

Assessing Tsunami Runup and Coastal Inundation Hazards on the coast of Hilo, The Big Island, Hawaii

GIS Final Project: Fall 2015

By: Calyn Jew

Introduction of Problem

The Hawaiian Islands are a target for local and distant earthquake triggered tsunamis. These tsunamis put the coastal regions of Hawaii at threat. In this project, we want to address the coastal hazard zones of the Big Island based on 5 historic earthquakes. Historic data shows that the coast of Hilo (a district of Hawaii) is a location of highly concentrated tsunami events. Previous studies on tsunamis provide runup and horizontal inundation data, however we want to combine this information to quantify the coastal area that would be affected by various tsunami wave heights along the eastern coast of the Big Island. The tsunami data for particular regions of the Big Island are sparsely scattered and/or undefined for each historic earthquake. Therefore, we must combine historic runup and horizontal inundation data to determine the best averaged values for our analysis.

How much does varying wave height influence the amount of horizontal inundation along the coast of Hilo?

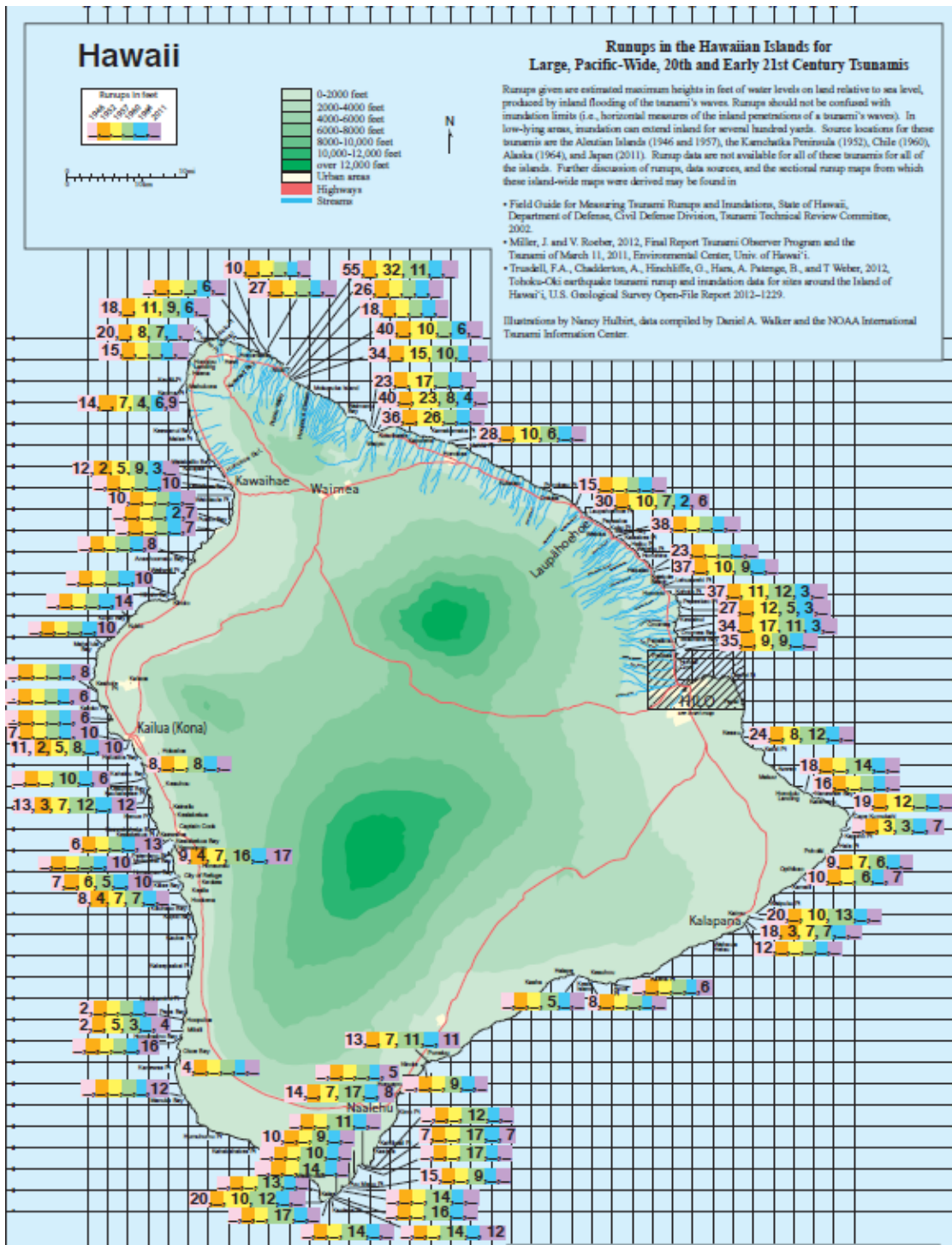
Data Collection

- DEM taken from the coastal geology group at the University of Hawaii Manoa.
 - <http://www.soest.hawaii.edu/coasts/data/hawaii/dem.html>
- Census Blocks-2010 containing census block polygons with populations
 - <http://planning.hawaii.gov/gis/download-gis-data/>
- Hawaii shape files found on the state of Hawaii government website
 - Shapefiles: Tsunami Heights and Elevation contours (100ft)
 - <http://planning.hawaii.gov/gis/download-gis-data/>
- Historic tsunami run up data taken from the International Tsunami Information Center
 - https://www.ngdc.noaa.gov/nndc/struts/results?bt_0=&st_0=&type_3=Exact&query_10=None+Selected&op_12=eq&v_12=&type_14=Exact&query_14=80&op_3=eq&v_3=USA&type_4=Like&query_4=&bt_17=&st_17=&st_5=&bt_6=&st_6=&bt_5=&type_3=Exact&query_15=None+Selected&bt_1=&st_1=&bt_2=&st_2=&bt_16=&st_16=&d=166&query=&t=101650&s=167&submit_all=Search+Database

Tsunami Run up Background Information

- Runups: The estimated maximum heights (in feet) of water levels relative to sea level, caused by inland flooding of tsunami's waves.
- Horizontal Inundation: The maximum horizontal distance of inland flooding
- Inundation Area: An area of land subject to flooding
- The Maximum water height above mean sea level can be measured in multiple ways.
 - Type 1: Water height via eyewitness observation
 - Type 2: Tide Gauge
 - Type 3: Deep ocean gauge
 - Type 4: Water height (post tsunami measurements)
 - Type 5: Run up height (post tsunami measurements)
 - Type 6: Run up height in harbor

○ Type 7: Flow depth (post tsunami measurements)



http://itic.ioc-unesco.org/images/stories/media_resources/hawaii_information/runups/hawaii_2013_11x17_insetseparate_small.pdf

This project will take tsunami wave height data produced by 5 historic earthquakes that reached the coast of Hilo, Hawaii.

- 1) 1946 Aleutian Islands Earthquake, Alaska (8.2)
 - 2,400 miles from earthquake's epicenter
- 2) 1952 Kamchatka Earthquake (Far Eastern Russia) (9.0)
 - 3,389 miles from earthquake's epicenter
- 3) 1957 Aleutian Earthquake, Alaska (8.6)
 - 2,400 miles from earthquake's epicenter
- 4) 1960 Chile Earthquake, off the coast of southern Chile (9.5)
 - 6,687 miles from earthquake's epicenter
- 5) 1964 Alaska Earthquake (9.2)
 - 2,300 miles from earthquake epicenter

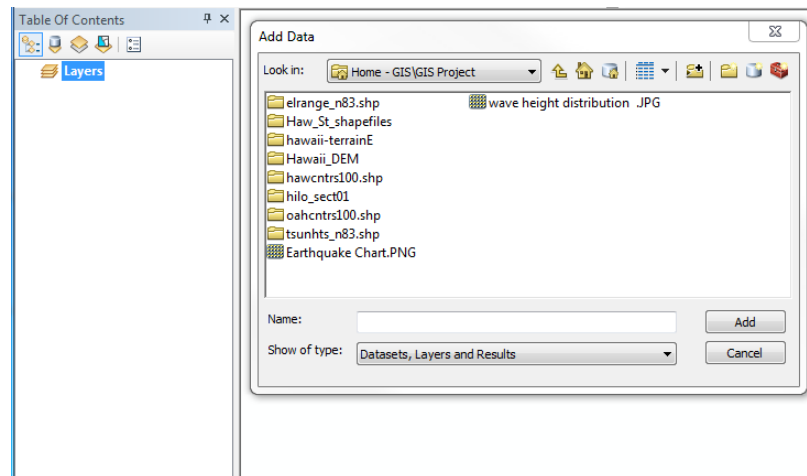
Procedure:

Make a polygon of specific location, use mask to define properties

The procedure to create a map highlighting coast hazard zones is outline below.

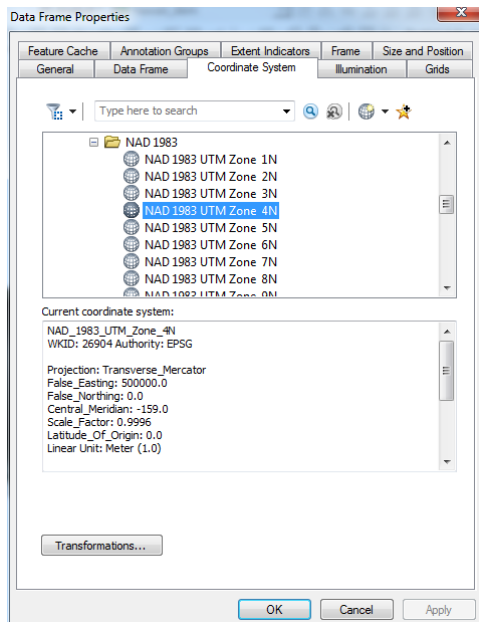
1) Loading GIS Data

I downloaded shapefiles and DEM data of Hawaii online. I had to extract the files in order to access them. I worked off of my student S drive which was already connected in ArcMap. In order to load my Hawaii DEM, tsunami data, and county districts I right clicked the layer icon and followed it to my S drive.



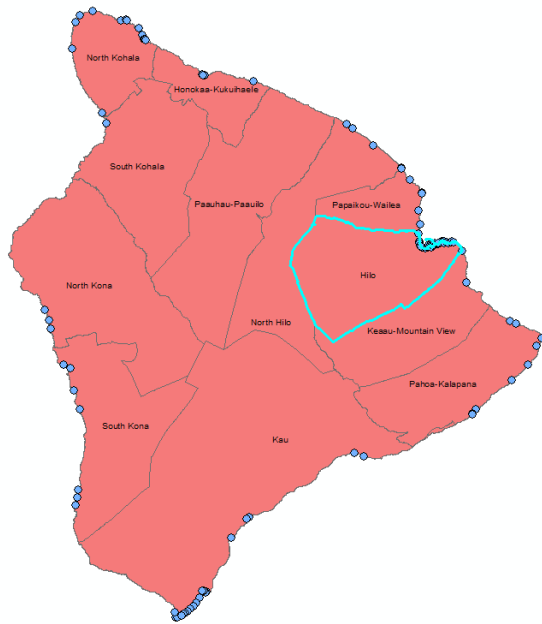
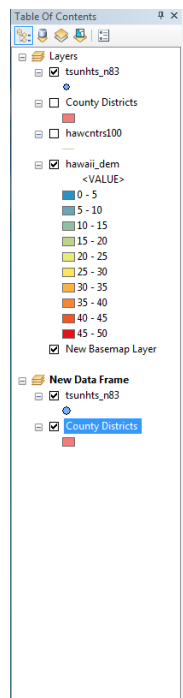
2) Projected Coordinate System Check

After loading the DEM, county districts, and tsunami heights, I made sure the data frame coordinate system was set properly. The projection for this project was set by right clicking the "Layers", "Properties", then "Coordinate System". I chose Projected Coordinate System> UTM> NAD 1983>NAD 1983 UTM Zone 4N.



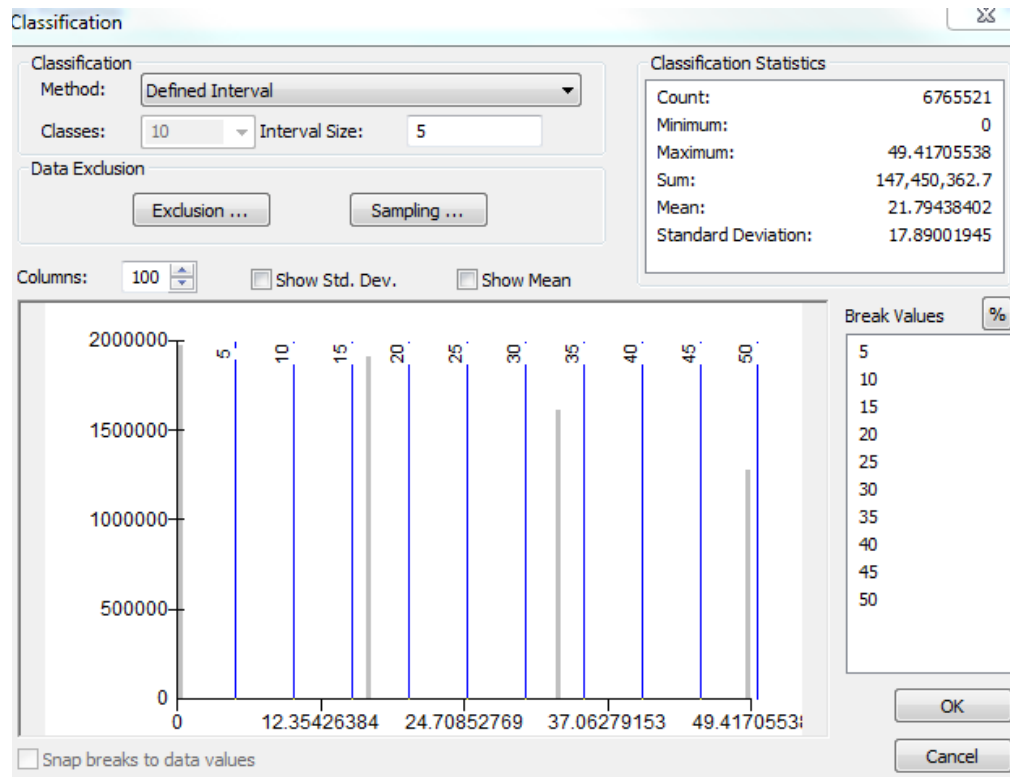
3) Determining a Target Area

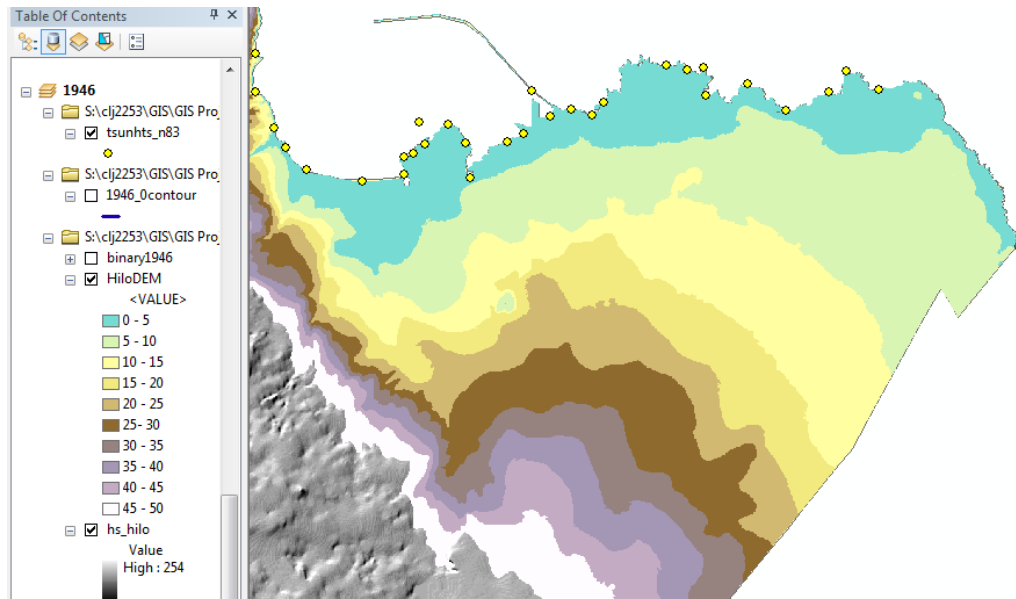
Looking at the distribution of tsunami wave height points, the coast of Hilo has the most abundant wave height data, and therefore is more prone to wave hazards. For this reason, we focused on the horizontal inundation along the coast of this district. The wave height points are based on data collected during the 1946, 1952, 1957, 1960, and 1964 earthquake events.



4) Classifying the DEM Interval

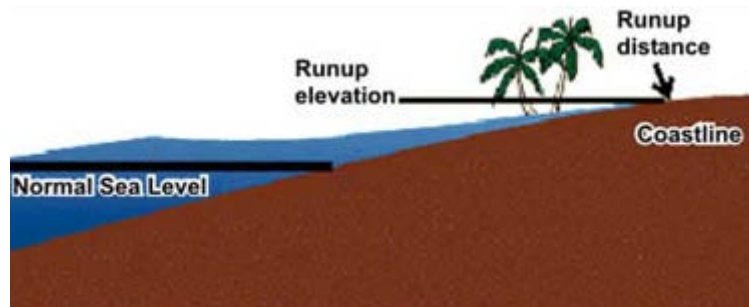
Next, I changed the symbology of the elevation raster by right clicking on the DEM raster, selecting the "Symbology tab", hitting "Classify", then choosing "Defined Interval" under classification, and selecting an interval size of 5 m. I excluded values greater than and equal to 55 m, because GIS crashed with so many classes at the small interval size and it is not necessary for the purpose of this project (majority of the wave heights are less than 11 meters). Click "ok". I then changed the color ramp.





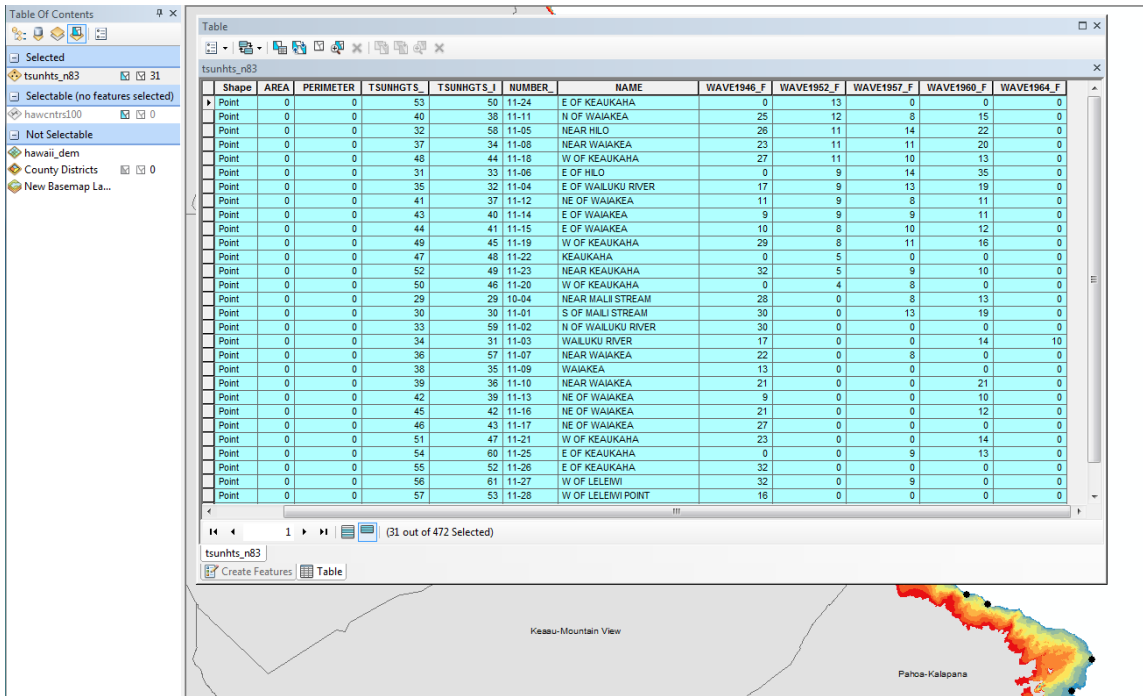
5) Defining Inundation parameters

I want to map the inundation area based on historic wave heights along the coast of Hilo. We will assume for the purpose of this project that the measured wave height is equivalent to the vertical component on the DEM or the onshore elevation. The actual ratio between wave height and horizontal inundation/runup distance varies due to the loss of wave energy as it encounters obstacles and migrates onshore. Therefore, we will assume that the documented wave height represents the elevation of inland flooding.



<http://www.sms-tsunami-warning.com/pages/runup-inundation#.VI4SI62FN9M>

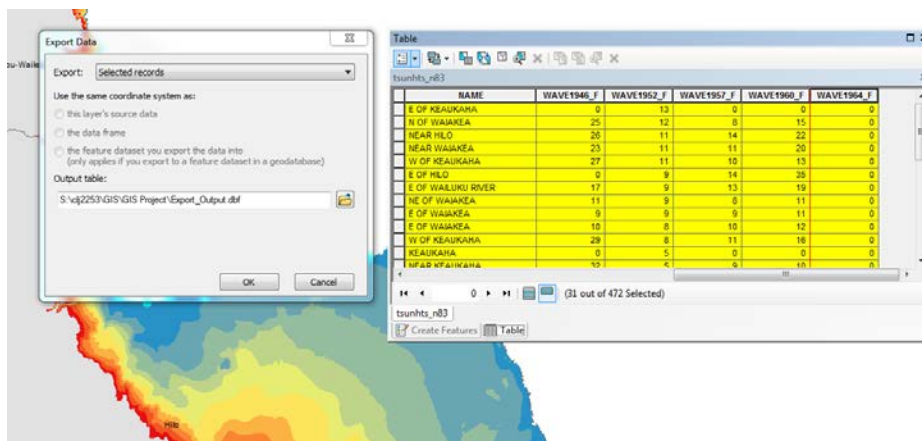
Clicking the list by selection icon in the table of contents, I made the tsunhts_n83 layer selectable. Using the select features tool, I selected the wave heights along the coast of Hilo (while holding the 'Shift' key).



Due to the variable nature of tsunami wave heights and lack of data for certain earthquake events, the average wave height along the Hilo coast is used to project the elevation of inland flooding.

6) Obtaining Wave Data for Hilo

The wave height data obtained along the Hilo coast is measured in feet. The loaded DEM is in meters, so converting is necessary. In order to convert the wave heights (feet) to meters, I exported the selected attribute table. I did so by highlighting the name and 5 wave height columns, clicking the table options dropdown box, selecting “Export” and adding the output destination in dbf format. This allowed me to open up the attribute table in excel.



	F	G	H	I	J	K
1	NAME	WAVE1946_F	WAVE1952_F	WAVE1957_F	WAVE1960_F	WAVE1964_F
2	NEAR MALII STREAM	28.000	0.000	8.000	13.000	0.000
3	S OF MALII STREAM	30.000	0.000	13.000	19.000	0.000
4	E OF HILO	0.000	9.000	14.000	35.000	0.000
5	NEAR HILO	26.000	11.000	14.000	22.000	0.000
6	N OF WAILUKU RIVER	30.000	0.000	0.000	0.000	0.000
7	WAILUKU RIVER	17.000	0.000	0.000	14.000	10.000
8	E OF WAILUKU RIVER	17.000	9.000	13.000	19.000	0.000
9	NEAR WAIAKEA	22.000	0.000	8.000	0.000	0.000
10	NEAR WAIAKEA	23.000	11.000	11.000	20.000	0.000
11	WAIAKEA	13.000	0.000	0.000	0.000	0.000
12	NEAR WAIAKEA	21.000	0.000	0.000	21.000	0.000
13	N OF WAIAKEA	25.000	12.000	8.000	15.000	0.000
14	NE OF WAIAKEA	11.000	9.000	8.000	11.000	0.000
15	NE OF WAIAKEA	9.000	0.000	0.000	10.000	0.000
16	E OF WAIAKEA	9.000	9.000	9.000	11.000	0.000
17	E OF WAIAKEA	10.000	8.000	10.000	12.000	0.000
18	NE OF WAIAKEA	21.000	0.000	0.000	12.000	0.000
19	NE OF WAIAKEA	27.000	0.000	0.000	0.000	0.000
20	KEAUKAHA	0.000	5.000	0.000	0.000	0.000
21	W OF KEAUKAHA	27.000	11.000	10.000	13.000	0.000
22	W OF KEAUKAHA	29.000	8.000	11.000	16.000	0.000
23	W OF KEAUKAHA	0.000	4.000	8.000	0.000	0.000

1 foot = .3048 meters. I converted all the wave values by multiplying by .3048.

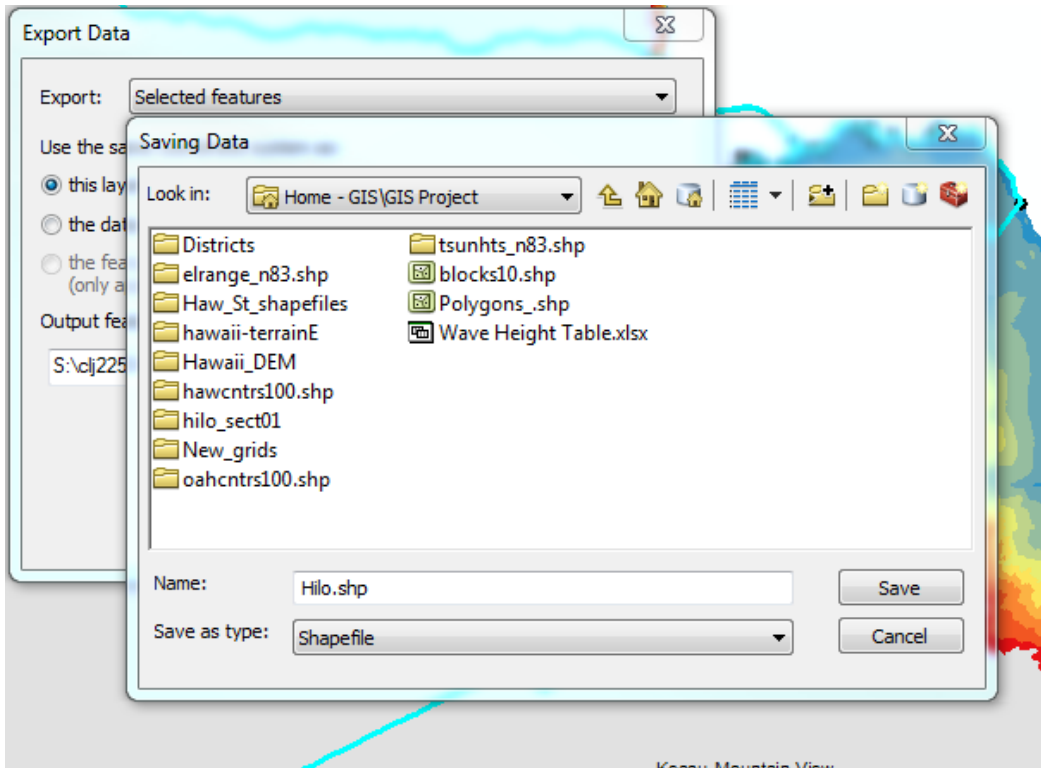
Two parameters dictate the values that will be mapped...

- Average of wave heights not including zero heights. *The zero heights indicate that the particular location along the coast was unaffected.* For the purpose of this project, we will assume that in the event of that earthquake (or similar one) the coast will be uniformly affected.
- Maximum wave heights

	1946 Earthquake (8.2)	1952 Earthquake (9.0)	1957 Earthquake (8.6)	1960 Earthquake (9.5)	1964 Earthquake (9.2)
Average wave heights not including zero (m)	6.7056 m	2.6997 m	3.0839 m	4.6787 m	3.0480 m
Maximum Wave Heights (m)	9.7536 m	3.9624 m	4.2672 m	10.668 m	3.0480 m

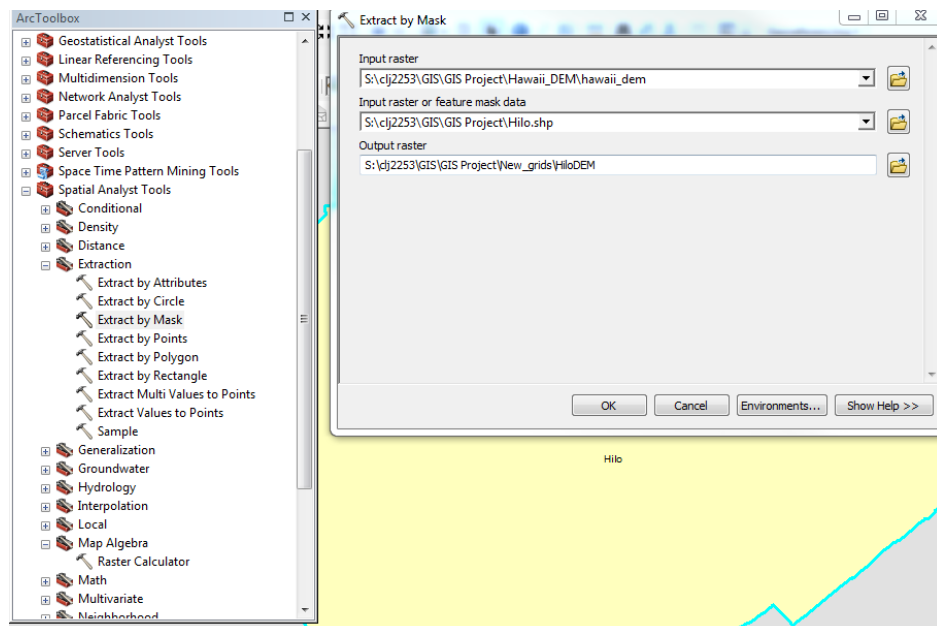
7) Creating a polygon for Hilo

I opened up the attribute table for the County Districts and selected the Hilo district. In order to extract this polygon, I right clicked on the County Districts layer > data > export data. I saved this feature as a shapefile. A pop up appeared enabling me to display the exported data as a layer.

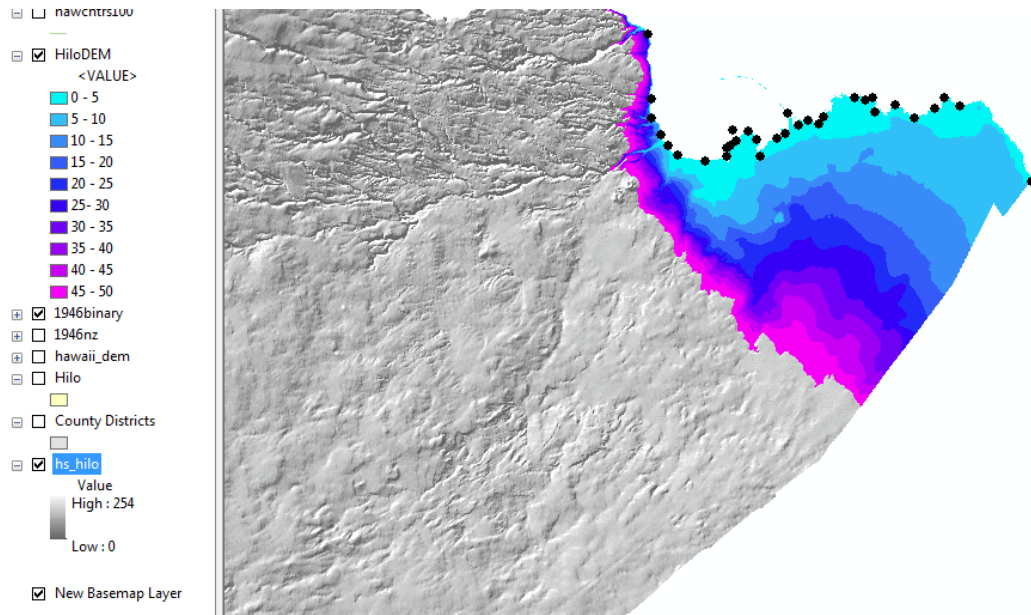


8) Extract By Mask: Use Mask to Define Properties

I then used the extract by mask tool (toolbox>spatial analyst tools>extract by mask) to extract the Hilo polygon from the Hawaii_dem to make a HiloDEM. I made sure that 3D analyst and spatial analyst were checked under the extensions tab.



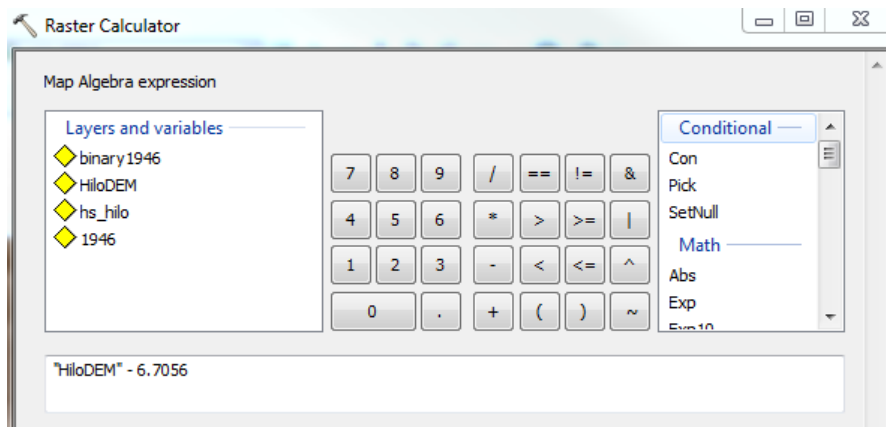
For image purposes, I created a hillshade for Hilo. I did this by opening the Surface toolbox>hillshade. This provides shaded relief. The image below shows the hillshade and dem for hilo.



9) Representing water inundation along the coast- 1946 example

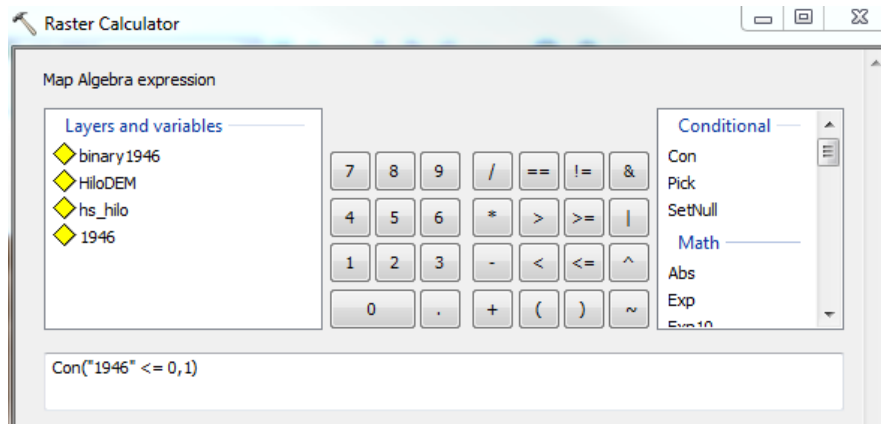
NOTE: All coastal inundation analyses are done in a new data frame classified by earthquake year.

I applied the raster calculation (arctool box>spatial analyst tools> map algebra> raster calculator) for the water depth during an earthquake event. The image below uses the 1946 averaged water depth/assumed inundation depth.

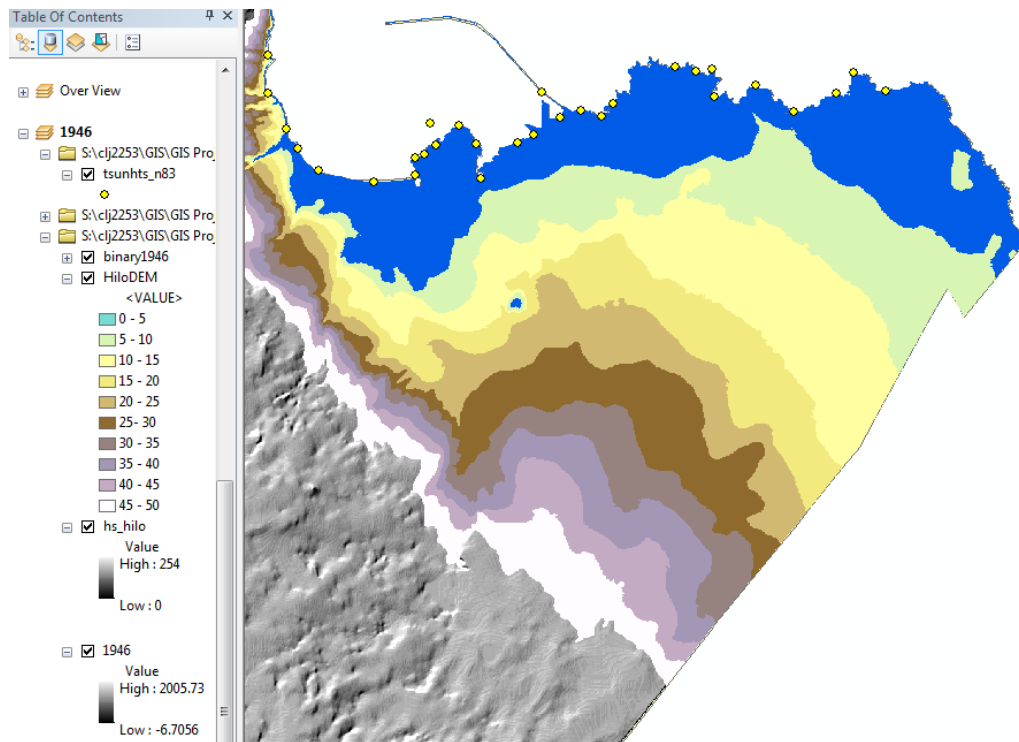


I then created a binary raster using the new raster created above. A binary raster is necessary for defining the new shoreline that adjusts for the area flooded by water. This was done so by using the raster calculator again.

The conditional statement assigns a value of 1 to elevations less than or equal to 0.



The figure below represents the 1946 inundation (contains 1946 binary raster, hiloDEM at 5m intervals, hilo hillshade, and 1946 raster with 6.7m adjustment)



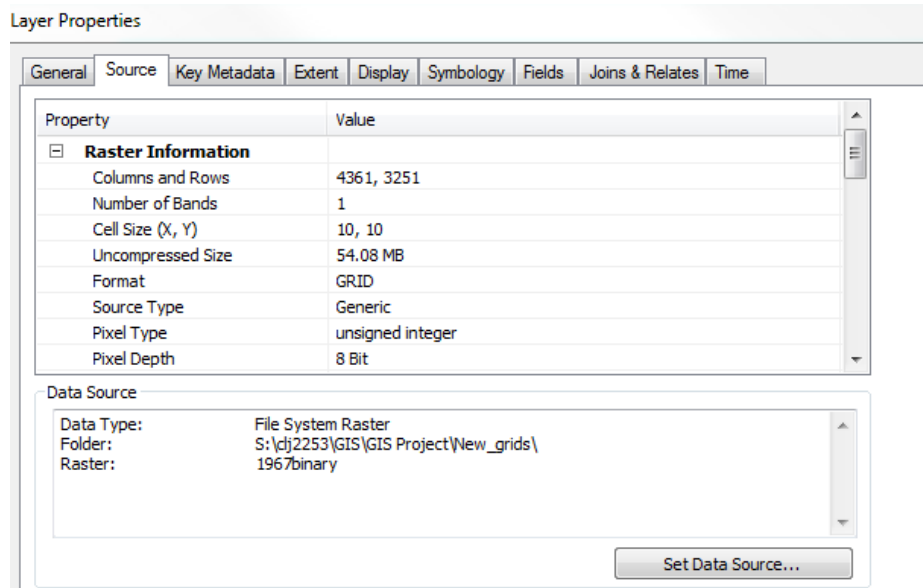
The blue represents the area of inundation during the 1946 Aleutian Islands 8.2 magnitude earthquake.

10) Repeat for Other Earthquake Events

I repeated steps 9 and 10 for 1952, 1957, 1960, and 1964. I also repeated steps 9 and 10 for the maximum wave heights during the 1946, 1952, 1957, 1960, and 1964 events. I did this in a new ArcMap document, and created specific rasters within each year's data frame.

11) Quantifying Inundation Area

Since my inundation area is in raster form, the attribute table doesn't have area data. It does have count data, which is the number of cells. Looking at the layer properties within the Inundation Area (right click layer> properties> source), the resolution reveal a cell size of 10,10.

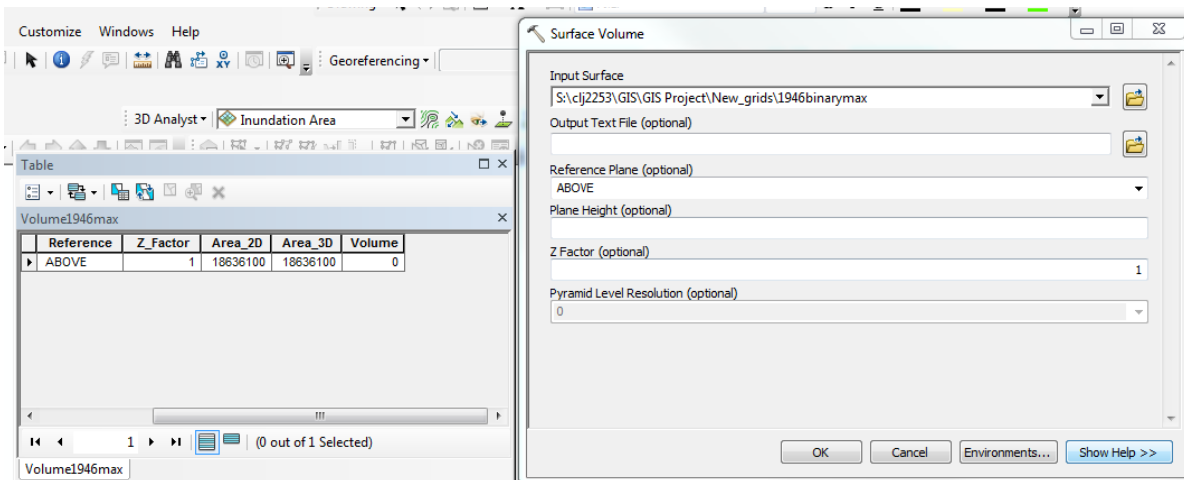


	1946	1952	1957	1960	1964
Averaged Waves	112,761 count	40604	48328	70022	48328
Max Waves	189,875	61,588	65,868	205,527	48,328

The resolution reveals a cell size of 10 by 10 meters. For example, the cell count for the 1967 averaged wave height is 48,328.

*Calculation applied in excel: $48,328 * 10m * 10m = 4832800m^2 * (1 \times 10^{-6} km^2 / 1 m^2) = 4.8328 km^2$*

Luckily, there is a 3D Analyst tool called *surface volume* (searched for tool in search bar). I put the binary surface for the specific earthquake year in the input surface bar, and specified an output text file. Opening up the volume attribute table (right click open) shows the 2D and 3D area for the selected raster.



I applied this surface volume tool to all 5 earthquake events (averaged wave heights and max wave heights). The area delivered in the attribute tables is in square meters. Converting these values to km² was done in excel.

*Converting m² to km² example: 18636100 m² * (1x10⁻⁶km²/1m²)*

The chart below displays the point count obtained from the binary inundation layer, and the area calculated using the 3D volume raster tool.

The area calculated using the 3D volume tool is slightly smaller, because “A raster surface is evaluated using the extent of the center point of each cell, as opposed to the extent of the entire cell area”. So if part of a cell is cut off, the center point of the cell will not be counted in the area of the raster. This resulted in slightly smaller area values acquired via the 3D volume tool.

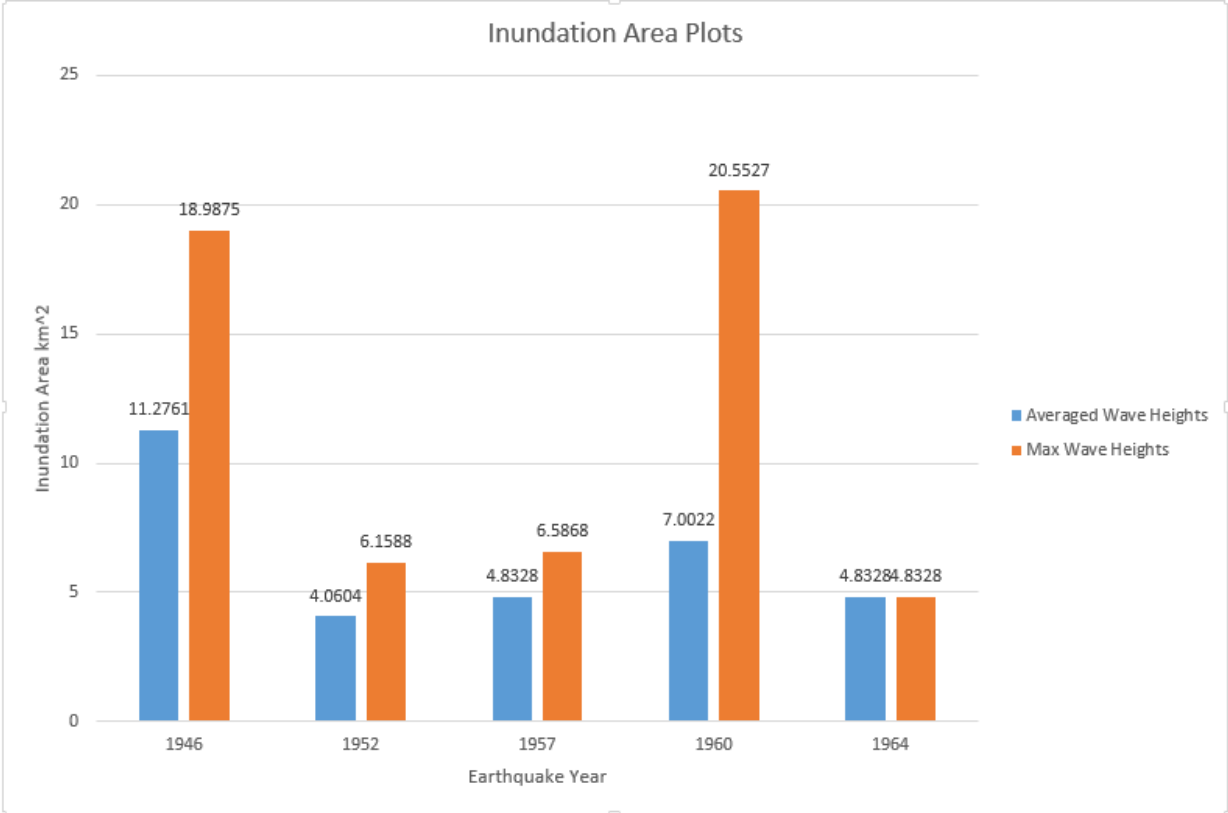
Averaged Wave Height Inundation Area					Max Wave Height Inundation Area				
Year	Count	km ²	Area m ²	Area km ²	Year	Count	km ²	Area m ²	Area km ²
1946	112761	11.2761	10937800	10.9378	1946	189875	18.9875	18636100	18.6361
1952	40604	4.0604	3753800	3.7538	1952	61588	6.1588	5844100	5.8441
1957	48328	4.8328	4513200	4.5132	1957	65868	6.5868	6277600	6.2776
1960	70022	7.0022	6688400	6.6884	1960	205527	20.5527	20194900	20.1949
1964	48328	4.8328	4513200	4.5132	1964	48328	4.8328	4513200	4.5132

Cell count: obtained from binary raster attribute tables, converted using 10x10 cell size
 Area: obtained from using 3D volume tool

Results and Conclusions

The results of this project conclude that wave inundation on coasts is variable. Mapping and quantifying the results of the maps indicates that the minimum inundation area is 4.0604 km² along the coast of Hilo, Hawaii. Again, this information assumes that the wave height is projected equally along the coast and that wave height is equivalent to inland flooding height. This data can be valuable

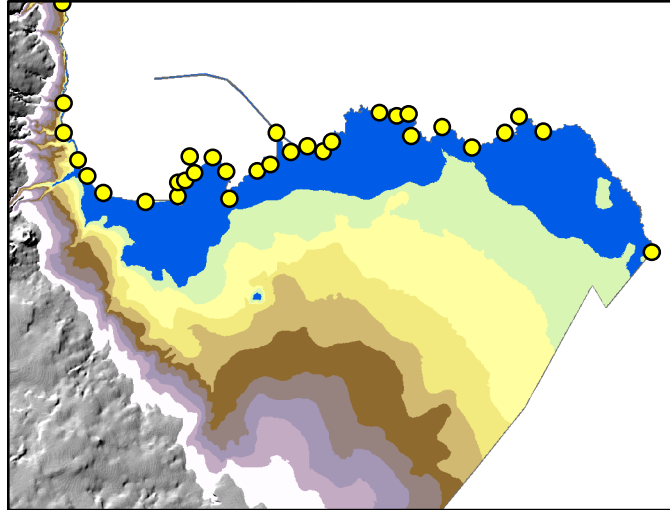
for Hilo residents, because Hilo is the most populated district in Hawaii and most susceptible to tsunami threats. The conclusions for this project are based on distant 8.2 to 9.5 magnitude earthquakes.



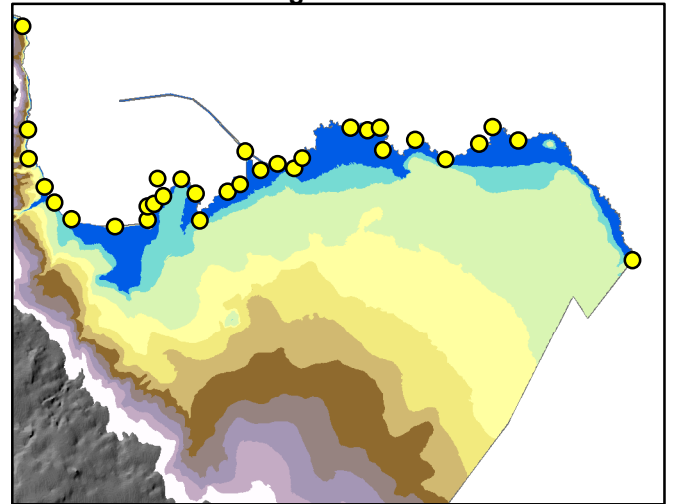
Inundation Area Based on Five Historic Earthquake Averaged Wave Height Data Off the Coast of Hilo, The Big Island, Hawaii

By: Calyn Jew
12/2/15

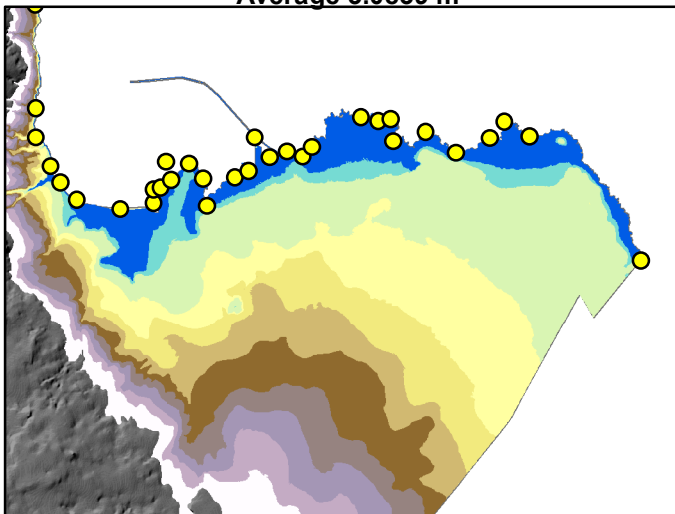
1946 Aleutian Islands Earthquake (8.2)
Average 6.7056 m



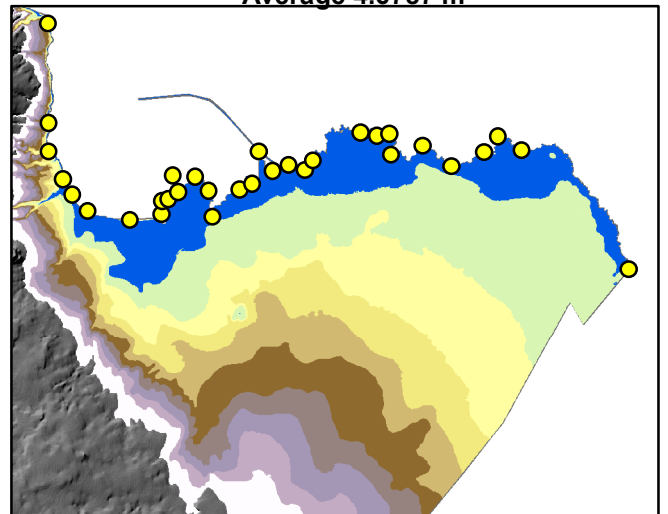
1952 Kamchatka Earthquake (9.0)
Average 2.6997 m



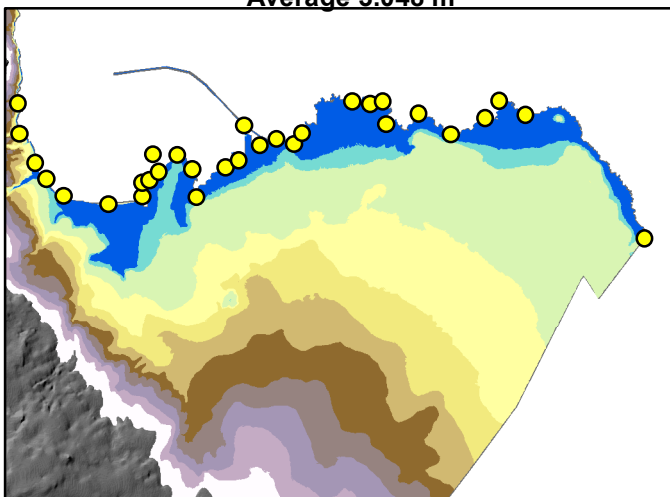
1957 Aleutian Earthquake (8.6)
Average 3.0839 m



1960 Chile Earthquake (9.5)
Average 4.6787 m

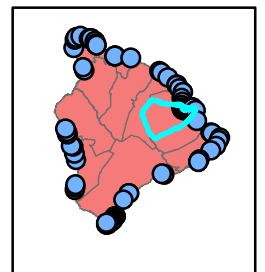
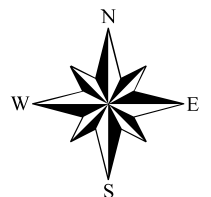


1964 Alaska Earthquake (9.2)
Average 3.048 m



Explanation

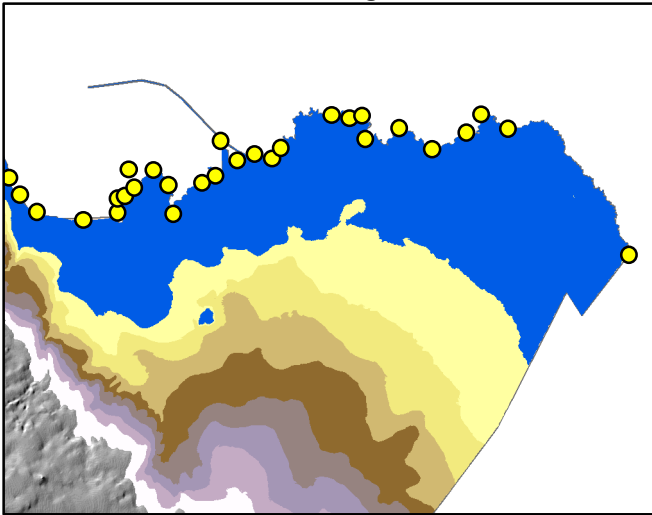
- Tsunami Data
- 1
- 15 - 20
- 20 - 25
- Hilo DEM**
- meters**
- 0 - 5
- 5 - 10
- 10 - 15
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45
- 45 - 50



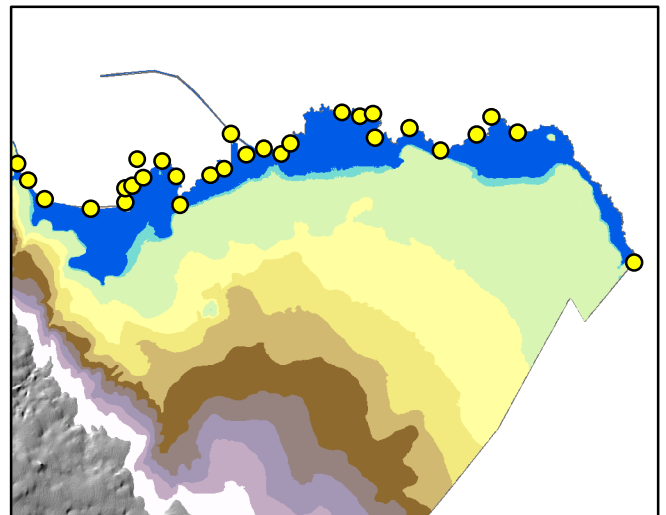
Inundation Area Based on Five Historic Earthquake Max Wave Height Data Off the Coast of Hilo, The Big Island, Hawaii

By: Calyn Jew
12/2/15

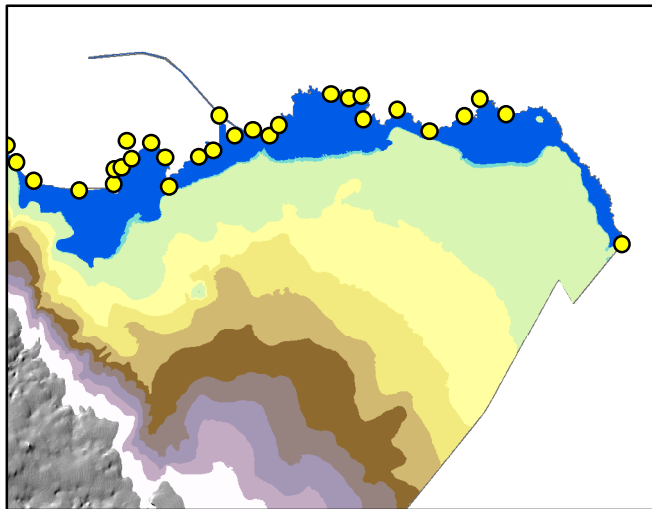
1946 Aleutian Islands Earthquake (8.2)
Max Wave Height 9.7536 m



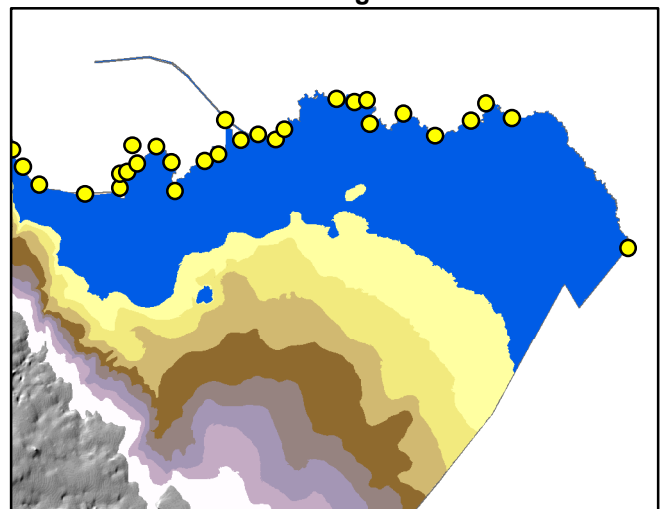
1952 Kamchatka Earthquake (9.0)
Max Wave Height 2.6997 m



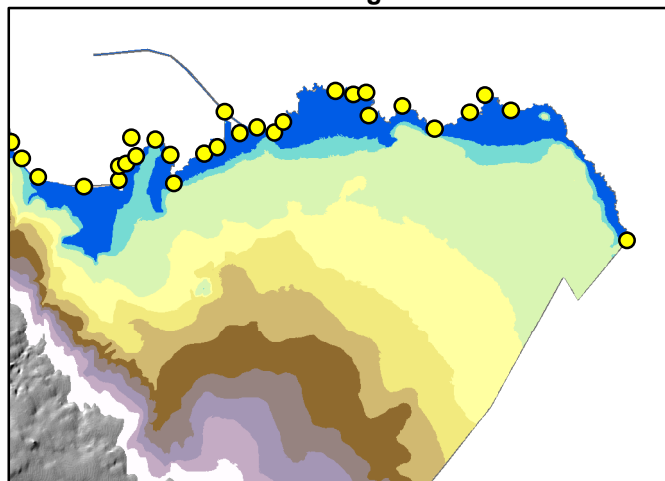
1957 Aleutian Earthquake (8.6)
Max Wave height 4.2672 m



1960 Chile Earthquake (9.5)
Max Wave Height 10.668 m



1964 Alaska Earthquake (9.2)
Max Wave height 3.0480 m



Explanation

- Tsunami Data
- Inundation Area**
- 1
- HiloDEM meters**
- 0 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45
- 45 - 50

