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## **ABSTRACT**

### **DEVELOPMENT OF GIS DATABASE FOR HAYWARD**

#### **FAULT**

**by**

**Olugbope Maku**

Earthquake activity and its attendant effects on the earth surface have been a major concern for some time now, especially considering their negative effects in loss of human life, property damage including the emotional impact on witnesses. This study focuses on the Hayward Fault, located in the heart of population center in Contra Costa County of the San Francisco Bay Area, California.

Geographical Information System (GIS) has proved to be a valuable tool in recent years in the study and analysis of earthquakes to complement emergency response efforts. GIS has been adapted to estimate the impact of the geologic hazards on the population in the area of study, including the vulnerability of utilities, facilities and infrastructures in the event of an earthquake triggered by the Hayward Fault. The end product of this study is a GIS database for the Hayward Fault compiled from various sources including maps of geology, topography, land use/land cover and geologic hazards (i.e., landslide, fire, liquefaction, ground displacement, creep and trench) in combination with maps of community services and demography. The GIS database will provide complementary data to emergency response efforts to protect the population that will be

impacted in the event of a geologic hazard including the redesign and upgrading of infrastructures crossing the fault.

**DEVELOPMENT OF GIS DATABASE FOR HAYWARD  
FAULT**

by  
**Olugbope Maku**

**A Thesis  
Submitted to the Faculty of  
New Jersey Institute of Technology  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Science in Civil Engineering**

**Department of Civil and Environmental Engineering**

**January 2012**

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**DEVELOPMENT OF GIS DATABASE FOR HAYWARD  
FAULT**

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## **LIST OF ABBREVIATIONS**

|      |  |
|------|--|
| GIS  | Geographical Information System                  |
| USGS | United States Geological Survey                  |
| NCRS | Natural Resource Conservation Service            |
| MRLC | Multi-Resolution Land Characteristics Consortium |
| GPS  | Global Positioning System                        |

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Objective**

The objective of this study is to establish a Geographical Information System (GIS) database to complement emergency response efforts to geological hazards such as fire, trench, liquefaction, creep and landslide triggered by an earthquake. The study area is the perimeter of the Hayward Fault within the Richmond Quadrangle of the San Francisco Bay Area, Contra Costa County, California.

The GIS database includes the land characteristic data layers and the locations of community services within the Hayward Fault, in addition to the population concentration centers that will ultimately require evacuation in the event of an earthquake. The ArcGIS software functions were utilized to develop the database for the analysis/integration of the data focusing on the actual perimeter of the Hayward Fault.

### **1.2 Background Information**

The project focuses on the location of Hayward Fault which has recently been described by United States Geological Survey (USGS) as a tectonic time bomb, due anytime for another magnitude 6.8 to 7.0 earthquake. Hayward fault is located in the heart of the San Francisco Bay Area, having a total population with direct impact of any catastrophic event as a result of the fault at 5 million according to USGS. There were previously recorded earthquakes by USGS originating from the Hayward Fault in 1868 (magnitude 7.0) and 1906 (magnitude 6.8). The Hayward Fault is a 74 mile long strike-slip fault

situated mainly along the western base of the hills on the east side of San Francisco Bay.  
(USGS, 1982)

The Hayward Fault runs through densely-populated areas including the cities of Richmond, El Cerrito, Berkeley, Oakland, San Leandro, Hayward, Fremont and San Jose. The Hayward Fault merges with the Calaveras Fault east of San Jose. The famous and longer San Andreas Fault lies offshore through the San Francisco Peninsula to the west of the Hayward Fault. (USGS, 1984)



## **CHAPTER 2**

### **PROJECT DESCRIPTION**

#### **2.1 Study Area**

The area of study lies in the limits of Geographical Positioning System (GPS) coordinate N 39.96, W -122.37 with an estimated population of 948,816 and standard deviation 162.4, the area is located within the Richmond Quadrangle in Contra Costa County, California. The study area focuses on the regions around the fault susceptible to landslide, creep, trench and liquefaction. Also, locations of springs are identified.

Hayward Fault described as the most dangerous urban fault by USGS is a major branch of the San Andreas Fault system. It is a right-lateral strike-slip fault (Wallace, 1990). The Hayward Fault was created by the motion of the North American plate at the transform boundary of the San Andreas Fault resulting in additional faulting generated by the release of stresses in the crust on either side of the boundary. (Benioff, 1955) The recorded earthquake magnitude of over 5.5 by the USGS has resulted in billions of dollars of significant damage to structures and utilities over the past few years.

#### **2.2 Characteristics of Hayward Fault System**

The effects of faults on earthquakes depend on the nature of the rock along the fault, if it is weak and ductile, the little strain energy that could be stored will be released relatively slowly and the movement will occur aseismically. If on the other hand, the rock is strong and brittle, the failure will be rapid, rupture of the rock will release the stored energy

explosively, partly in the form of heat and partly in the form of stress waves that are felt as earthquakes. (Reid, 1911)

The plates of the earth are in constant motion and plate tectonics indicate that majority of their relative movement occurs near their boundaries. The long term effect of this movement observed in the geologic record reflects deformations over very long period of time. As relative movement of the plate occurs, elastic strain energy is stored in the materials near the boundary as shear stresses increase on the fault planes that separate the plates. When the stress reaches the shear strength of the rock along the fault, the rock fails and the accumulated strain energy is released. (Cramer, 1996)

The transform boundary defines the San Andreas Fault and the motion of the North American plate is not entirely parallel to the plate boundary, resulting in additional faulting on both sides of the San Andreas Fault that gave birth to the Hayward Fault. (Kanamori and Stewart, 1978)

According to the California Geological Survey, the Hayward Fault is considered to be at great risk due to the poor soil conditions in the alluvial plain that drops from the East Bay Hills to the eastern shoreline of San Francisco Bay. The soil is mostly water saturated mud and sand that tends to amplify the effects of an earthquake and thus producing significantly greater ground motion with the regions susceptibility to geologic hazards.

The location of the Hayward Fault is made up of the following soils based on California Geological Survey categorization, soils type C is overlain by soil type D, and then overlain by soil type E, soil type A and B are at great depths, this is noticeable in the vegetation layer of the map to comprise of grasslands, the area cannot support forest

vegetation as documented by the California Department of Conservation. The soils of the area for the whole of San Francisco Bay Area comprise the following soils:

|                    |   |  |
|--------------------|---|--|
| <b>Soil Type A</b> | $V_s > 1500$<br>m/sec                       | Includes unweathered intrusive igneous rock. Occurs infrequently in the bay area. Soil types A do not contribute greatly to shaking amplification.   |
| <b>Soil Type B</b> | $1500$<br>$m/sec >$<br>$V_s > 750$<br>m/sec | Includes volcanics, most Mesozoic bedrock, and some Franciscan bedrock. (Mesozoic rocks are between 245 and 64 million years old. The Franciscan Complex is a Mesozoic unit that is common in the Bay Area.) Soil types B do not contribute greatly to shaking amplification.                          |
| <b>Soil Type C</b> | $750$ m/sec<br>$> V_s >$<br>$350$ m/sec     | Includes some Quaternary (less than 1.8 million years old) sands, sandstones and mudstones, some Upper Tertiary (1.8 to 24 million years old) sandstones, mudstones and limestone, some Lower Tertiary (24 to 64 million years old) mudstones and sandstones, and Franciscan melange and serpentinite. |
| <b>Soil Type D</b> | $350$ m/sec<br>$> V_s >$<br>$200$ m/sec     | Includes some Quaternary muds, sands, gravels, silts and mud. Significant amplification of shaking by these soils is generally expected.   |
| <b>Soil Type E</b> | $200$ m/sec<br>$> V_s$                      | Includes water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type.   |

*V<sub>s</sub> denotes secondary waves velocity (i.e., transverse waves velocity that typically follow primary waves during an earthquake displacing the ground perpendicular to the direction of propagation.)*

Source: California Geological Survey, Department of Conservation

The major earthquake related features includes faults, creep, springs, liquefaction and fault related folds, the observations along the surface traces of active faults in California indicate that tectonic displacement can occur either as seismic slip or aseismic fault creep. (USGS, 1984) The Hayward fault has associated geologic hazards as a result of the *aseismic creep* (measurable surface displacement along a fault in the absence of notable earthquakes) exists along the Hayward Fault, but insufficient to prevent a substantial earthquake. (USGS, 1984) The surface of the Hayward Fault as noted in the recent study by California Geological Survey is creeping at less than 0.2 inches per year,

the creep is sufficient to displace roads, curbs and sidewalks. Based on the account of the California Geological Survey, creep damage to asphaltic road surfaces will usually appear as a series of echelon cracks, creep effect is also noticeable in older structures crossing the fault, some of which have been fitted with expansion joints to accommodate the creep.

The size of an earthquake, the type of ground the earthquake wave travel through and the distance away from the earthquake source determines the intensity of ground shaking. Wet soil particles (sand and silt) shift and separate during strong ground shaking causing *liquefaction* – some of the damages to buildings in the San Francisco Marina District which lies in close proximity to the Hayward Fault during the 1989 Loma Prieta earthquake were due to liquefaction. A great deal of information has come from post-earthquake field investigations, which have shown that liquefaction often recurs at the same location when soil and groundwater conditions remained unchanged (Youd, 1984a)

Landslide caused by downhill movement of ground primarily as a result of gravity acting on weakened soil or rock by contributing factors such as vibration from earthquake, erosion, groundwater, thunder and human activity of grading. The nature of the materials in some sections along the Hayward fault makes it susceptible to landslide. A study of 300 U.S. earthquakes between 1958 and 1977 showed that the smallest earthquakes noted to have produced landslides had local magnitudes of 4.0. (Keefer, 1984)

*Springs* especially hot spring water are associated with earthquake when underground water channels are disrupted in the event of an earthquake causing the

sinking ground to push up some of the water. This is visible in few locations around the Hayward Fault. (Catchings, et al, 2009)

## **CHAPTER 3**

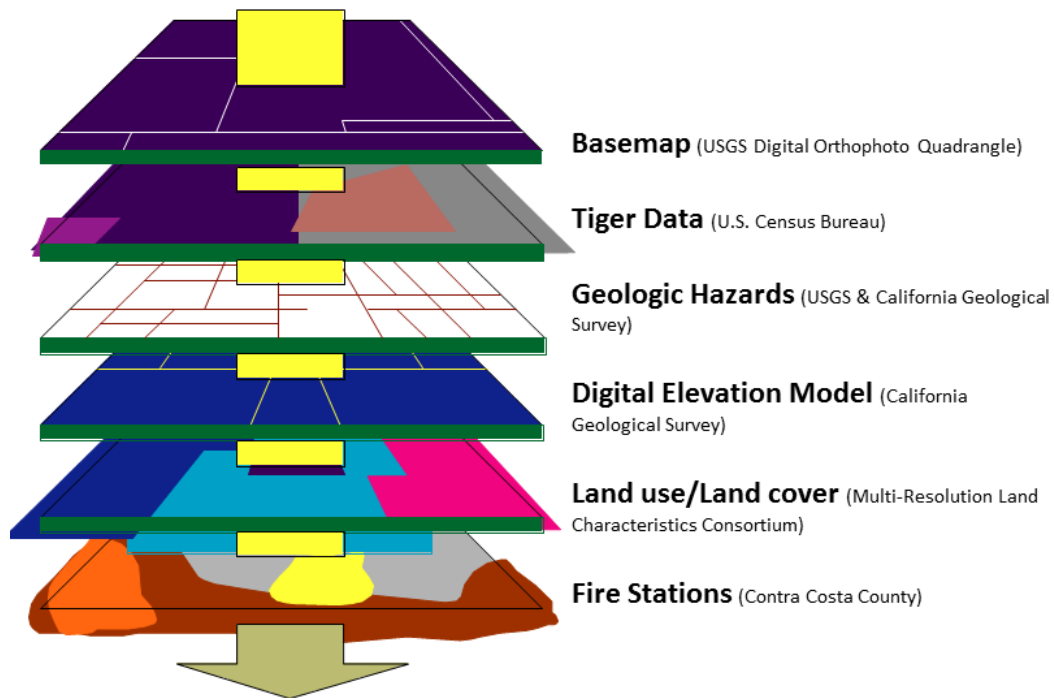
### **GIS DATABASE**

#### **3.1 Data Characteristics**

This study utilizes the USGS Digital Orthophoto Quadrangle (DOQ) as base map for Richmond, Mare island, Petaluma Point and San Quentin California; other data layers include Tiger data from the U.S. Census Bureau comprising roads, hydrography and community services such as hospitals, schools, police station, public library and religious centers. The digital elevation model (DEM) obtained from the California Geological Survey. Map Layers of springs, trench, and areas susceptible to creep and landslide obtained from the USGS and California Geological Survey. The locations of fire stations obtained from the Contra Costa County GIS database. The soils layer from the Natural Resources Conservation Service (NCRS) and land use/land cover layer from the Multi-Resolution Land Characteristics Consortium (MRLC). The conceptual database is as shown in Figure 1.1

The project utilized GIS tools in creating a geodatabase for the data collected from various sources noted above in ArcCatalog, and then added as data layers to ArcMap in ArcGIS. The ArcGIS tools were used to determine the locations of most occurrences of landslide, creep and liquefaction in the vicinity of the fault line within the Richmond Quadrangle.

## GIS CONCEPTUAL DATABASE OF HAYWARD FAULT



**Figure 1.1: GIS conceptual database of Hayward Fault**

### 3.2 Data Analysis

The study area is approximately 128 square miles; the study length of the Hayward Fault is approximately nine (9) miles. Information obtained from the geologic data layer indicates that approximately 0.4 square mile and 0.3 square mile area lie in the vicinity of the fault in regions susceptible to risk of creep and landslide respectively. Also, 0.5 square mile area is at risk in trench location. Although, there seems to be no available data on liquefaction within the study area, locations of spring could serve as potential

locations for liquefaction due to the groundwater level variation with the development of excess pore pressure during earthquake shaking.

It can be deduced from the layers that many services such as roads, bridges and of course various utilities including electricity, gas and water services to the communities crosses the Hayward fault, some hospitals, schools and other landmarks are noted to be in the vicinity of the fault. One fire station actually lies in a region susceptible to landslide and liquefaction. The digital elevation model layer in the map shows that the fault system is at a lower elevation. The vegetation layer indicates grassland vegetation in the study area. Also, information obtained from the land use/land cover indicated that a lot of pasture land around the perimeter of the Hayward Fault have been developed in the last ten (10) years.

The demographic data layer provides data on the dense population along the perimeter of the fault in regions susceptible to risk of creep and landslide. It is obvious that the locations of the fire stations for emergency response purposes will fall short of expectations with respect to their locations – two fire stations appears to be sitting on top of creep zone both at the Hill Top Mall and El Cerrito, one out of the two fire stations in the creep zone of El Cerrito also lies in the vicinity of potential landslide with another fire station located directly on the Hayward Fault. In the event of an earthquake triggered by the Hayward Fault three fire stations in Kesington will be rendered incapacitated to render any form of service due to utility cut-off. An estimated eight community service centers are known to be at risk of geologic hazards.



It is apparent that the number of population that will be affected in the event of an earthquake will be enormous due to the dense population distribution in the vicinity of the Hayward Fault location. Analysis of the information provided by the demographic layer indicate that an approximate total population of 63,444 people are located on the Hayward Fault, total population on creep location is 3,500 people, an estimated 12,000 people are on landslide prone locations and a total population of 2,000 people in trench locations. The above statistics indicate that approximately 12% (81,508 people) of the entire population of the study area are susceptible to geologic hazards of one sort.

## CHAPTER 4

### CONCLUSIONS AND RECOMMENDATIONS

This project will help authorities synchronize the provision and management of emergency services in an event of an earthquake triggered by the Hayward Fault according to priority in the threatened communities and establishes the amount and type of resources required to cater for the affected population.

No doubt, a lot has been accomplished over the past few years in the construction of earthquake resistant structures with California building code providing the required data and technical support services in building construction. It is certain that work is still required in the upgrading of infrastructures to be able to cope with the challenges of an earthquake. The locations of community services such as fire stations, hospitals, police stations and schools on creep locations (San Pablo, Giant, Richmond Golf Course and Alvarado Park), potential landslide sites (El Cerrito and Kesington), trench locations (Union City, Oakland and Berkeley) and potential liquefiable soils (San Leandro and Pioneer Park) will require redesign and construction upgrade to be able to withstand an earthquake. There is need to relocate all population and facility from the Hayward Fault. The design and construction of infrastructures crossing the Hayward Fault yet to be upgraded will require the provision of expandable sleeves to accommodate movement during earthquake activity.

The lower elevation of the fault location could hamper or limit helicopter usage during emergency operations and this has to be taken into consideration. Also, the vegetation of grassland in the vicinity of the fault makes the area susceptible to sustained

fire during an earthquake. There is need for provision of emergency response command centers in locations that can stand the test of time during earthquake activity to cater for the population in the geologic hazard zone of creep, landslide, trench and liquefaction.

## LOCATION OF HAYWARD FAULT WITH THE STUDY AREA

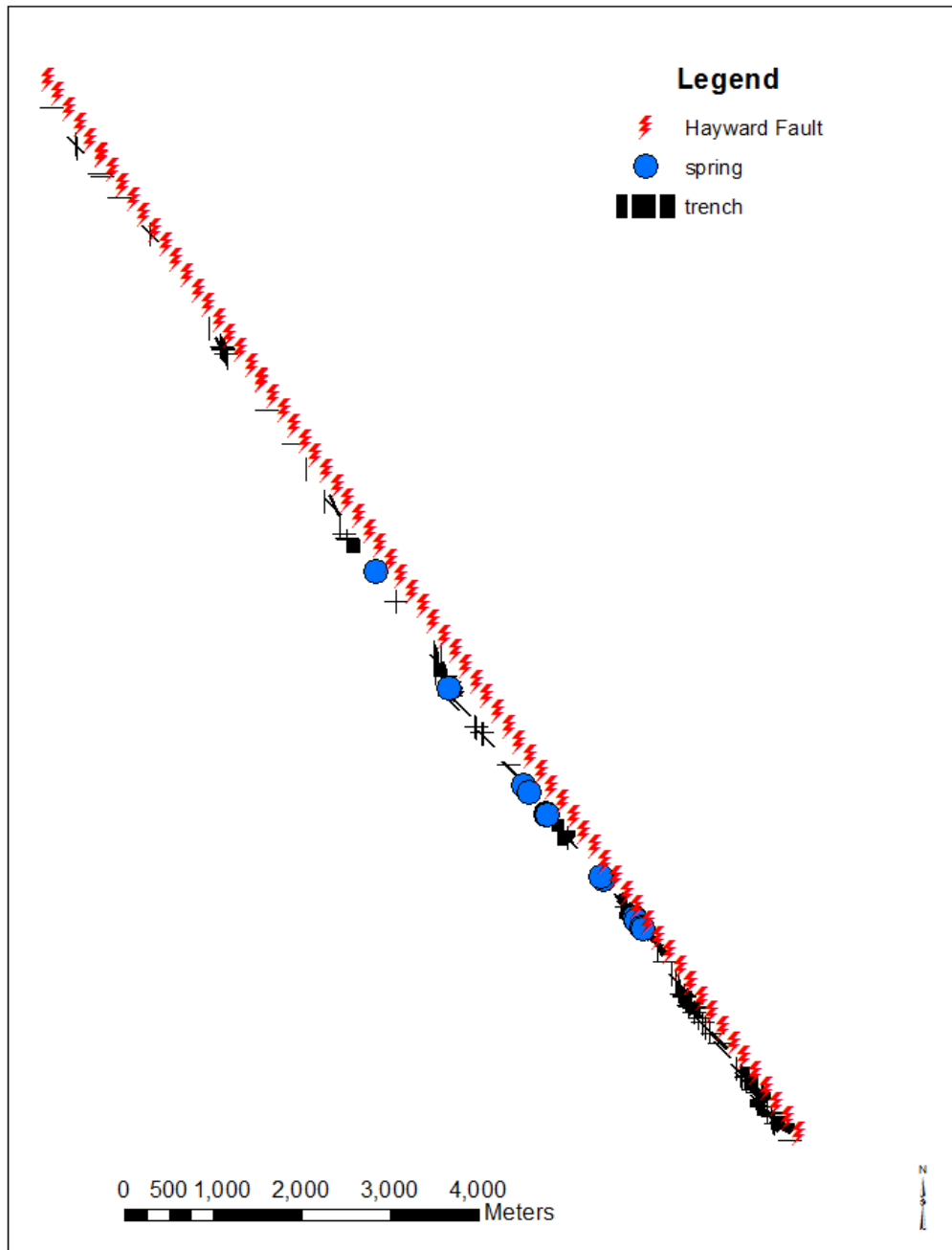


Source: U.S. Geological Survey

<http://earthquake.usgs.gov/regional/nca/haywardfault/gis/>

Figure A.1: Map of the study area

## HAYWARD FAULT WITH SPRING AND TRENCH LOCATIONS

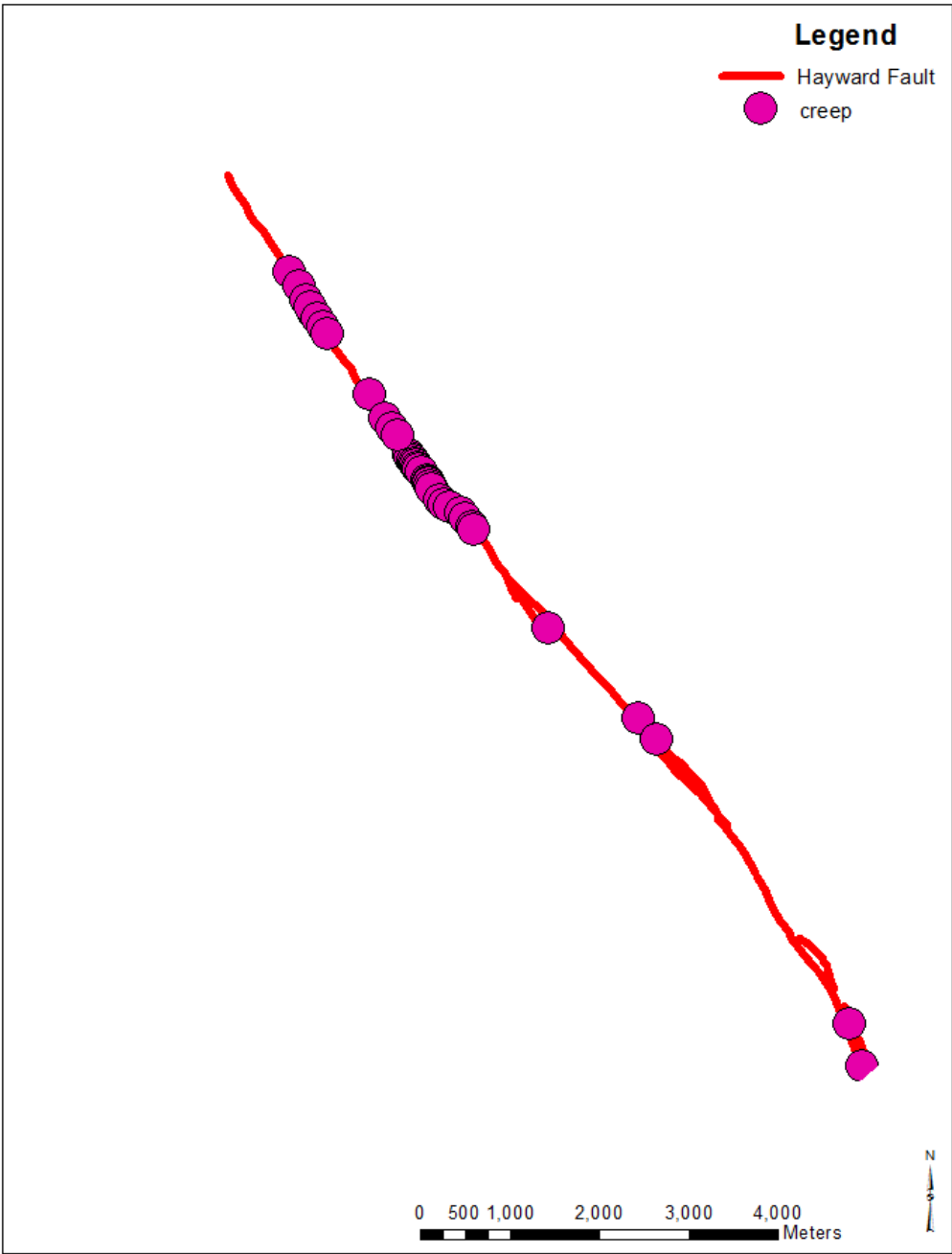


Source: U.S. Geological Survey

<http://earthquake.usgs.gov/regional/nca/haywardfault/gis/>

Figure A.2: Hayward Fault spring and trench locations

# HAYWARD FAULT CREEP LOCATIONS

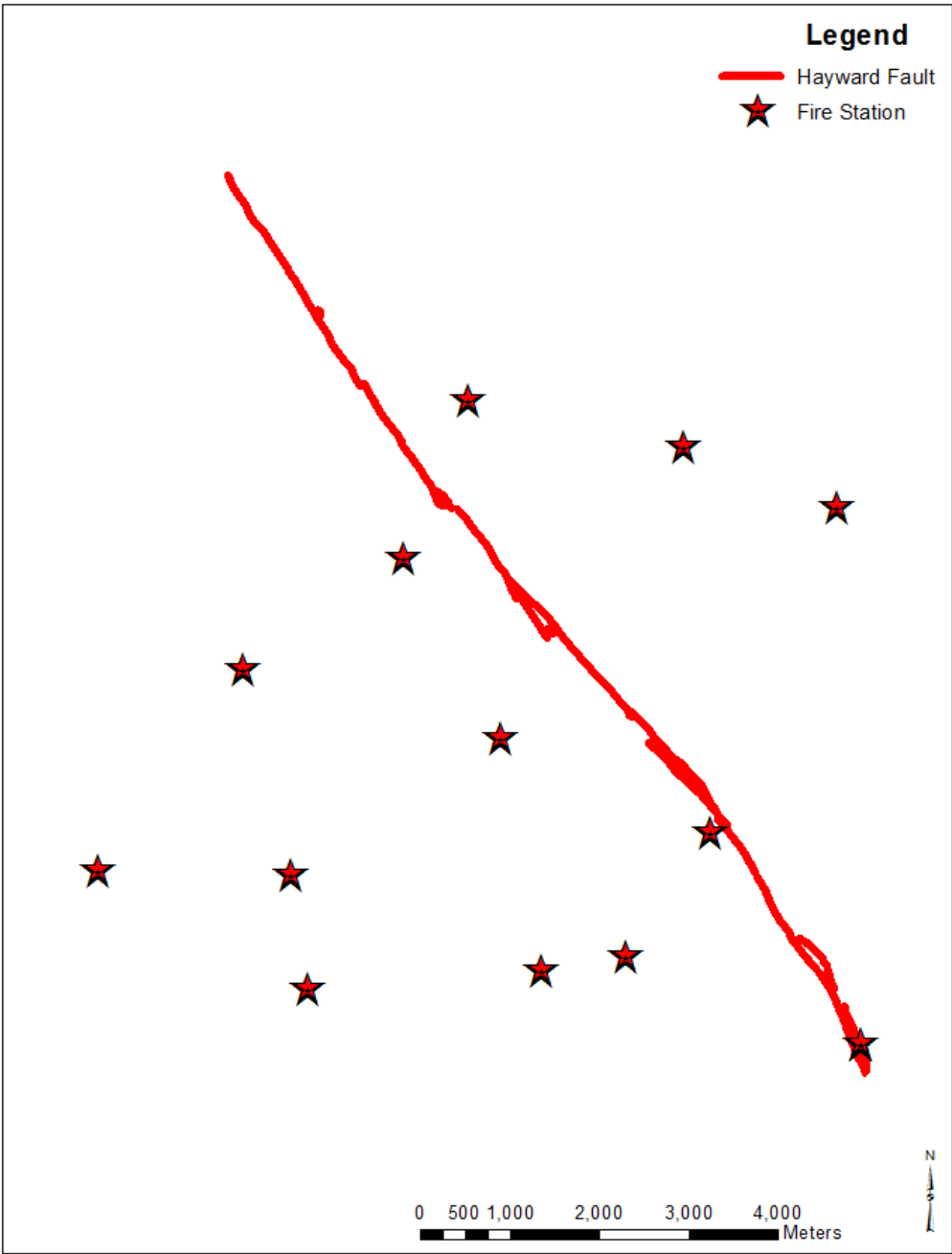


Source: California Geological Survey

<http://www.conservation.ca.gov/index/Pages/NewSeismicHazard.aspx>

**Figure A.3: Hayward Fault creep locations**

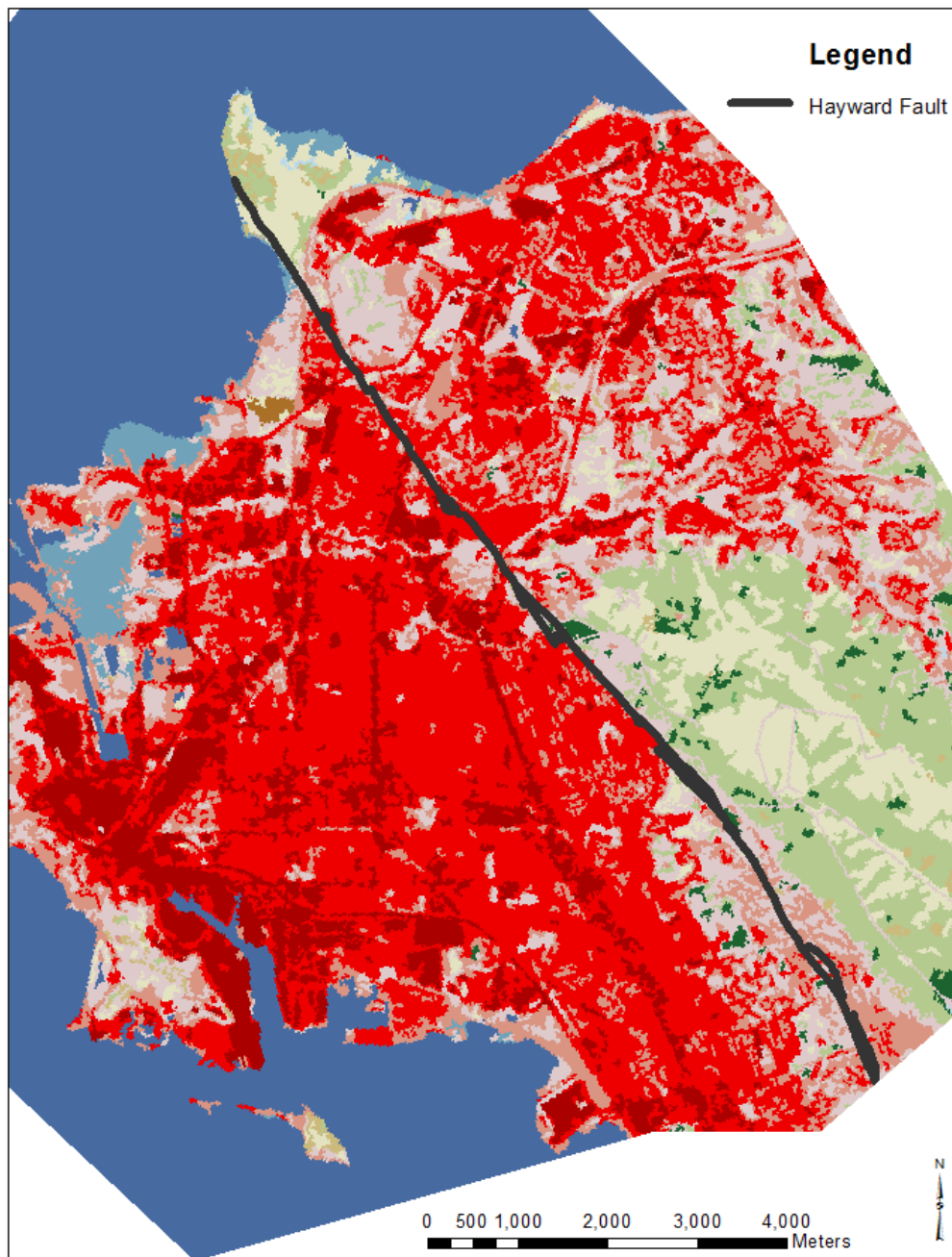
# HAYWARD FAULT WITH FIRE STATION LOCATIONS



Source: Contra Costa County, CA

<http://www.ccmmap.us/information.asp>  
**Figure A.4: Hayward Fault fire station locations**

## HAYWARD FAULT LAND USE/LAND COVER MAP



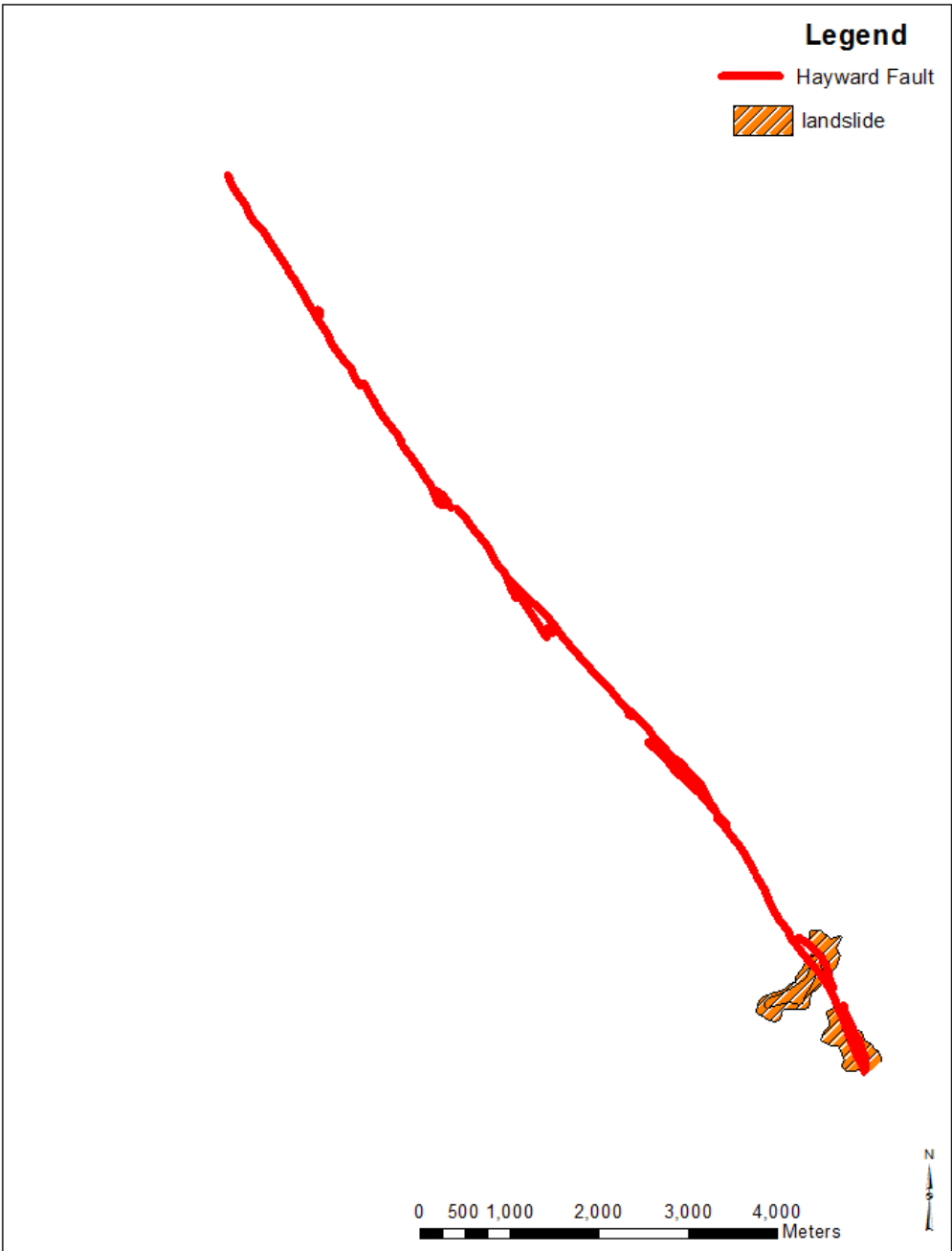
Source: Multi-Resolution Land Characteristics Consortium

[http://www.mrlc.gov/nlcd06\\_data.php](http://www.mrlc.gov/nlcd06_data.php)

Figure A.5: Hayward Fault land use/land cover map



# HAYWARD FAULT WITH POTENTIAL LANDSLIDE LOCATIONS

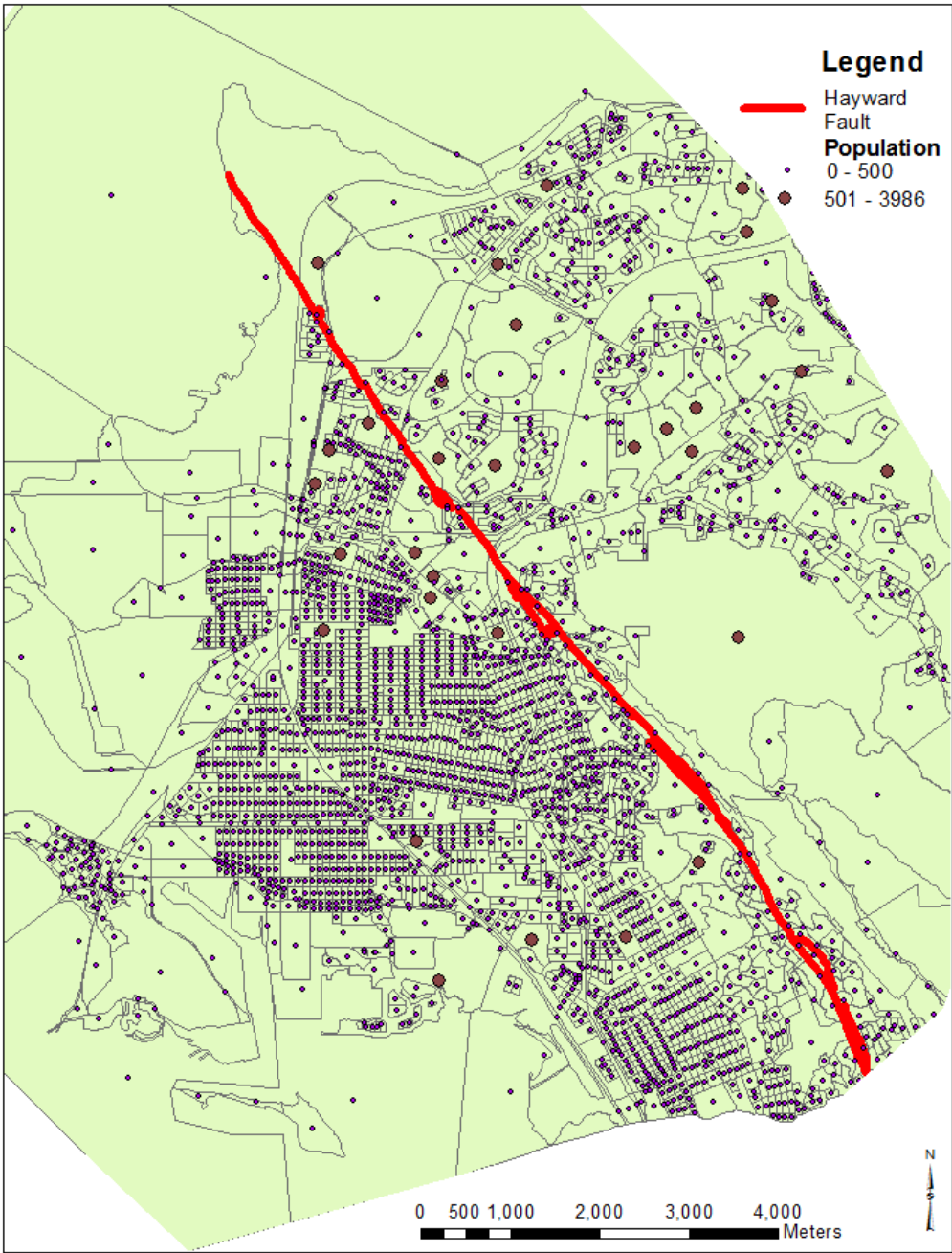


Source: California Geological Survey

<http://www.conservation.ca.gov/index/Pages/NewSeismicHazard.aspx>

**Figure A.6: Hayward Fault potential landslide locations**

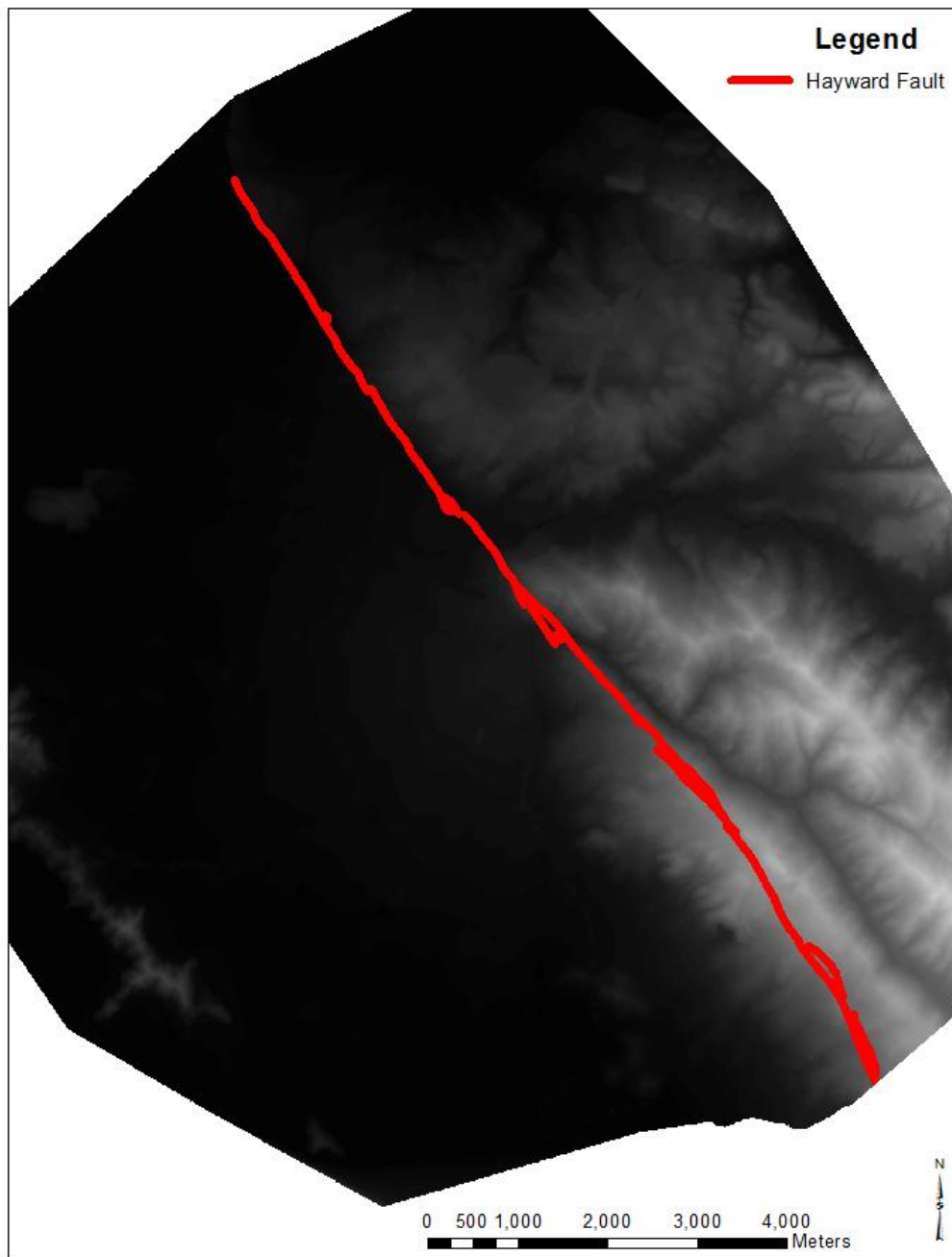
# HAYWARD FAULT POPULATION CENTER DISTRIBUTIONS



Source: US Census Bureau

<http://www.census.gov/geo/www/tiger/tgrshp2000/>  
**Figure A.7: Hayward Fault population distributions**

## HAYWARD FAULT DIGITAL ELEVATION MODEL

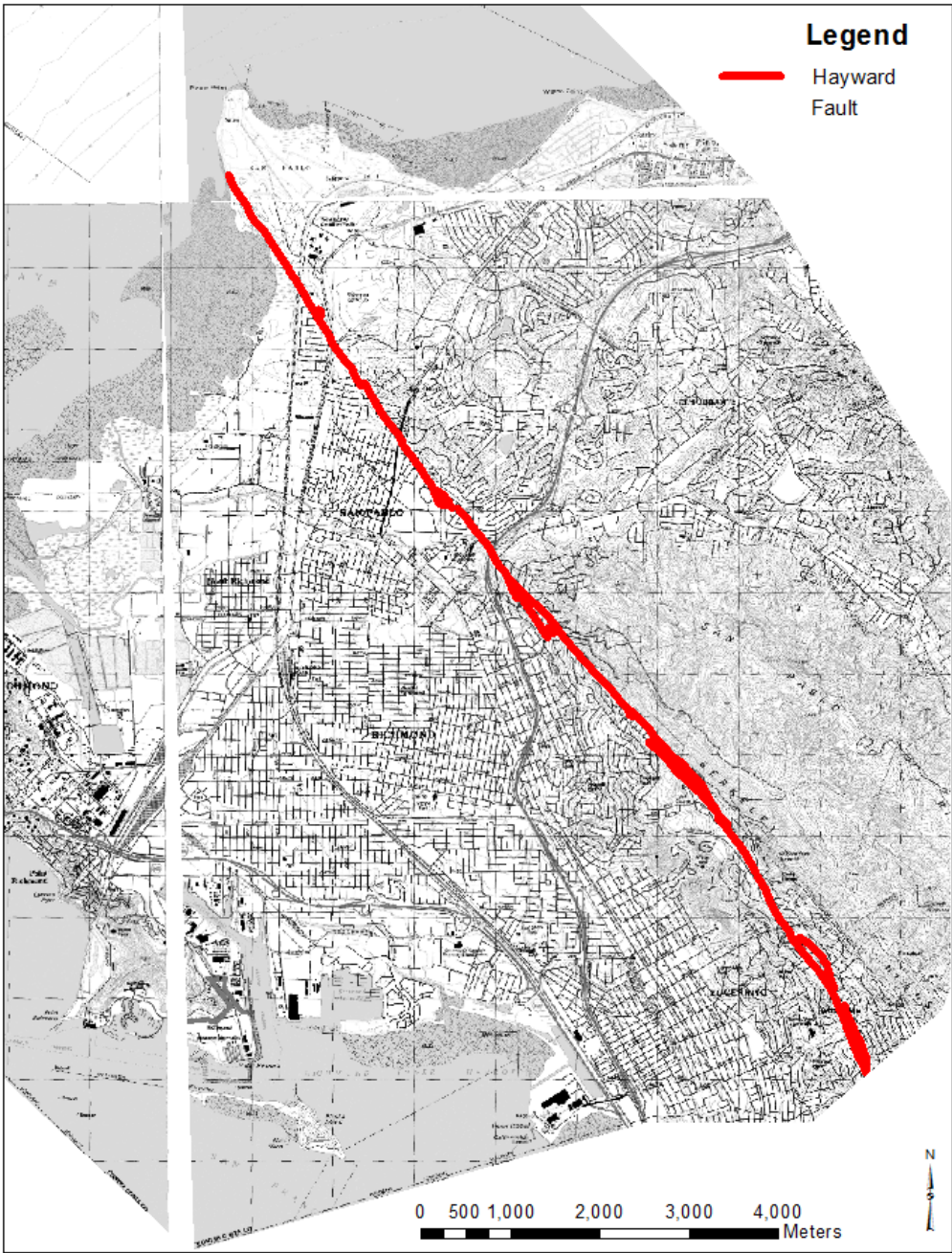


Source: California Geological Survey

<http://www.conservation.ca.gov/index/Pages/NewSeismicHazard.aspx>

**Figure A.8: Hayward Fault digital elevation model**

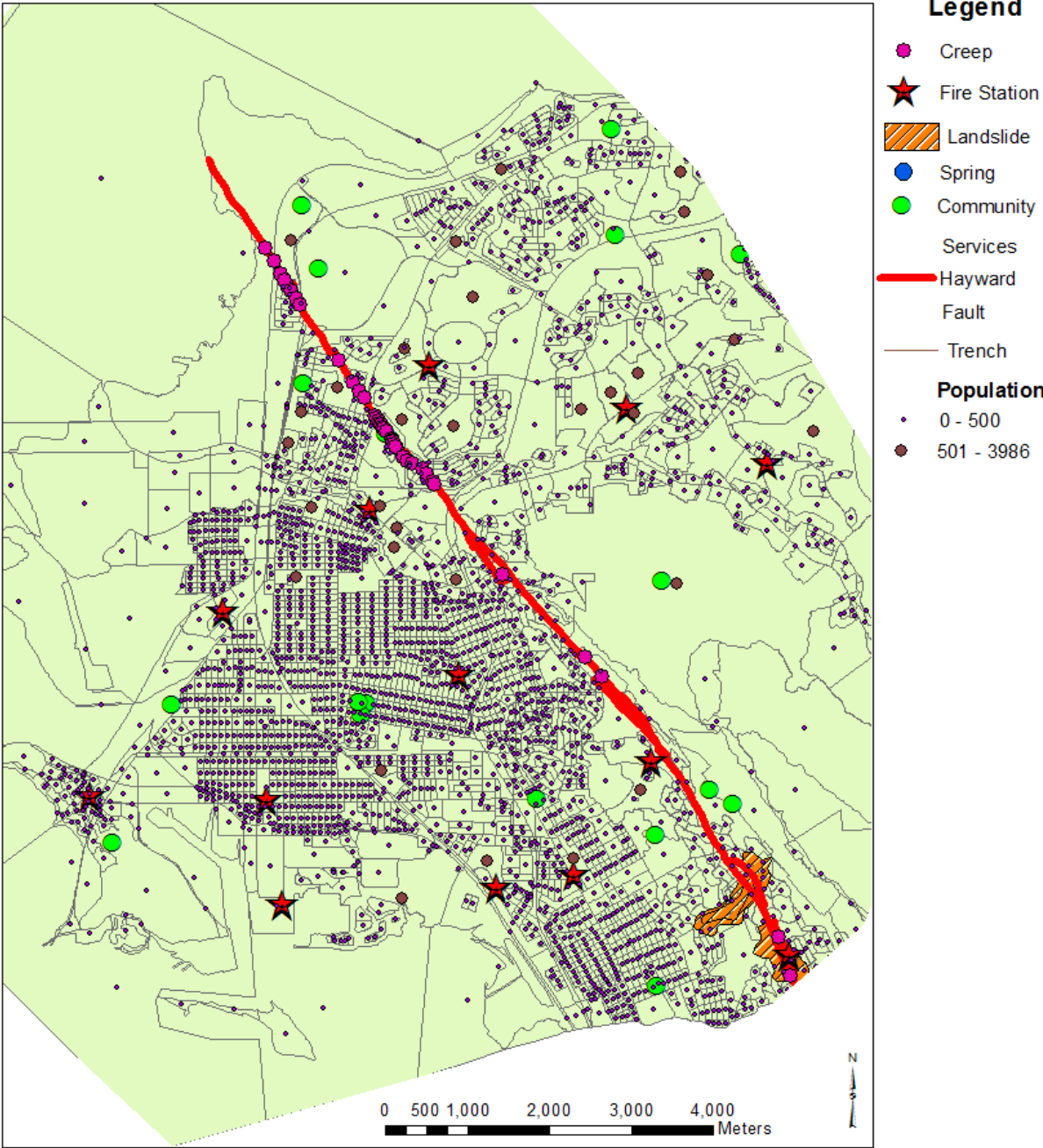
# HAYWARD FAULT TOPOGRAPHIC MAP



Source: US Geological Survey

<http://earthquake.usgs.gov/regional/nca/haywardfault/gis/>  
**Figure A.9: Hayward Fault topographic Map**

# HAYWARD FAULT GIS DATABASE



Sources: USGS, US Census Bureau, California Geologic Survey, MRLCC and Contra Costa County

**Figure B.1: Hayward Fault GIS database**

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