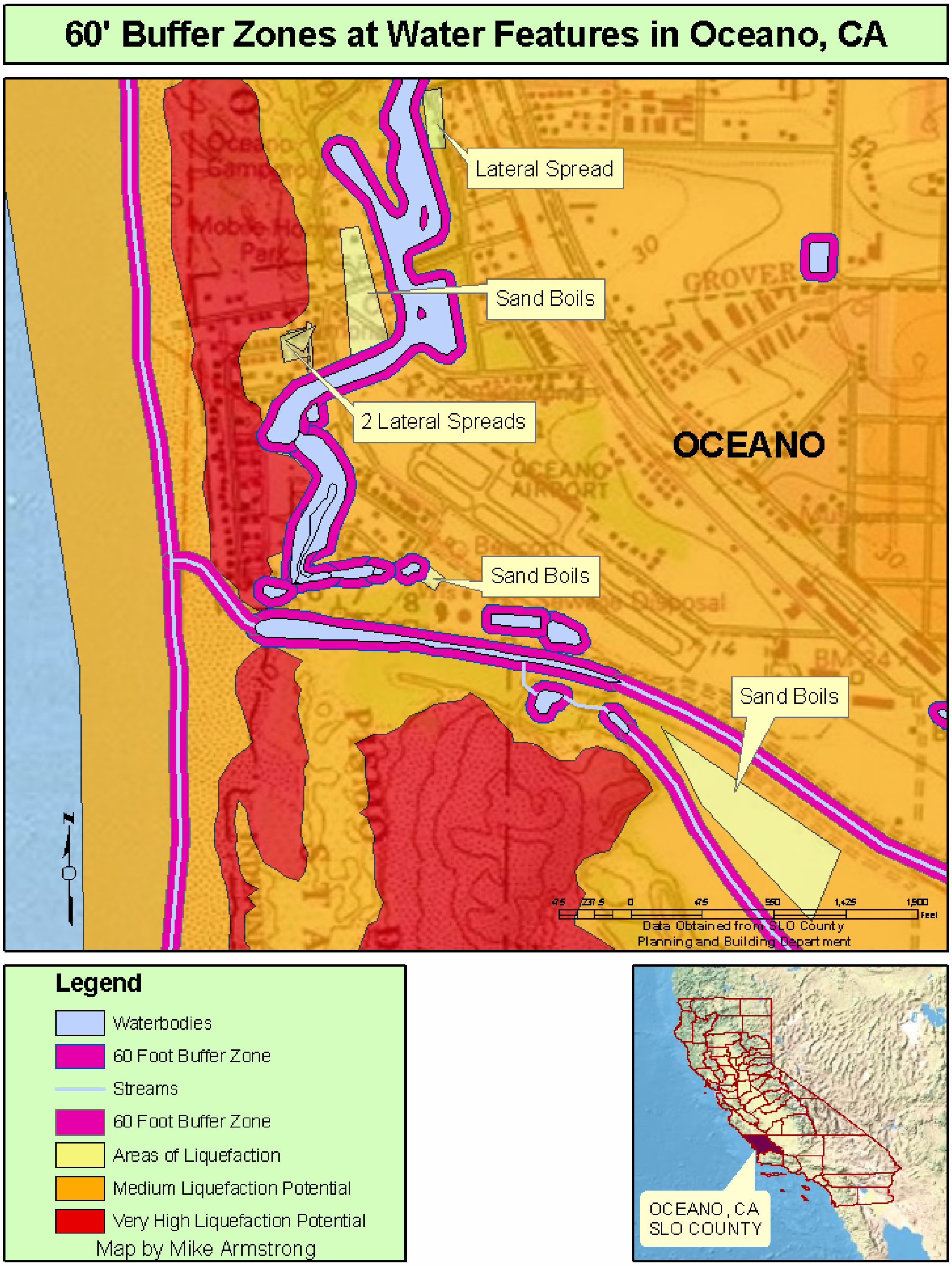


Figure 13. Zoom in on the water feature 60-foot buffer zone map showing known areas of liquefaction in Oceano, California. The areas of liquefaction were close to the buffer zones in some instances but did not intersect the buffer zones.

Having exhausted the surface water proximity theory of water migration causing the liquefaction at Oceano, we focused attention on the proximity of groundwater having contributed to the Oceano liquefaction events. We were not successful in finding any free online data for groundwater elevation, however we did find a shapefile on groundwater basin locations in the County of San Luis Obispo. The groundwater basin under Oceano is the Arroyo Grande Valley Basin, the extent of which you can see in Figure 14 on page 42. Even though the data layer did not contain the groundwater elevation information we needed for our proximity calculations, the report done by Holzer et al. in 2004 did. Per the Holzer report, ground water was observed to be 3-6 feet above sea level within 4 site borings by the USGS. One additional boring showed an elevation 5 feet below sea level but for mapping purposes we ignored this boring as an anomaly. In the 2004 report by Holzer et al., the depth to water table was inferred using various factors to arrive at a conservative water table elevation of 2.5 – 11 feet above sea level as shown in Table 2 on page 43. The assumption they made was that the water table rose 1% as it extended eastwardly from the coast. For the purposes of the revised map, depth to water table was assumed to be approximately 5 feet above sea level on average. We arrived at this figure by adding up all the surface elevations and the inferred elevations, divided both by 37 samples, subtracted the average sum of the inferred water table elevation (4.32 meters) from the average sum of the inferred water table elevation (2.55 meters) = 1.77 meters X 3 feet per meter = 5.33 feet rounded to 5 feet. As you can see by the surface elevations map, shown in Figure 15 on page 44, the surface elevations at the areas of know liquefaction in Oceano were between 3-6 feet as represented on the map by dark red and red colored areas, and confirmed by checking the map elevations with the Information

Tool of ArcMap. The groundwater was very close to the surface at the locations where the liquefaction occurred in Oceano.

Figure 14. Geographic extent of the groundwater table found to be near surface in Oceano, California.

Table 2. Elevations of soundings and depths to ground water used by the team for the revised liquefaction map analysis. Observed water tables are from USGS borings drilled March 22-26, 2004 as reported by Holzer et al. in their 2004 report.

CPT	Elevation, m	Depth to water table, m	
		Inferred[1]	Observed
SOC001	2.040	0.52	
SOC002	2.793	1.08	
SOC003	3.732	1.79	
SOC004	4.494	2.35	
SOC005	6.146	3.79	
SOC006	8.028	6.50	
SOC007	2.457	0.93	
SOC008	2.269	0.75	
SOC009	2.563	1.04	
SOC010	4.946	4.11	6.6
SOC011	4.296	2.59	
SOC012	3.395	1.87	
SOC013	7.286	5.20	
SOC014	5.284	3.42	
SOC015	3.147	1.62	1.7
SOC016	5.310	3.36	
SOC017	2.616	1.09	
SOC018	6.027	4.22	
SOC019	13.411	11.6	11.6
SOC020	7.010	5.20	
SOC021	9.144	7.33	
SOC022	2.764	1.24	
SOC023	0	0	
SOC024	0	0	
SOC025	2.480	0.96	
SOC026	2.323	0.80	
SOC027	3.353	1.27	
SOC028	3.353	1.27	1.3
SOC029	3.353	1.27	
SOC030	2.908	1.38	1.8
SOC031	5.192	3.67	
SOC032	2.975	1.45	
SOC033	2.764	1.24	
SOC034	2.604	1.08	
SOC035	6.372	2.71	
SOC036	6.372	2.71	
SOC037	6.372	2.71	

[1] Inferred values of the water table that were used for liquefaction hazard computations by Holzer et al.

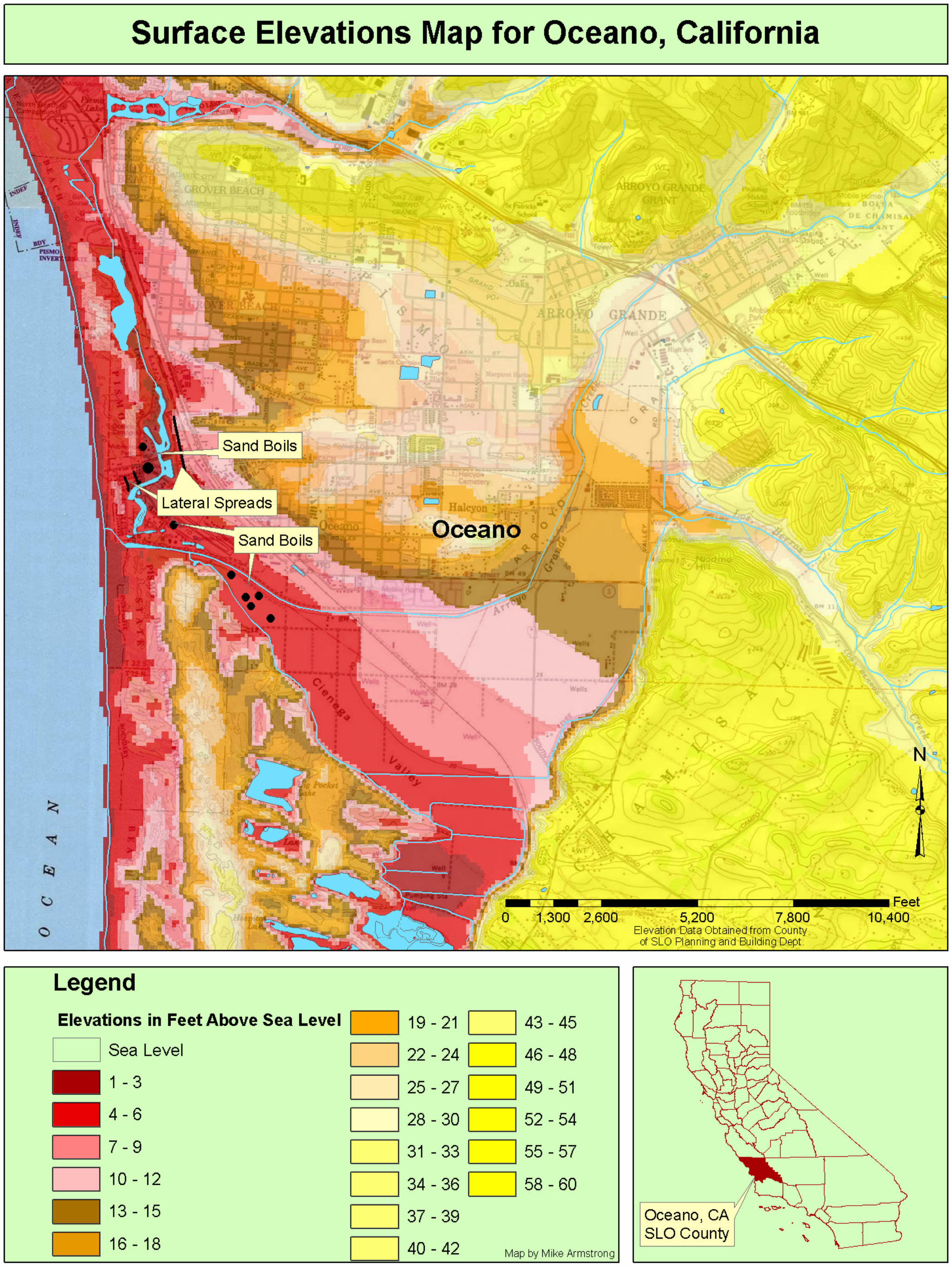


Figure 15. Surface elevations map with known areas of liquefaction plotted for reference. All ground surface elevations are referenced in feet above sea level. The areas of known liquefaction occurred at surface elevations between 3 to 6 feet above sea level as color coded in dark red and red, and confirmed with the Information Tool. In these areas the groundwater would have been at or near the surface when the liquefaction occurred.

As previously stated, saturated soil is an essential ingredient in the phenomenon of liquefaction occurrence. The other essential ingredient of liquefaction occurrence is the composition of what lies under the surface. Extensive statistics have been compiled on the subject of liquefaction by Moss & Seed et al(2006) as referenced in the “Materials and Methods” section of this report. They compiled a collection of over 500 case histories covering the last three decades of earthquake events, with 188 case histories ultimately being inputted in their database for their study. There are many factors addressed in their report besides the presence of saturated soil and the properties of underlying soils; factors such as liquefiable layer thickness, cyclic stress ratios, earthquake magnitude, etc., all factors that require field and laboratory testing, which is not a part of this report.

We reviewed the database table of the 188 events and found that most liquefaction events occurred with groundwater within 10 feet of the surface. The deepest groundwater depth recorded in this 2006 report was 22 feet. We utilized their study to arrive at the maximum threshold surface elevation in the project study to determine the breaks between liquefaction potential levels; 15 foot from sea level surface elevation = 10 foot from surface groundwater elevation = Very High Liquefaction Potential and 22 foot from sea level surface elevation = 17 foot from surface groundwater elevation = High Liquefaction Potential. For Moderate and Low Liquefaction Potential, we used the CGS criteria called out in *“Special Publication 118 – Recommended Criteria for Delineating Seismic Hazard Zones in California*, *dated May 1992, Revised April 2004” – Pages 3-5,* factoring in the limit of liquefiable soils per the site geology and soil classification reference maps as shown in Figure 16 and figure 10 on page 31.

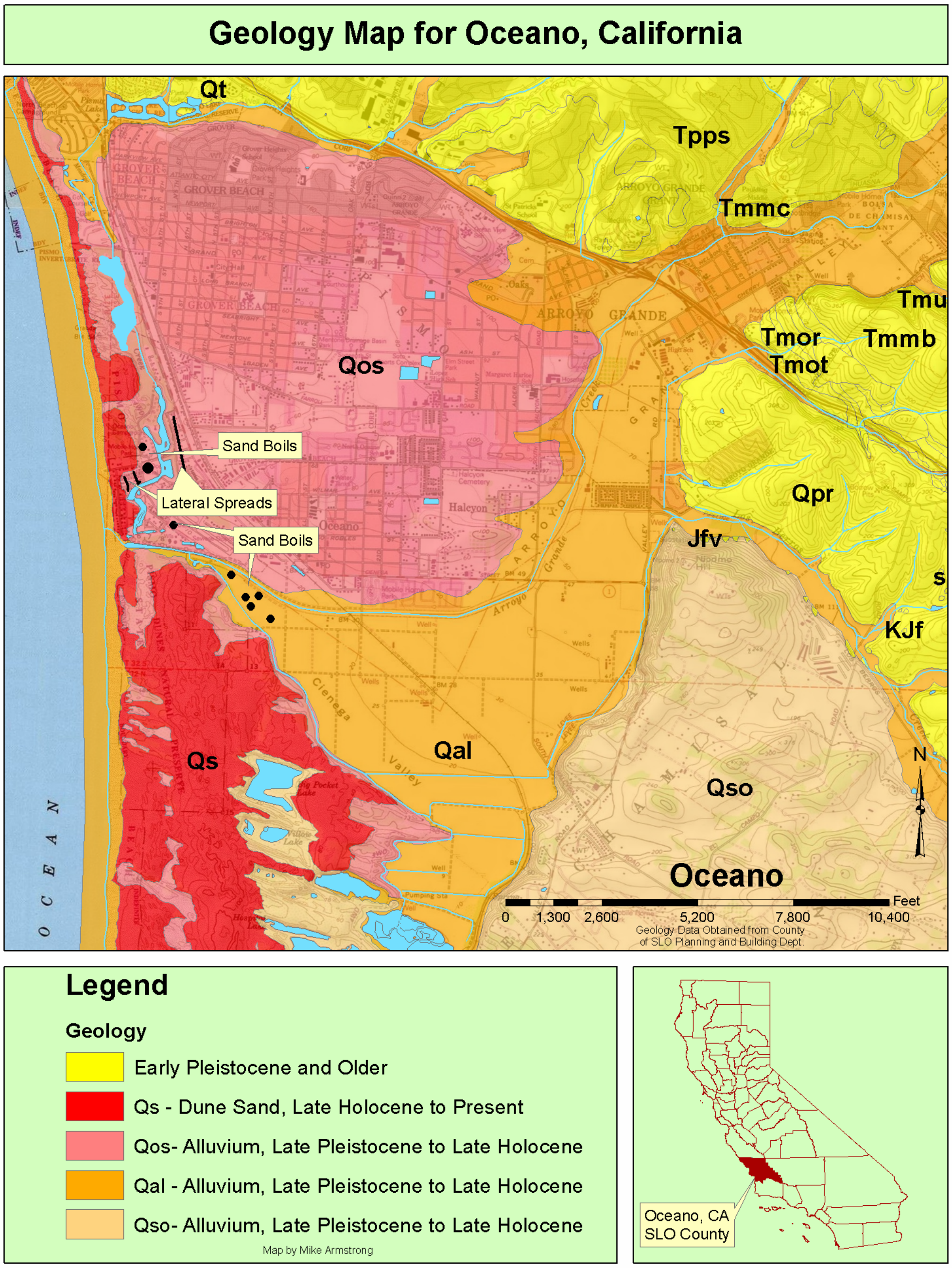


Figure 16. Geology map colorized to help show liquefaction susceptibility based on age of geologic units: Red and pink for very high to high liquefaction susceptibility. Orange and tan for moderate liquefaction susceptibility. Yellow for low to very low liquefaction susceptibility. All the Legend "Q" deposits are Quaternary surficial, unconsolidated sand, gravel and silt deposits from recent geologic history i.e. 100 – 11,000 years.

In Figure 16 we color coded the geologic areas by age; red being youngest and yellow being oldest based on the County of San Luis Obispo criteria. We used the geologic definitions per the USGS to arrange the order of the geologic units. According to the USGS, all of the soils that are considered susceptible to liquefaction are from the Late Pleistocene to Late Holocene Epoch of the Quaternary Period. All geologic units in this period have a name starting with "Q"; such as Qs, Qos, Qal and Qso as referenced on the geology map for Oceano. The next letters in the designation gives you a hint of the history. "Qs" represents undifferentiated, surficial deposits such as dune sands of recent origin, most likely the Late Holocene Epoch. "Qos" represents obscurely bedded silts or clays from recent origin or older, up to the Late Pleistocene Epoch. Most of the populated area of Oceano is underlain by Qos. It should be noted that liquefaction did occur in areas containing this sediment, therefore the team is of the opinion that this material is of more recent origin. "Qal" represents unconsolidated silt, sand and gravel that ranges in age from recent alluvial origin to Late Pleistocene. It should be noted that liquefaction also occurred in the areas underlain by this soil type, therefore the team is of the opinion that this material is most likely of more recent origin. "Qso" represents older deposits of sands, gravels and silts from the Late Pleistocene Epoch. These soils are considered moderately liquefiable by the CGS.

According to the liquefaction map provided by the County, the liquefaction in Oceano occurred outside of the areas deemed highly susceptible to liquefaction. We are of the opinion that the entire area of Oceano has been underlain by a liquefiable layer of alluvial soils in recent geologic history, within the Late Holocene Epoch, and should be considered highly susceptible to liquefaction as outlined in the CGS publication regarding seismic hazard zones.

In Figure 10 on page 31, we color coded the soils classifications based on the soil texture triangle as defined by the USDA and the generally accepted criteria that sandy soils through sandy silts are susceptible to liquefaction up to a 15% clay content; Bennett et al (2009). By applying the USDA criteria to the soil triangle shown in Figure 17 on page 50, we determined that sand, loamy sand, sandy loams with less than 15% clay content (all soils from the base of the triangle up to 15 % clay), some loams, silty sands, sandy silts and silty loams with less than 15% clay content are all moderately to highly susceptible to liquefaction. We color coded all of the above soil types, as they coincide with the specific Oceano soil names, coloring them from red to tan, depending on the clay content.

Liquefaction has been known to occur up to depths of over 50 feet, therefore both the geology of the region and the morphology of the surface soil, which is considered to only extends down the first 6 feet per the USDA, needed to be taken into account when researching the possible areas of liquefaction potential to include on the revised map. As you can see in Figure 10 on page 31 and Figure 16 on page 46, large areas of Oceano are susceptible to liquefaction both at the surface due to soil susceptibility and below the surface due to geologic susceptibility.

To summarize, after thorough review of recent studies of the liquefaction phenomenon and taking into account the proximity to water, geology, soil morphology and geography of the Oceano area, we made the following assumptions to create our revised liquefaction potential map for Oceano:

1. The area just west of the foothills east of town, all the way to the Pacific Ocean (the entire area under Oceano), is underlain with a 90-foot thick, recently lain alluvial fan deposit (Holzer et al. 2004, Weber and Hanamura 1970), that is highly susceptible to liquefaction when saturated. Our assumptions are based on the historic flood plain topography of the area as illustrated in Figure 18 on page 51, the CGS definition of a highly liquefiable soil per Table 3 on page 50 and the fact that actual liquefaction occurred in the areas deemed to only be moderately liquefiable by the County of San Luis Obispo.

2. The surface soil composition was not factored into creation of the map as the liquefaction phenomenon most often occurs at depths below 6 feet in geologic layers of soil beneath the surface soils.

3. Surface elevation, as it relates to groundwater elevation, became the main determining factor in development of the map. All geologic units from the Late Pleistocene to the Late Holocene Epochs were categorized into liquefaction potential ratings by mapping the depth to water table. All areas containing soils from the early Pleistocene Epoch and older were considered to have low to very low liquefaction potential, regardless of depth to water table.

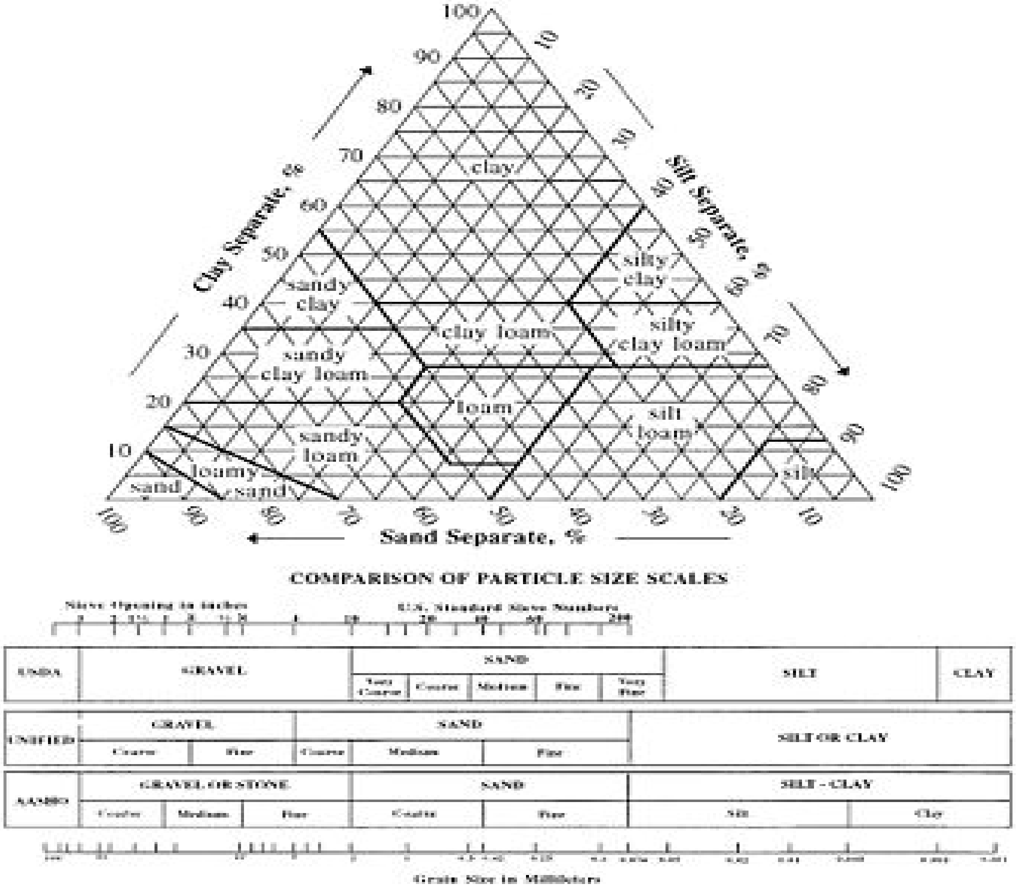


Figure 17. USDA soil texture triangle graph. Courtesy of Wikimedia Commons. Soil Texture Triangle. JPG. Source USDA.

Table 3. CGS Liquefaction Hazard Risks. Youd and Perkins (1978). Lowman (2009).

Risk	Very Low	Low	Moderate	High
Rock Types and Age Associated with each Risk Type	Older than Pleistocene Rock Layers. Pleistocene dunes. Quaternary Old alluvium, Jurassic, Cretaceous or Quaternary & Tertiary combined as the prefix.	Pleistocene rock layers. Holocene estuary, alluvial fan, marine terrace, volcanic rocks. Td (Talus).	Quaternary sands, Quaternary Land Slides, dune sand. Pleistocene to Holocene dune sands.	Recent Dunes, Riverbeds & Recent Alluvial Fan, Coastal River Delta, Quaternary young alluvium, Quaternary Young Alluvium & Quaternary Sands mixed. Artificial Fill.

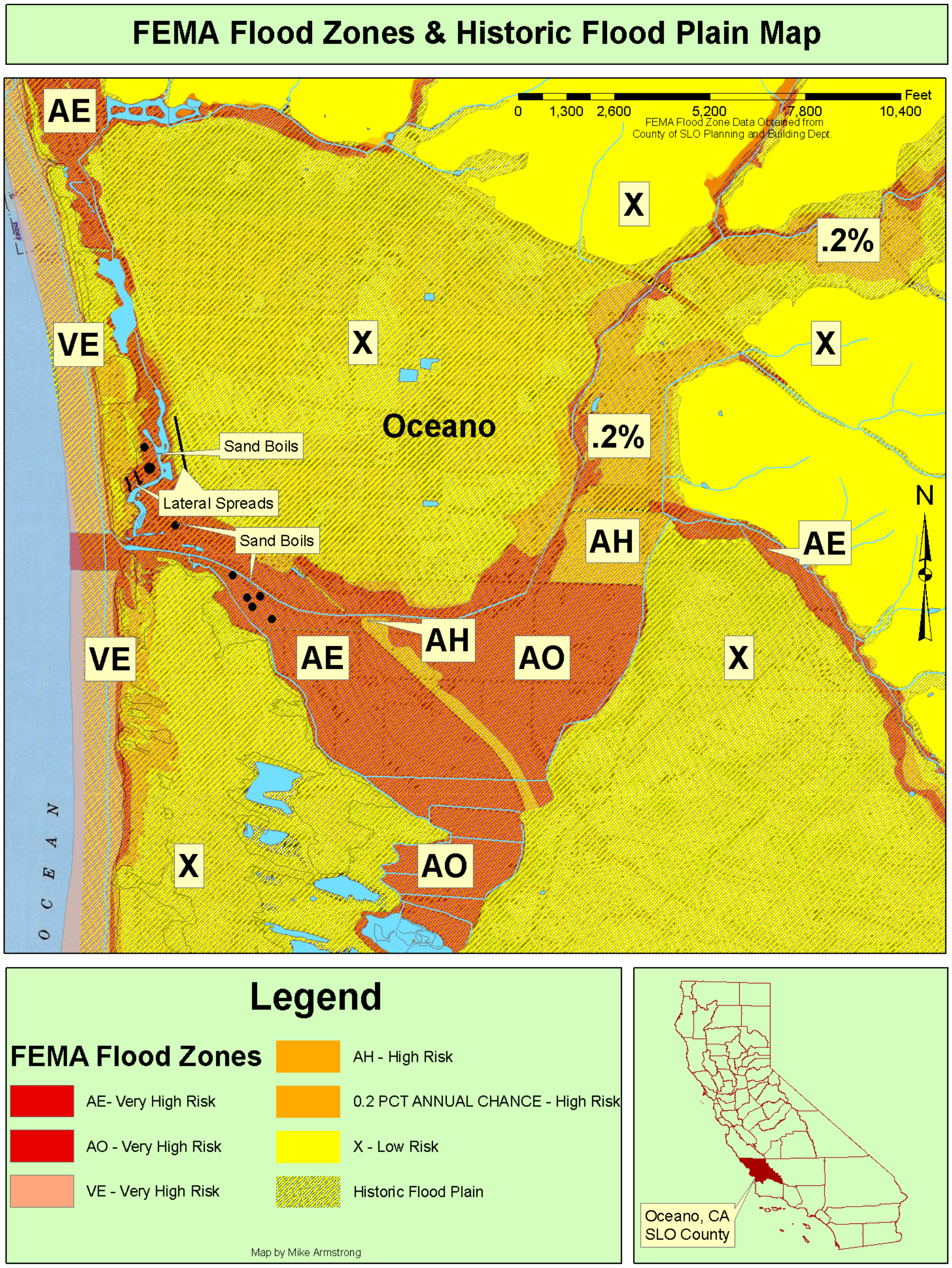


Figure 18. Present FEMA flood zones and inferred historically recent flood plain. Hatched areas represent boundary of alluvial deposits of recent geologic history. Most of hatched areas shown are above the present day flood zone **[X]**. Depth of unconsolidated granular to silty deposits susceptible to liquefaction range up to 90 feet deep. A full description of FEMA flood zones can be found in Table 12 of the "Appendices" section, page 82.

CONCLUSIONS

The premise of this project was to create a revised GIS-based, site specific liquefaction potential map utilizing free online data that would hopefully improve on the existing liquefaction susceptibility data that was published by the County of San Luis Obispo in 2007. At the onset of the project we were of the opinion that adding the relationship of proximity to water to existing geologic layers would make a liquefaction potential map more accurate, we just needed to find the available free data and determine the map making processes to accomplish that. We found most of the data files we needed at SLODataFinder. Additional files were downloaded from the USGS web site and the State of California web site. Site specific data was also obtained from a report completed in 2004 by Holzer et al. We downloaded the shapefiles and raster files into the project computer, then into the ArcMap platform, to create research maps for this project. By reviewing the soils properties, recent geologic and flood history, surface water feature influence and their locations along with the surface proximity to groundwater, applying the data to individual GIS-based research maps, then ultimately to the revised liquefaction potential map for this project, we are confident we have been successful in creating an improved Site Specific Liquefaction Potential Map for Oceano, California.

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APPENDICES

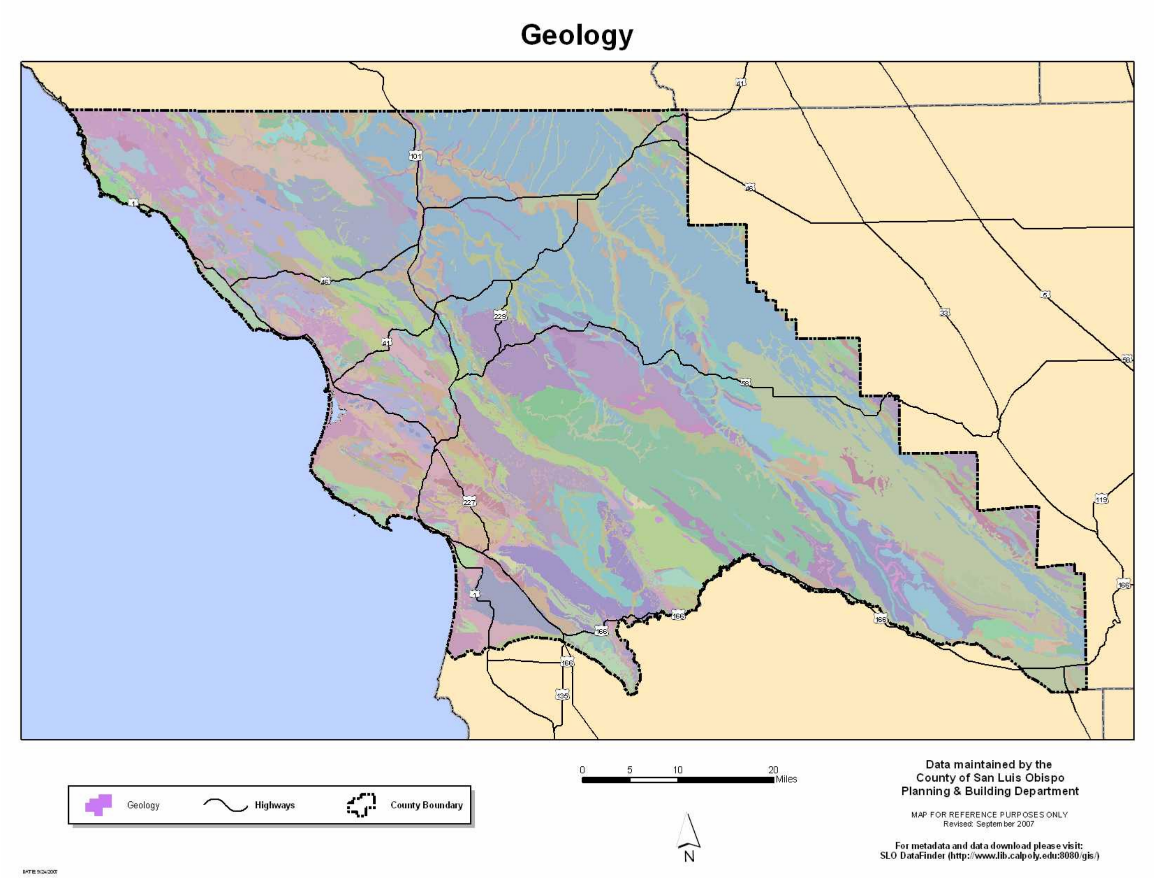

Figure 19. JPG copy of the shapefile data for geology in San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Table 4. Geology map of San Luis Obispo County content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Content Citation	
Title of Content:	**Digital geologic map database of San Luis Obispo County, California**
Type of Content:	Downloadable Data
Content Publisher:	San Luis Obispo County Planning & Building Department
Publication Date:	20071112
Content Description	
Content Summary: For geologic and seismic hazard evaluation, the most important factor is the geologic model. In this study, the geologic model is a digital compilation of stratigraphic formations in San Luis Obispo County. This dataset was developed by digitizing scanned geologic maps published mainly by the U.S. Geological Survey and the California Geological Survey, at a scale of 1:24,000 for the western part of the county, and 1:62,500 for the eastern part of the count. It serves as an interim update of the geology map database created for the county's 1999 Safety Element. Future versions will include more detailed geologic mapping.	
Content Purpose: The purpose of this map is to provide a seamless, regionally consistent geologic database for regional planning studies in San Luis Obispo County.	
Time Period of Content	
Date:	2007
Content Status	
Progress:	Planned
Update Frequency:	in progress
Spatial Domain	
West Coordinate:	-121.349563
East Coordinate:	-119.469406
North Coordinate:	35.831702
South Coordinate:	34.861629
Coverage Area:	California, Arroyo Grande, Atascadero, Los Osos, Cambria, Cayucos, Paso Robles, Grover Beach, Lake Nacimiento, Morro Bay, Nipomo, Oceano, Pismo Beach, San Luis Obispo, San Miguel, Shandon, Templeton, Huasna, Santa Margarita

Content Keywords	
Theme Keywords:	geology, bedrock geology, surficial geology, geologic history, terranes, geologic structures, landslides
Place Keywords:	California, Arroyo Grande, Atascadero, Los Osos, Cambria, Cayucos, Paso Robles, Grover Beach, Lake Nacimiento, Morro Bay, Nipomo, Oceano, Pismo Beach, San Luis Obispo, San Miguel, Shandon, Templeton, Huasna, Santa Margarita
Spatial Data Information	
Data Type:	vector digital data
Data Format:	Shapefile
Data Projection:	Lambert Conformal Conic
Access and Usage Information	
Access Constraints:	Acknowledgment of the County of San Luis Obispo would be appreciated in products derived from these data.
Use Constraints:	While every effort has been made to ensure that these data are accurate and reliable, the County of San Luis Obispo does not assume liability for any damages caused by any errors or omissions in these data, nor as a result of the failure of the data to function on a particular system. The County of San Luis Obispo makes no warranty, express or implied, that these data are accurate and reliable, nor does the fact of distribution constitute such a warranty. Users must assume responsibility to determine the appropriate use of these data. The County of San Luis Obispo provides these data to you for your exclusive use. These data may not be given away, sold or otherwise distributed to any third party without express written permission from the County of San Luis Obispo.

San Luis Obispo County Boundary Map

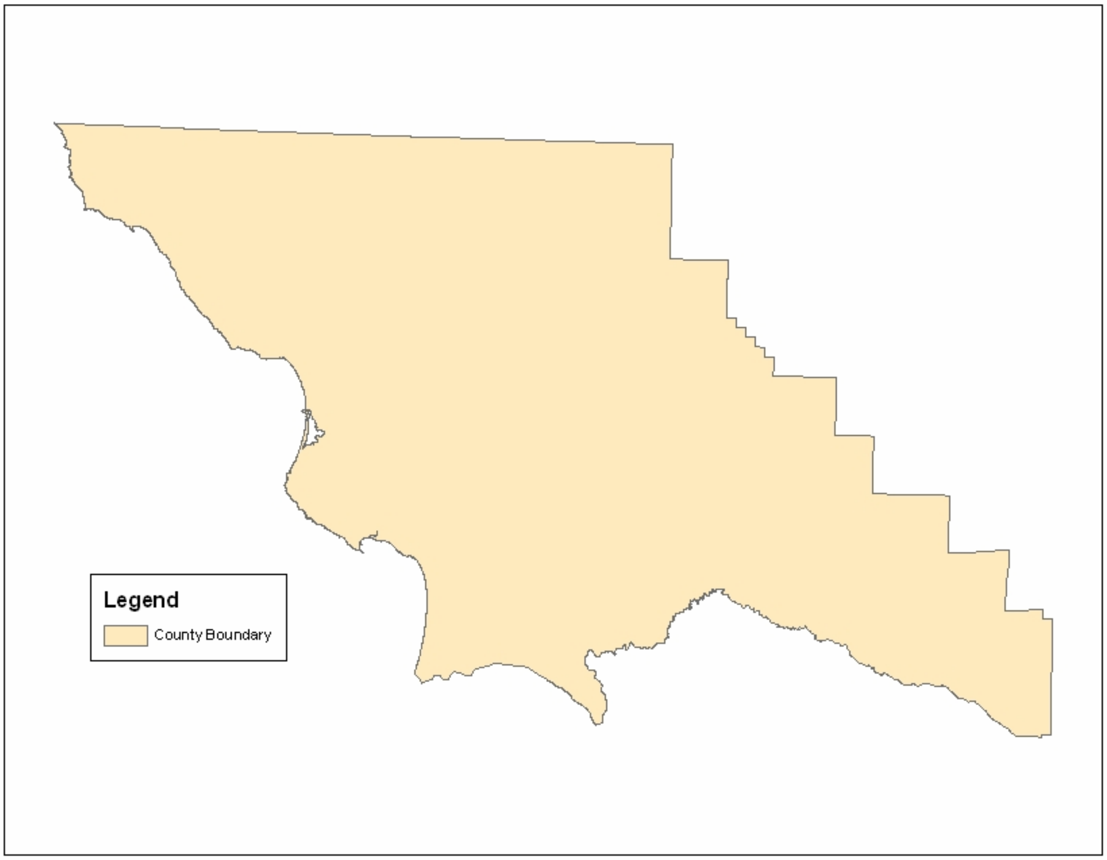

Figure 20. JPG copy of the shapefile data for the county boundaries of San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

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Table 5. County boundary map of San Luis Obispo County content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Content Citation		
	Title of Content:	**co_bndry**
	Type of Content:	vector digital data
	Content Publisher:	San Luis Obispo County - Mapping/Graphics 781-5600
	Publication Date:	October 1998
Content Description		
	Content Summary: County Wide Boundary in polygon format that contains county-wide population attribute data. The coordinate system of this data is State Plane Coordinate System, Zone V, NAD 83 Feet.	
	Content Purpose: This data provides suitable base map information for many mapping applications. This data is appropriate for use at a regional scale and is intended as a reference.	
	Supplemental Information: This shapefile was created by manually transferring county information from official mylar maps to individual USGS 7½ minute series maps. The linework was then digitized in AutoCAD using the California State Plane Coordinate System, NAD 27, units in feet, for registration and control. Finally, the linework from each quad was reprojected into a mathematically correct USGS NAD 27 grid and then edgematched to adjacent quad linework. Once this process was completed, the data was reprojected with ArcINFO into the California State Plane Coordinate System, NAD 83, units in feet, and converted to the native ArcView shapefile format.	
Time Period of Content		
	Date:	October 1998
Content Status		
	Progress:	Complete
	Update Frequency:	None planned
Spatial Domain		
	West Coordinate:	-121.347753
	East Coordinate:	-119.469406
	North Coordinate:	35.831667
	South Coordinate:	34.861677
	Coverage Area:	San Luis Obispo County

Content Keywords		
	Theme Keywords:	County Boundary, Basemap, Population, Governmental Boundary, Regulatory Boundary
	Place Keywords:	San Luis Obispo County
Spatial Data Information		
	Data Type:	vector digital data
	Data Format:	Shapefile
	Data Projection:	Lambert Conformal Conic
Access and Usage Information		
	Access Constraints:	Acknowledgment of the County of San Luis Obispo would be appreciated in products derived from these data.
	Use Constraints:	While every effort has been made to ensure that this data is accurate and reliable, the County of San Luis Obispo does not assume liability for any damages caused by any errors or omissions in the data, nor as a result of the failure of the data to function on a particular system. The County of San Luis Obispo makes no warranty, express or implied, that this data is accurate and reliable, nor does the fact of distribution constitute such a warranty. Users must assume responsibility to determine the appropriate use of these data. The County of San Luis Obispo provides this data to you for your exclusive use. This data may not be given away, sold or otherwise distributed to any third party without express written permission from the County of San Luis Obispo.

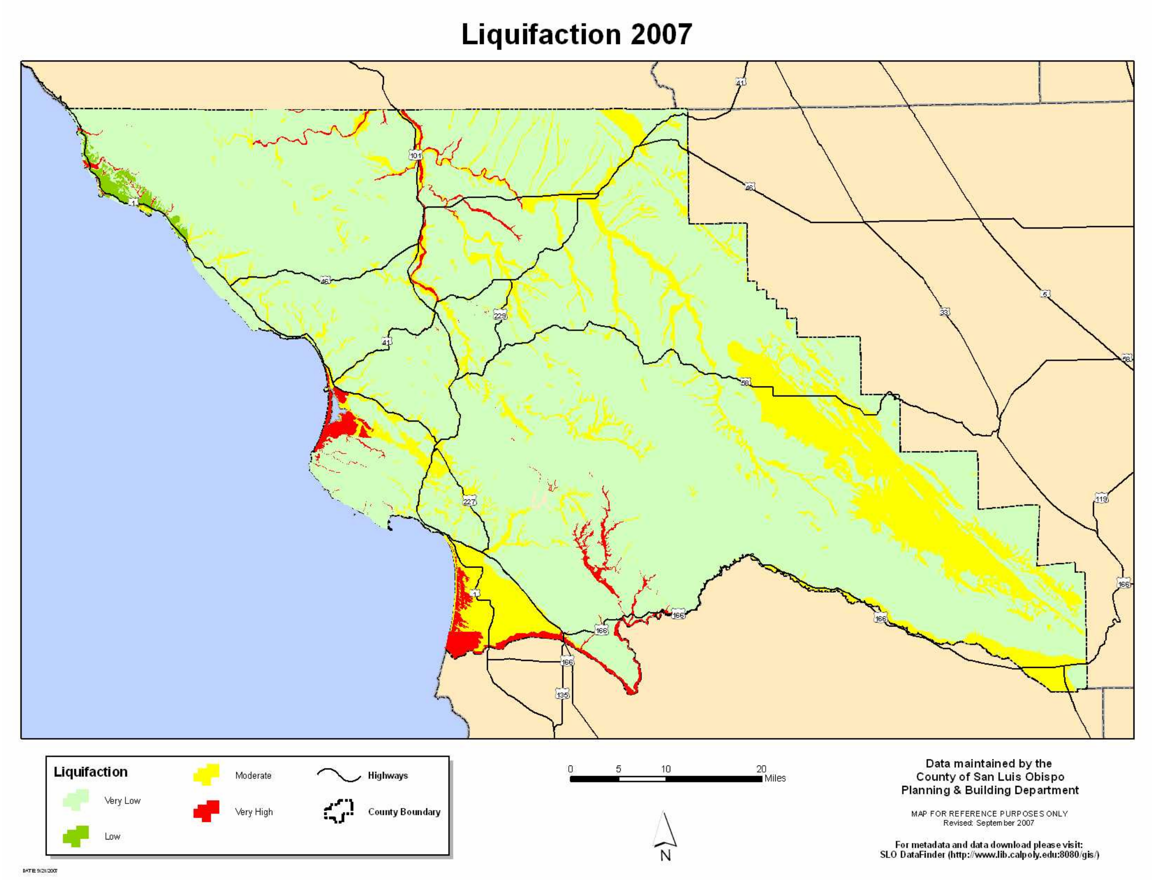
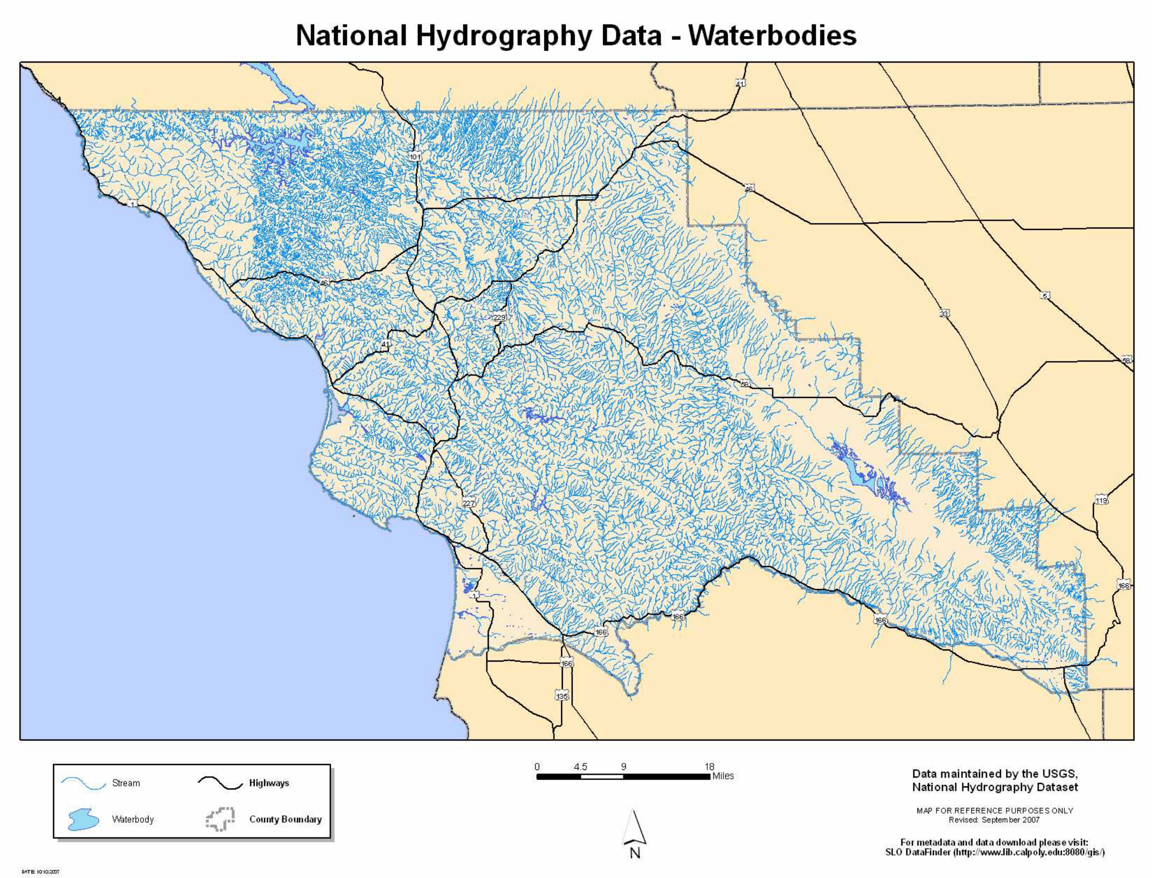


Figure 21. JPG copy of the shapefile data for the 2007 liquefaction susceptibility map of San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Table 6. County 2007 liquefaction susceptibility map of San Luis Obispo County content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Content Citation	
Title of Content:	**Relative liquefaction susceptibility of San Luis Obispo County, California**
Type of Content:	Downloadable Data
Content Publisher:	San Luis Obispo County Planning & Building Department
Publication Date:	20071112
Content Description	
Content Summary: A common type of ground failure associated with moderate and large earthquakes is liquefaction in which water-saturated fine-grained cohesionless sediments lose strength and may fail during strong ground shaking. Liquefaction susceptibility depends on the age and type of material, relative density of the material, and the depth to first (shallowest) water. Generally, younger sediments (especially latest Holocene that are less than 1,000 years old) such as loose fill, river channel, and flood plain deposits are more likely to liquefy than older Pleistocene terrace deposits. This map database depicts the relative liquefaction susceptibility for San Luis Obispo County	
Content Purpose: This map depicts the relative liquefaction susceptibility of sediments in San Luis Obispo County. The purpose of this map is to provide a comparison of relative liquefaction susceptibility for regional planning studies in San Luis Obispo County.	
Time Period of Content	
Date:	2007
Content Status	
Progress:	Planned
Update Frequency:	in progress
Spatial Domain	
West Coordinate:	-121.349563

East Coordinate:	-119.469406
North Coordinate:	35.831702
South Coordinate:	34.861629
Coverage Area:	California, Arroyo Grande, Atascadero, Los Osos, Cambria, Cayucos, Paso Robles, Grover Beach, Lake Nacimiento, Morro Bay, Nipomo, Oceano, Pismo Beach, San Luis Obispo, San Miguel, Shandon, Templeton, Huasna, Santa Margarita
Content Keywords	
Theme Keywords:	earthquakes, liquefaction, geologic hazards, ground failure
Place Keywords:	California, Arroyo Grande, Atascadero, Los Osos, Cambria, Cayucos, Paso Robles, Grover Beach, Lake Nacimiento, Morro Bay, Nipomo, Oceano, Pismo Beach, San Luis Obispo, San Miguel, Shandon, Templeton, Huasna, Santa Margarita,
Spatial Data Information	
Data Type:	vector digital data
Data Format:	Shapefile
Data Projection:	Lambert Conformal Conic
Access and Usage Information	
Access Constraints:	Acknowledgment of the County of San Luis Obispo would be appreciated in products derived from these data.
Use Constraints:	While every effort has been made to ensure that these data are accurate and reliable, the County of San Luis Obispo does not assume liability for any damages caused by any errors or omissions in these data, nor as a result of the failure of the data to function on a particular system. The County of San Luis Obispo makes no warranty, express or implied, that these data are accurate and reliable, nor does the fact of distribution constitute such a warranty. Users must assume responsibility to determine the appropriate use of these data. The County of San Luis Obispo provides these data to you for your exclusive use. These data may not be given away, sold or otherwise distributed to any third party without express written permission from the County of San Luis Obispo.


National Hydrography Data - Waterbodies

Data maintained by the USGS, National Hydrography Dataset

MAP FOR REFERENCE PURPOSES ONLY
Revised: September 2007

For metadata and data download please visit:
SLO DataFinder (http://www.lib.calpoly.edu:8080/gis/)

DATE: 10/10/2007

Figure 22. JPG copy of the shapefile data for the County of San Luis Obispo NHD - Waterbodies map of San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Table 7. NHD waterbodies map of San Luis Obispo County content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Content Citation	
Title of Content:	**nhd_waterbodies_sloco**
Type of Content:	Downloadable Data
Content Publisher:	REQUIRED: The name of an organization or individual that developed the data set.
Publication Date:	REQUIRED: The date when the data set is published or otherwise made available for release.
Content Description	
Content Summary: REQUIRED: A brief narrative summary of the data set.	
Content Purpose: REQUIRED: A summary of the intentions with which the data set was developed.	
Time Period of Content	
Date:	REQUIRED: The year (and optionally month, or month and day) for which the data set corresponds to the ground.
Content Status	
Progress:	REQUIRED: The state of the data set.
Update Frequency:	REQUIRED: The frequency with which changes and additions are made to the data set after the initial data set is completed.
Spatial Domain	
West Coordinate:	-121.315152
East Coordinate:	-119.471934
North Coordinate:	35.924799
South Coordinate:	34.874227
Content Keywords	
Theme Keywords:	REQUIRED: Common-use word or phrase used to describe the subject of the data set.
Spatial Data Information	
Data Type:	vector digital data
Data Format:	Shapefile
Data Projection:	Lambert Conformal Conic

Access and Usage Information	
Access Constraints:	REQUIRED: Restrictions and legal prerequisites for accessing the data set.
Use Constraints:	REQUIRED: Restrictions and legal prerequisites for using the data set after access is granted.

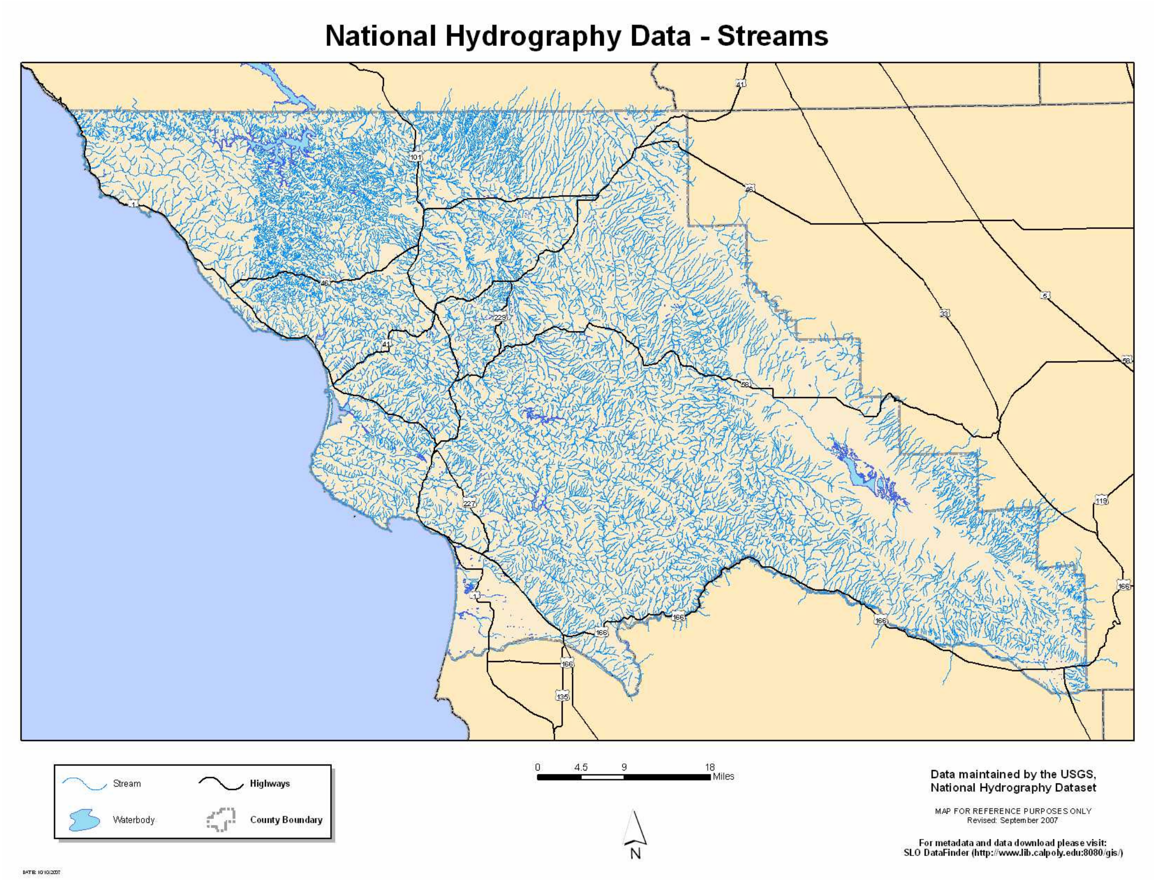


Figure 23. JPG copy of the shapefile data for the County of San Luis Obispo NHD - Streams map of San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

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Table 8. NHD streams map of San Luis Obispo County content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Content Citation		
	Title of Content:	**nhd_streams_sloco**
	Publication Date:	10/12/2007
Content Description		
	Content Summary: The National Hydrography Dataset (NHD) is a comprehensive set of digital spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs and wells. Within the NHD, surface water features are combined to form "reaches," which provide the framework for linking water-related data to the NHD surface water drainage network. These linkages enable the analysis and display of these water-related data in upstream and downstream order. The NHD is based upon the content of USGS Digital Line Graph (DLG) hydrography data integrated with reach-related information from the EPA Reach File Version 3 (RF3). The NHD supersedes DLG and RF3 by incorporating them, not by replacing them. Users of DLG or RF3 will find the National Hydrography Dataset both familiar and greatly expanded and refined. While initially based on 1:100,000-scale data, the NHD is designed to incorporate and encourage the development of higher resolution data required by many users.	
Time Period of Content		
	Date:	2007
Content Status		
	Progress:	Complete
Spatial Domain		
	West Coordinate:	-121.350028
	East Coordinate:	-119.414603
	North Coordinate:	35.848066
	South Coordinate:	34.848787

Spatial Data Information		
	Data Type:	vector digital data
	Data Format:	Shapefile
	Data Projection:	Lambert Conformal Conic
Access and Usage Information		
	Access Constraints:	While every effort has been made to ensure that this data is accurate and reliable, the County of San Luis Obispo does not assume liability for any damages caused by any errors or omissions in the data, nor as a result of the failure of the data to function on a particular system. The County of San Luis Obispo makes no warranty, express or implied, that this data is accurate and reliable, nor does the fact of distribution constitute such a warranty. Users must assume responsibility to determine the appropriate use of these data. The County of San Luis Obispo provides this data to you for your exclusive use. This data may not be given away, sold or otherwise distributed to any third party without express written permission from the County of San Luis Obispo.
	Use Constraints:	Acknowledgment of the County of San Luis Obispo would be appreciated in products derived from these data.

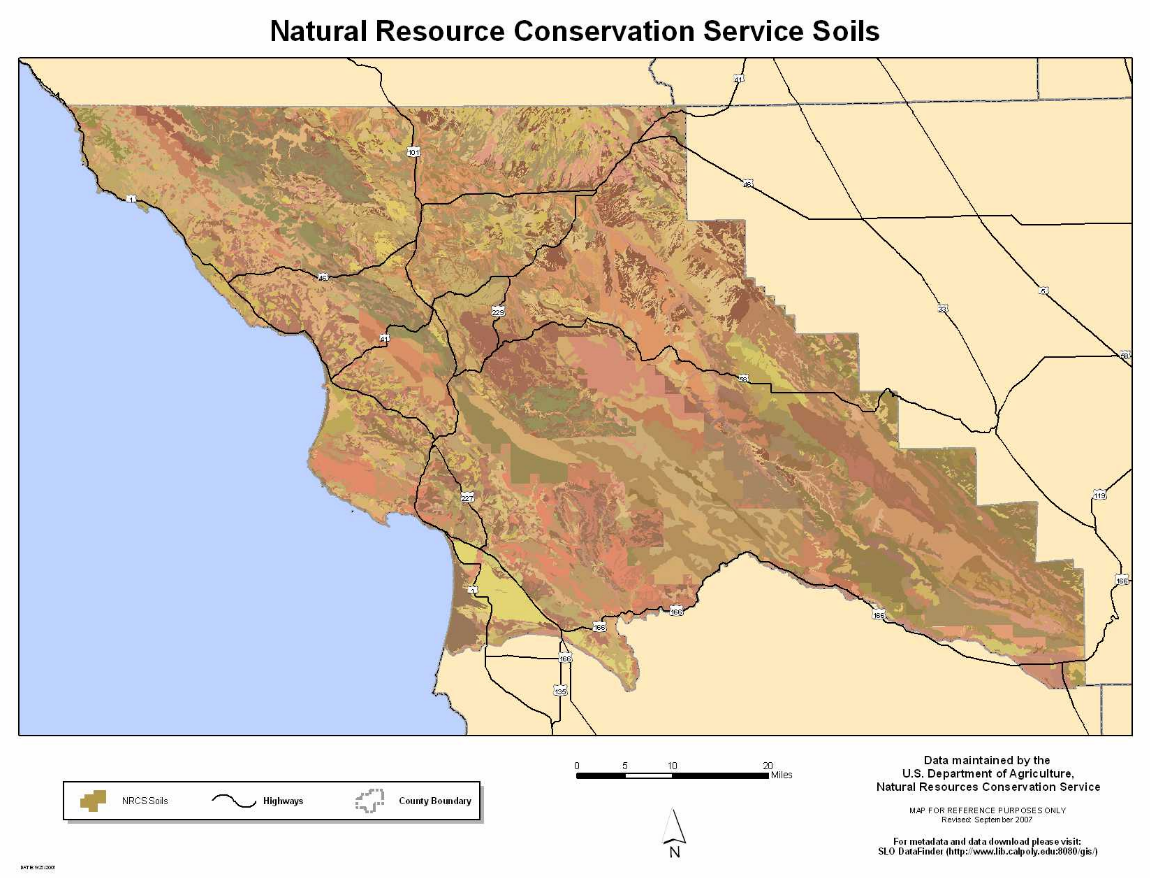

Figure 24. JPG copy of the shapefile data for the County of San Luis Obispo NRCS Soils Classifications Map of San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Table 9. SLO County NRCS soils classification map content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo from the U.S. Department of Agriculture, Natural Resources Conservation Service.

Content Citation		
	Title of Content:	**SLOCo_NRCS_Soils**
	Content Publisher:	U.S. Department of Agriculture, Natural Resources Conservation Service
	Publication Place:	Fort Worth, Texas
	Publication Date:	20051017
Content Description		
	Content Summary: This data set is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The information was prepared by digitizing maps, by compiling information onto a lpanimetric correct base and digitizing, or by revising digitized maps using remotely sensed and other information. This data set consists of georeferenced digital map data and computerized attribute data. The map data are in a soil survey area extent format and include a detailed, field verified inventory of soils and miscellaneous areas that normally occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. A special soil features layer (point and line features) is optional. This layer displays the location of features too small to delineate at the mapping scale, but they are large enough and contrasting enough to significantly influence use and management. The soil map units are linked to attributes in the National Soil Information System relational database, which gives the proportionate extent of the component soils and their properties.	
	Content Purpose: SSURGO depicts information about the kinds and distribution of soils on the landscape. The soil map and data used in the SSURGO product were prepared by soil scientists as part of the National Cooperative Soil Survey.	
	Supplemental Information: Digital versions of hydrography, cultural features, and other associated layers that are not part of the SSURGO data set may be available from the primary organization listed in the Point of Contact.	
Time Period of Content		
	Beginning Date:	20040218
	Ending Date:	20051017
Content Status		

Progress:	Complete
Update Frequency:	As needed
Spatial Domain	
West Coordinate:	-121.347497
East Coordinate:	-119.469503
North Coordinate:	35.831752
South Coordinate:	34.861410
Coverage Area:	California State, San Luis Obispo County
Content Keywords	
Theme Keywords:	soil survey, soils, Soil Survey Geographic, SSURGO
Place Keywords:	California State, San Luis Obispo County
Spatial Data Information	
Data Type:	vector digital data
Data Format:	Shapefile
Data Projection:	State Plane Coordinate System 1983
Data Scale:	24000
Access and Usage Information	
Access Constraints:	None
Use Constraints:	The U.S. Department of Agriculture, Natural Resources Conservation Service, should be acknowledged as the data source in products derived from these data. This data set is not designed for use as a primary regulatory tool in permitting or citing decisions, but may be used as a reference source. This is public information and may be interpreted by organizations, agencies, units of government, or others based on needs; however, they are responsible for the appropriate application. Federal, State, or local regulatory bodies are not to reassign to the Natural Resources Conservation Service any authority for the decisions that they make. The Natural Resources Conservation Service will not perform any evaluations of these maps for purposes related solely to State or local

		regulatory programs. Photographic or digital enlargement of these maps to scales greater than at which they were originally mapped can cause misinterpretation of the data. If enlarged, maps do not show the small areas of contrasting soils that could have been shown at a larger scale. The depicted soil boundaries, interpretations, and analysis derived from them do not eliminate the need for onsite sampling, testing, and detailed study of specific sites for intensive uses. Thus, these data and their interpretations are intended for planning purposes only. Digital data files are periodically updated. Files are dated, and users are responsible for obtaining the latest version of the data.

County Digital Elevation Model (DEM Elevations)

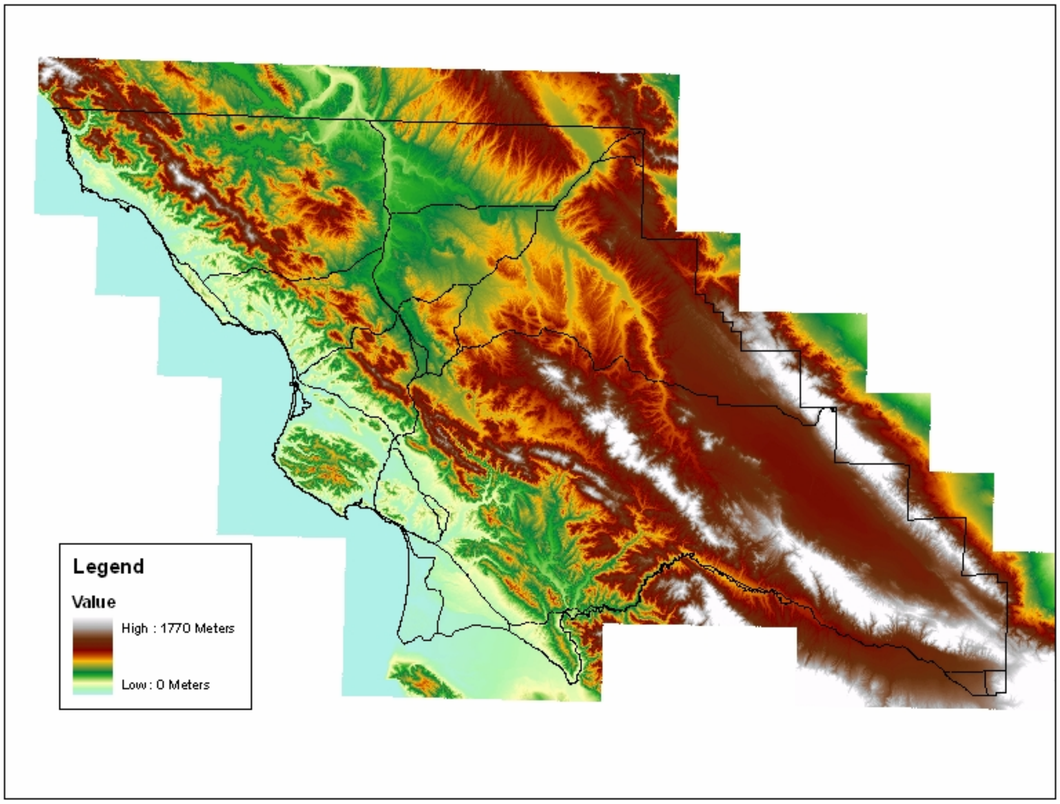

Figure 25. JPG copy of the shapefile data for the County of San Luis Obispo Digital Elevations Map of San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Table 10. SLO County digital elevations map content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo

Content Citation		
	Title of Content:	**county_dem**
	Type of Content:	raster digital data
	Content Publisher:	San Luis Obispo County - Mapping/Graphics 781-5600
	Publication Date:	November 2001
Content Description		
	Content Summary: County DEM that consolidates all the planning area DEM's into one complete DEM courtesy of C. Chay Casso, UCSB. A digital elevation model (DEM) contains a series of elevations ordered from south to north with the order of the columns from west to east. The DEM is formatted as one ASCII header record (A-record), followed by a series of profile records (B- records) each of which include a short B-record header followed by a series of Standards for the Preparation of Digital Geospatial Metadata Part 7: 7.5-Minute Digital Elevation Models.	
	Content Purpose: DEM's can be used as source data for digital orthophotos and as layers in geographic information systems for earth science analysis. DEM's can also serve as tools for volumetric analysis, for site location of towers, or for drainage basin delineation.	
	Supplemental Information: 7.5-minute DEM (up to 30-meter square grid spacing, cast on Universal Transverse Mercator (UTM) projection). The horizontal grid spacing allows for integers from between 1- and 30-meters. Unless otherwise specified in a cooperative agreement, DEM data collected by or for the USGS will have a 10- or 30-meter grid spacing. Provides coverage in 7.5- by 7.5-minute blocks. Each product provides the same coverage as a standard USGS 7.5-minute quadrangle without overedge. It is important to note that users of ESRI's ArcView 3.x MUST have the Spatial Analyst Extension in order to open/view the DEM. This is not a requirement for users of ESRI's ArcGIS 8.x. Note: When downloading the DEM, please be sure to save the dataset under a folder name that contains no spaces and is less than eight characters long. This will allow the DEM to be properly accessed in ArcView.	
Time Period of Content		
	Date:	November 2001
Content Status		

	Progress:	Complete
	Update Frequency:	None planned
Spatial Domain		
	West Coordinate:	-121.437796
	East Coordinate:	-119.312081
	North Coordinate:	35.937224
	South Coordinate:	34.802117
	Coverage Area:	San Luis Obispo County
Content Keywords		
	Theme Keywords:	Elevation, DEM, Digital Elevation Model, Digital Terrain Model, Height, Altitude, Hypsography, Slope, Shaded Relief, Relief
	Place Keywords:	San Luis Obispo County
Spatial Data Information		
	Data Type:	raster digital data
	Data Format:	Raster Dataset
	Data Projection:	State Plane Coordinate System
Access and Usage Information		
	Access Constraints:	Acknowledgment of the County of San Luis Obispo and the UC Santa Barbara Donald Bren School of Environmental Science and Management would be appreciated in products derived from these data.

	Use Constraints:	While every effort has been made to ensure that this data is accurate and reliable, the County of San Luis Obispo does not assume liability for any damages caused by any errors or omissions in the data, nor as a result of the failure of the data to function on a particular system. The County of San Luis Obispo makes no warranty, express or implied, that this data is accurate and reliable, nor does the fact of distribution constitute such a warranty. Users must assume responsibility to determine the appropriate use of these data. The County of San Luis Obispo provides this data to you for your exclusive use. This data may not be given away, sold or otherwise distributed to any third party without express written permission from the County of San Luis Obispo.

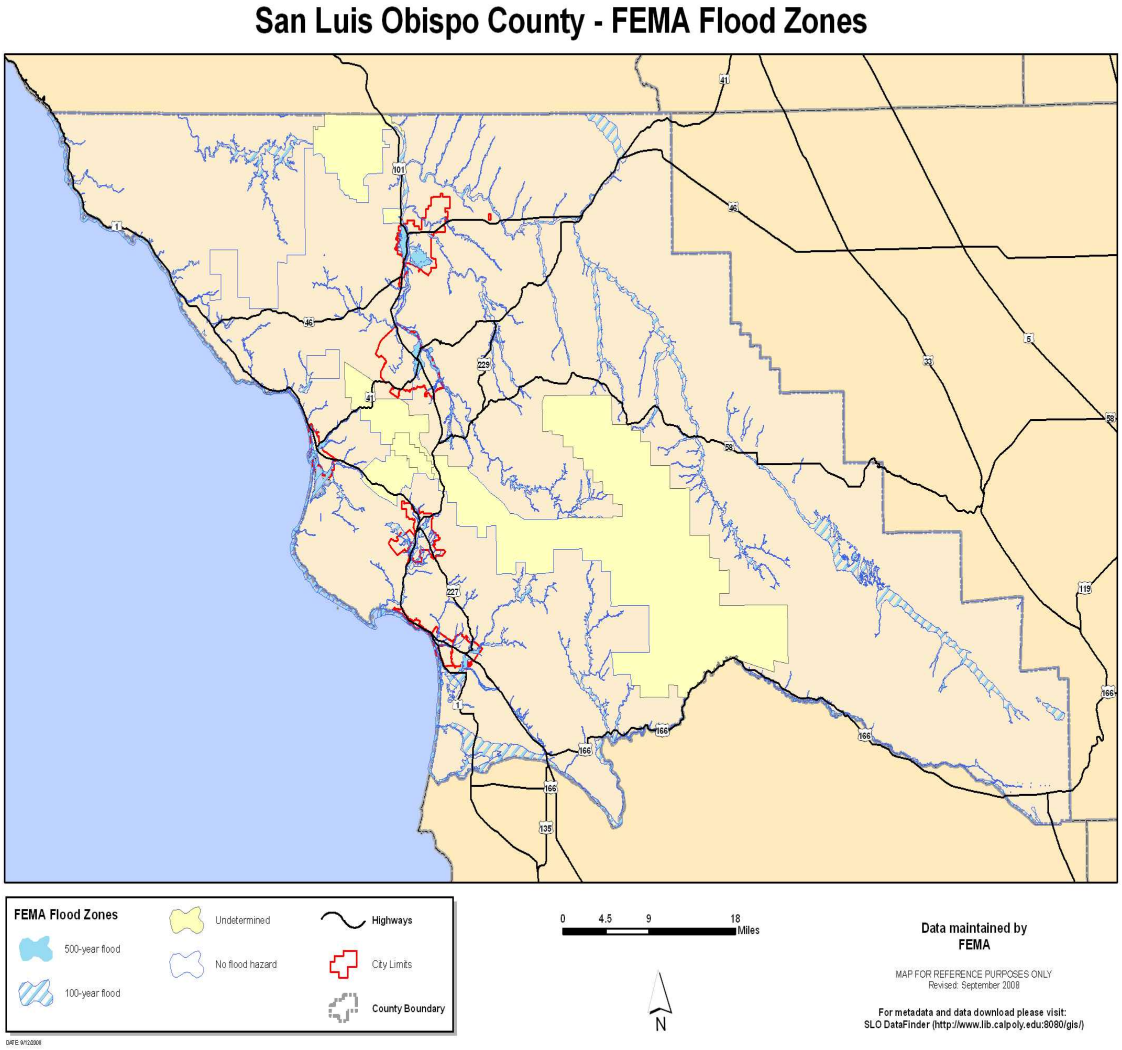

Figure 26. JPG copy of the shapefile data for the County of San Luis Obispo FEMA Flood Hazards Map of San Luis Obispo County downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Table 11. SLO County FEMA flood map content metadata downloaded from SLODataFinder. All data provided by the County of San Luis Obispo.

Content Citation	
Title of Content:	**DIGITAL FLOOD INSURANCE RATE MAP DATABASE, SAN LUIS OBISPO COUNTY, CALIFORNIA, USA**
Type of Content:	Downloadable Data
Content Publisher:	Federal Emergency Management Agency
Publication Place:	Washington,DC
Publication Date:	20080828
Content Description	
Content Summary: The Digital Flood Insurance Rate Map (DFIRM) Database depicts flood risk information and supporting data used to develop the risk data. The primary risk classifications used are the 1-percent-annual-chance flood event, the 0.2-percent-annual-chance flood event, and areas of minimal flood risk. The DFIRM Database is derived from Flood Insurance Studies (FISs), previously published Flood Insurance Rate Maps (FIRMs), flood hazard analyses performed in support of the FISs and FIRMs, and new mapping data, where available. The FISs and FIRMs are published by the Federal Emergency Management Agency (FEMA). The file is georeferenced to earth's surface using the UTM projection and coordinate system. The specifications for the horizontal control of DFIRM data files are consistent with those required for mapping at a 12,000 scale.	
Content Purpose: The FIRM is the basis for floodplain management, mitigation, and insurance activities for the National Flood Insurance Program (NFIP). Insurance applications include enforcement of the mandatory purchase requirement of the Flood Disaster Protection Act, which "... requires the purchase of flood insurance by property owners who are being assisted by Federal programs or by Federally supervised, regulated or insured agencies or institutions in the acquisition or improvement of land facilities located or to be located in identified areas having special flood hazards," Section 2 (b) (4) of the Flood Disaster Protection Act of 1973. In addition to the identification of Special Flood Hazard Areas (SFHAs), the risk zones shown on the FIRMs are the basis for the establishment of premium rates for flood coverage offered through the NFIP. The DFIRM Database presents the flood risk information depicted on the FIRM in a digital format suitable for use in electronic mapping applications. The DFIRM database is a subset of the Digital FIS database that serves to archive the information collected during the FIS.	
Time Period of Content	

	Date:	20080828
Content Status		
	Progress:	Complete
	Update Frequency:	Irregular
Spatial Domain		
	West Coordinate:	-121.4889
	East Coordinate:	-119.2358
	North Coordinate:	36.0118
	South Coordinate:	34.7373
	Coverage Area:	REGION 9, STATE CA, COUNTY SAN LUIS OBISPO, COUNTY-FIPS 060304, CALIFORNIA, COMMUNITY San Luis Obispo County Unincorporated Areas, FEMA-CID 06079C
Content Keywords		
	Theme Keywords:	hydrology, environment, inlandwaters, structure, transportation, elevation, FEMA Flood Hazard Zone, DFIRM, Digital Flood Insurance Rate Map, Special Flood Hazard Area, DFIRM Database, NFIP, SFHA, Flood Insurance Rate Map, FIRM, Riverine flooding, Floodway, Base Flood Elevation
	Place Keywords:	REGION 9, STATE CA, COUNTY SAN LUIS OBISPO, COUNTY-FIPS 060304, CALIFORNIA, COMMUNITY San Luis Obispo County Unincorporated Areas, FEMA-CID 06079C
Spatial Data Information		
	Data Type:	FEMA-DFIRM-Final
	Data Format:	Shapefile
	Data Projection:	Lambert Conformal Conic
	Data Scale:	6000
Access and Usage Information		

	Access Constraints:	None
	Use Constraints:	The hardcopy FIRM and DFIRM and the accompanying FISs are the official designation of SFHAs and Base Flood Elevations (BFEs) for the NFIP. For the purposes of the NFIP, changes to the flood risk information published by FEMA may only be performed by FEMA and through the mechanisms established in the NFIP regulations (44 CFR Parts 59-78). These digital data are produced in conjunction with the hardcopy FIRMs and generally match the hardcopy map exactly. However the hardcopy flood maps and flood profiles are the authoritative documents for the NFIP.Acknowledgement of FEMA would be appreciated in products derived from these data.

Table 12. FEMA flood zone designations as provided by FEMA.

Definitions of FEMA Flood Zone Designations

Flood zones are geographic areas that the FEMA has defined according to varying levels of flood risk. These zones are depicted on a community's Flood Insurance Rate Map (FIRM) or Flood Hazard Boundary Map. Each zone reflects the severity or type of flooding in the area.

Moderate to Low Risk Areas

In communities that participate in the NFIP, flood insurance is available to all property owners and renters in these zones:

ZONE	DESCRIPTION
B and X (shaded)	Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. B Zones are also used to designate base floodplains of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 sq. mile.
C and X (unshaded)	Area of minimal flood hazard, usually depicted on FIRMs as above the 500-year flood level. Zone C may have ponding and local drainage problems that don't warrant a detailed study or designation as base floodplain. Zone X is the area determined to be outside the 500-year flood and protected by levee from 100-year flood.

High Risk Areas

In communities that participate in the NFIP, mandatory flood insurance purchase requirements apply to all of these zones:

ZONE	DESCRIPTION
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
AE	The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 Zones.
A1-30	These are known as numbered A Zones (e.g., A7 or A14). This is the base floodplain where the FIRM shows a BFE (old format).
AH	Areas with a 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
AO	River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.
AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements will apply, but rates will not exceed the rates for unnumbered A zones if the structure is built or restored in compliance with Zone AR floodplain management regulations.
A99	Areas with a 1% annual chance of flooding that will be protected by a Federal flood control system where construction has reached specified legal requirements. No depths or base flood elevations are shown within these zones.

High Risk - Coastal Areas

ZONE	DESCRIPTION
V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.
VE, V1 - 30	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.