The Application of GIS on Nuclear Power & Seismic Risk to the Public & Environment in the United States

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Introduction

The history of nuclear power in the United States dates back to the early 1960’s when the first fully commercial pressurized water reactor became operational with an output capacity of 250 MWe (“Nuclear power in,” 2012). The United States is the world’s largest producer of nuclear power with 63 nuclear plants that have 104 reactors. This accounts for over 19% of the energy produced in the States and the Nuclear Regulatory Commission (NRC) is the governing body. There is a much longer history of seismic hazards in the United States, especially along the western coast which is in an area known as the ring of fire. It has been controversial as to where the most at-risk nuclear reactors are situated. The age and technology associated with the reactors are key factors in determining the risk level. Nuclear meltdown disasters have occurred most recently in Fukushima, Japan on March 11, 2011 and at Chernobyl, Ukraine on April 26, 1986.

Over forty groups and individuals formally requested the NRC to suspend 21 nuclear projects and facilities in 15 states (Wolfe, 2011). In only a few moments of power failure, a meltdown could occur which would put millions of people and natural environments at risk. Seismic hazard and risk are rated from historical earthquake and fault zone data. Situating a nuclear facility near a high seismic hazard area will make the location more vulnerable than facilities that are in a lower risk zone (“Your earthquake risk,” 2011).
Objectives

The purpose of our project is to locate one nuclear facility in the United States that is situated in the most at-risk zone for populations and water bodies due to seismic hazard and historical earthquake data. We can use Geographic Information Systems to overlay data and create maps to determine, calculate and analyze the most at-risk nuclear plant. For our project, there are four primary objectives.

Our first objective is to locate all nuclear facilities in the United States and determine the one facility that is most at-risk due to the seismic hazard evaluation of the specific area. Our second objective is to calculate the amount of population residing within a 50-mile zone surrounding the one most at-risk facility. Our third objective is to look at the surrounding lakes and rivers with flow data to determine both the area of water bodies at risk within the same 50-mile zone and where contaminated water bodies will flow. Our fourth objective is to make assumptions for nuclear fallout carried by wind and air currents. Our prediction is that millions of people in the United States are residing in potential disaster areas.
Data Source

Table 1:

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>States</td>
<td><a href="http://arcgis.com">http://arcgis.com</a></td>
</tr>
<tr>
<td>Earthquakes</td>
<td><a href="http://mapcruzin.com">http://mapcruzin.com</a></td>
</tr>
<tr>
<td>Wind Speed</td>
<td>NREL (National Renewable Energy Laboratory)</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Wind Direction</td>
<td>SECOORA (Southeast Coastal Ocean Observing Regional Association)</td>
</tr>
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<td></td>
<td><a href="http://secoora.org/data/data_feeds">http://secoora.org/data/data_feeds</a></td>
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<td>FlowLine Direction</td>
<td>National Hydrography Dataset</td>
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<td><a href="http://nhd.usgs.gov/">http://nhd.usgs.gov/</a></td>
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<td>Seismic Hazard</td>
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</tr>
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<td>Counties (2000)</td>
<td>K:\drive mgisdata from UBCO: University Of British Columbia Okanagan</td>
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<td>Nuclear Facilities</td>
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</tr>
<tr>
<td>Rivers/Water bodies</td>
<td>Natural Earth Data</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.naturalearthdata.com/downloads/10m-physical-vectors/">http://www.naturalearthdata.com/downloads/10m-physical-vectors/</a></td>
</tr>
</tbody>
</table>

Methods

First, for evaluation of population at risk, a geodatabase named "nuclearproject.mxd" was created in ArcCatalog. This enabled us to organize layers of data, define the coordinate system and then add to the geodatabase. The geographic coordinate system chosen is the USA Contiguous Albers Equal Area Conic because it is appropriate for the area of study. It ensures that states with equal land area appear with equal areas on the map, which is more natural and less 'stretched' out horizontally. The transformation was the GCS North American 1983.
GIS Procedures

1. Population

   a. Acquire data and add it to a map in ArcMap
      i. States
      ii. Counties (POP2000)
      iii. Cities (POP2010)
      iv. Nuclear Facilities
      v. Seismic hazard
      vi. Earthquakes
      vii. Wind direction
      viii. Wind speed

   b. ArcToolbox = Analyst Tools = Multiple Ring Buffer
      i. Input feature is Nuclear Facility layer
      ii. Buffer is 50 miles
      iii. Dissolve is “None”
      iv. Export as new layer
      v. Name as Nuclear50 as a new ‘50-mile buffer zone’

   c. Select by location Cities WITHIN 50-mile buffer zone
      i. Create layer from selected features, name it ‘City50’
      ii. Attribute table: use Statistics on POP2000 field for total population
      iii. Calculate 1% growth rate from 2000 to 2012 for current population
d. **Select by location Counties that INTERSECT the 50-mile buffer zone**
   i. Create layer from selected features, name it ‘County50’
   ii. Attribute table: use Statistics on POP2010 field for total population
   iii. Attribute table: note the number of counties

e. **Select by location Earthquakes WITHIN 50-mile buffer zone**
   i. Create new layer from selected features, name it ‘Quake50’
   ii. Attribute table: use Statistics on number of earthquakes

f. **Select by attribute Quake50 layer**
   i. On the Magnitude field, an SQL query: [EARTHQUAKE] >= 5.5
   ii. Create new layer from selected features, named Quake5.5
   iii. Attribute table: use Statistics for sum and location of earthquakes
       >=5.5 magnitude to find most at-risk location by historical earthquake data

g. **ArcToolbox = convert = feature to raster**
   i. Input layer is Seismic Hazard
   ii. Extract Values to Points
   iii. Compare raster values to find most at-risk location by seismic hazard standards

h. **Display most-at-risk location on map**
   i. Properties in City layer; SQL Query: NAME=San Clemente
2. Water Bodies in States with Nuclear Facilities
   a. Layers acquired
      i. Nuclear Facilities
      ii. States
      iii. Seismic Hazards
      iv. Historical Earthquakes
      v. Streams, Rivers, Lakes
   b. Select by location states that completely contain nuclear facilities
   c. Export states that have nuclear facilities
   d. Clip-Input: streams, rivers and lakes
   e. Clip features: States containing nuclear facilities
   f. Select by location from earthquakes-layers that are in a distance from nuclear facilities-50 mile buffer

3. Flowdata of Water within 50 miles of the San Onofre Nuclear Facility
   a. Layers acquired
      i. Nuclear Facilities
      ii. States
      iii. Seismic Hazards
      iv. Cities
      v. Flowline Data
   b. Used all the projected layers from first map that were selected, exported, and clipped
c. Flowline- Select by location all that are in a distance of nuclear reactors
with a 50 mile buffer

d. Cities- Definition Query: City Name= San Clemente

e. Flowline-Definition Query: Flow Direction=1 (with digitized)

f. Nuclear Facilities: Definition Query: Name= San Onofre 2/3

4. **Wind speed and direction at and near the San Onofre nuclear facility near San Clemente, California**

   a. Layers required
      i. Wind direction
      ii. Wind speed
      iii. States
      iv. Cities
      v. Nuclear Facilities
      vi. Seismic Hazard

   b. Used all as projected layers with a large-scale perspective at the
      surrounding region of San Clemente, CA and the San Onofre nuclear
      facility

   c. Wind direction field in attribute table is text values, therefore, add a field
      and Field Calculator to have direction values as numbers between 0 and
      360 degrees. Choose ‘Long Integer’

   d. Wind direction: Layer Properties; Unique Values;

   e. Symbols: choose an arrow, i.e. usgs104 for direction of wind
f. Wind direction; revolution completed as Geographic so arrows reflect curvature of the wind flow

g. Wind speed: classify into 5 classes in the SPEED field. Graduated color map illustrated strengths of wind in polygons

h. Wind speed attribute table: in measurement field, Statistics calculates mean average wind speed at 4.5 miles/hour

i. City SQL Query and Label: NAME='SAN CLEMENTE'

j. Nuclear Facility SQL Query and Label: NAME = ‘SAN ONOFRE’


**Results**

The US government mandates a 50-mile zone around nuclear facilities for evacuation and disaster response to radiation leaks. Within a 50 mile zone of the 65 nuclear facilities in the United States, there are 699 historical earthquakes, 17 of which are of a magnitude greater than or equal to 5.5. There are 441 cities, 991 counties and 147.42 million people in the same 50-mile zone. Considering a 1% growth rate for population in the USA from 2000 to 2012, there are 165.11 million people residing within 50 miles of a nuclear facility (Soria, 2011). Population most at-risk was analyzed using ArcGIS 9.3 both from the City and County population data. City population proved to be very low due to the fact that not every person resides in a city. The population in counties intersecting the 50-mile buffer zone around nuclear facilities calculated a much more accurate population because it includes people living in all areas.

To evaluate the most at-risk location, we analyzed the highest seismic hazard raster value which read 30 out of a possible 100 at two locations. The two locations are San Onofre, CA and Avila Beach, CA. Since age is a key factor in vulnerability, the older facility, San Onofre near San Clemente, California, was chosen as the most at-risk.

Figure 6 illustrates the flow direction around the San Onofre nuclear facility. What we can infer from this map is that the path of water is largely controlled by local topography. There is an elevation difference of at least 500 feet going inland 50 miles from the coast. Most of the fallout from the San Onofre nuclear reactor will at
first settle into rivers, streams and soil surrounding the facility, then flow via natural channels towards the Pacific Ocean.

Illustrated in Figure 7, the mean wind speed and direction directly off the coast of California is 4.5 miles/hour in a south-easterly direction that will reach 108 miles inland across the southern United States and northern Mexico. Within two days, radiation may reach 216 miles inland depending on topography, roughness of ground cover and wind currents.
**Conclusion**

We can conclude from our research that aging nuclear reactors pose a greater threat to population and waterways than newer building technology used at more recent reactor sites. The San Onofre 2/3 reactor is twenty-nine years old and was commissioned in 1983. It is situated at the highest seismic hazard location compared to all other nuclear reactors in the United States. Upon completion of collection of data, GIS mapping and research the same reactor we predicted as the highest risk was coincidentally shut down in January 2012.

**Discussion**

The project can be improved by applying data and software that includes more accurate information on the population statistics, and more advanced software for analysis of weather, wind and water flow patterns to predict the results of radiation from nuclear fallout.

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Citations


Appendix I: Maps and Flow Diagrams

Figure 1: Map display of seismic hazards, nuclear facilities, and historic earthquakes
Figure 2: Map display of populations within 50 miles of a nuclear facility
Figure 3: Map display of rivers and lakes in states that contain nuclear facilities
Figure 4: Flow diagram of project overview
Figure 5: Flow diagrams of methods for map preparation and analysis
Figure 6: Map display of water flow direction near San Onofre nuclear plant
Figure 7: Map display of wind direction and speed indicating nuclear fallout

NB The wind direction revolutions possibly skewed the scale bar.
Appendix II: Metadata

Cities

Coordinate system name: North America Equidistant Conic

Geographic coordinate system name: GCS North American 1983

Bounding coordinates: Horizontal in decimal degrees

West: -158.061857

East: -67.986769

North: 64.869104

South: 19.693112

Counties

Projected coordinate system name: North America Equidistant Conic

Geographic coordinate system name: GCS North American 1983

Bounding coordinates: Horizontal in decimal degrees

West: -178.217598

East: -66.969271

North: 71.406235

South: 18.921786

Sources

Source 1: ArcUSA 1:25M (ArcUSA 1:25M)

Source 2: Summary Tape File-1A (STF-1A) (Census STF-1A)

Source 3: Pop cy (attribute) (CACI)

Source 4: 1987 Census of Agriculture (Census Farm)
Earthquakes

Horizontal coordinate system

Geographic coordinate system name: GCS WGS 1984

Bounding coordinates: Horizontal in decimal degrees

West: -179.992676
East: 180.000000
North: 68.688660
South: 12.686000

Nuclear Facilities

Geographic coordinate system name: GCS WGS 1984

Bounding coordinates: Horizontal in decimal degrees

West: -120.854440
East: -70.579440
North: 46.235500
South: 25.435000

Seismic Hazard

Geographic coordinate system name: GCS North American 1983

Bounding coordinates: Horizontal in decimal degrees

West: -178.217598
East: -66.969271
North: 71.406235
South: 18.921786
**Wind Direction**

Geographic Coordinate System: GCS WGS 1984  
Datum: D WGS 1984  
Prime Meridian: Greenwich  
Angular Unit: Degree  
Bounding coordinates: Horizontal in decimal degrees  
West: -177.750000  
East: -32.420000  
North: 61.082000  
South: -31.870000

**Wind speed**

Geographic Coordinate System: GCS WGS 1984  
Datum: D WGS 1984  
Prime Meridian: Greenwich  
Angular Unit: Degree  
Semi-major Axis: 6378137.000000  
Denominator of Flattening Ratio: 298.257224  
Originator: AWS Truepower/NREL National Renewable Energy Laboratory  
The offshore wind resource data were originally estimated by AWS Truepower as part of an onshore wind mapping project. These data have been extrapolated to 90m and interpolated to 50 nautical miles by NREL (which is operated by the Alliance for Sustainable Energy, LLC for the U.S. Department of Energy ("DOE")).
AWS Truepower used their MesoMap system and historical weather data. The raster datasets had a spatial 200 m resolution for California and 400 m resolution for Oregon and Washington with a projection of UTM zone 11, datum WGS 84. The shapefile was generated from these raster datasets and then projected to Geographic Decimal Degrees, datum WGS 84.

Bounding Coordinates: West Bounding Coordinate: -126.018020
East Bounding Coordinate: -117.096974
North Bounding Coordinate: 49.002895
South Bounding Coordinate: 31.967050

**National Hydrography Dataset: Flowline Data**

GCS: North American 1983
Datum: D North American 1983

Description: The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation’s surface water drainage system. NHD data was originally developed at 1:100,000-scale and exists at that scale for the whole country. This high-resolution NHD, generally developed at 1:24,000/1:12,000 scale, adds detail to the original 1:100,000-scale NHD.

Purpose: The NHD is a national framework for assigning reach addresses to water-related entities, such as industrial discharges, drinking water supplies, fish habitat areas, wild and scenic rivers. Reach addresses establish the locations of these entities relative to one another within the NHD surface water drainage network, much like addresses on streets. Once linked to the NHD by their reach addresses, the
upstream/downstream relationships of these water-related entities—and any associated information about them—can be analyzed using software tools ranging from spreadsheets to geographic information systems (GIS). GIS can also be used to combine NHD-based network analysis with other data layers, such as soils, land use and population, to help understand and display their respective effects upon one another. Furthermore, because the NHD provides a nationally consistent framework for addressing and analysis, water-related information linked to reach addresses by one organization (national, state, local) can be shared with other organizations and easily integrated into many different types of applications to the benefit of all.

Bounding coordinates:

West bounding coordinate: -200

East bounding coordinate: -56.8344239

North bounding coordinate: 143.165576

South bounding coordinate: 0

Local bounding coordinates:

*Left bounding coordinate: -119.579132

*Right bounding coordinate: -115.898491

*Top bounding coordinate: 34.819387

*Bottom bounding coordinate: 32.139979

Attribute accuracy report: Statements of attribute accuracy are based on accuracy statements made for U.S. Geological Survey Digital Line Graph (DLG) data, which is estimated to be 98.5 percent. One or more of the following methods were used to test attribute accuracy: manual comparison of the source with hardcopy plots;
symbolized display of the DLG on an interactive computer graphic system; selected attributes that could not be visually verified on plots or on screen were interactively queried and verified on screen. In addition, software validated feature types and characteristics against a master set of types and characteristics, checked that combinations of types and characteristics were valid, and that types and characteristics were valid for the delineation of the feature. Feature types, characteristics, and other attributes conform to the Standards for National Hydrography Dataset (USGS, 1999) as of the date they were loaded into the database. All names were validated against a current extract from the Geographic Names Information System (GNIS). The entry and identifier for the names match those in the GNIS. The association of each name to reaches has been interactively checked, however, operator error could in some cases apply a name to a wrong reach.