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2009

12th Annual High School Mathematical Contest in Modeling (HiMCM) Summary Sheet
(Please attach a copy of this page to each copy of your Solution Paper.)

Team Control Number:2332
Problem Chosen:B

Please type a summary of your results on this page. Please remember not to include the name of your school, advisor, or team members on this page.

Tsunamis are devastating to the areas they hit. They cause not only human loss, but property damage and societal harm as well. To build a model of the devastation a tsunami would cause in San Francisco, CA; Hilo, HI; New Orleans, LA; Charleston, SC; New York, NY; Boston, MA; and Seaside, OR, we considered all three types of devastation and designed a 100-point devastation scale that compares the total devastation caused to a city. Our model allows one to predict the devastation based on the city's characteristics and the magnitude of the earthquake, which determines the severity of the tsunami.

In our model we looked at the devastation of the seven cities by comparing damaged property, threat to human life, and social impact of the destruction. Threat to human life was quantified by the thoroughness of each city's emergency response and evacuation plans, as well as the percentage of the city's population that must evacuate and the furthest distance an evacuee must walk to reach safe ground. The cost of damaged property was calculated by adding the values of all the houses and major buildings in the city's inundation zone (area of the city flooded by tsunami waves). Social impact was quantified by examining the socially important buildings, such as police stations, hospitals, and schools, in the inundation zone that would be destroyed. Each category's values were adjusted to fit on the 100-point scale, in which 0 is no damage and 100 is the complete destruction of the city. Because these devastation scores assume the entire inundation area was affected by the tsunami, we also utilized a tsunami magnitude equation, which adjusts the devastation value for the severity of the tsunami based on the magnitude of the earthquake.

Overall we found that in the event of a severe tsunami, New York City would experience the most destruction, 41.292 points, followed by New Orleans, 25.862, Seaside, 25.114, San Francisco, 19.31, Charleston, 9.325, Boston, 8.264, and Hilo, 5.675. To analyze our model, we compared our findings to data from recent tsunamis around the world.

Problem B Paper: Tsunami ("Wipe Out!")

RESTATEMENT OF PROBLEM

Tsunamis, defined as series of waves caused by disturbances along the sea floor, are often caused by underwater earthquakes, which result in huge waves crashing into the shore. These waves, ranging in size from 3 to over 100 feet tall, can have devastating effects on coastal cities. Our model compares the devastation of tsunamis at San Francisco, CA; Hilo, HI; New Orleans, LA; Charleston, SC; New York, NY; Boston, MA; and Seaside, OR. We defined devastation using three main points: the threat to human life, the cost of damaged property, and the social impact of the destruction. Threat to human life is quantified by the breadth of each city's tsunami (or emergency) response plan and the feasibility of their evacuation strategy. Social impact is quantified as the damage of socially important buildings, such as hospitals and schools.

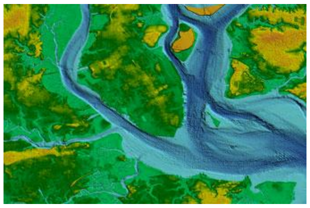
ASSUMPTIONS and JUSTIFICATIONS

1. All tsunamis are caused by earthquakes. Though tsunamis may also be caused by landslides or volcanic eruptions, our model does not address these possibilities.
2. All city and state emergency response plans are available online. In other words, if we could not find a tsunami response plan for a city, it does not exist.
3. If a city does not have a tsunami-specific response plan, in the case of a tsunami, it would put its emergency response plan into action.
4. In the case of a tsunami, all inundation maps used would be accurate and correctly display maximum inundation zones.
5. All property in the inundation zones is completely destroyed.
6. The worth of a business is proportionate to the average worth of the houses around it.
7. The total devastation points for a city are spread out equally in the inundation zone.
8. An average person walks 3 miles per hour. This was found online.
9. No flooding occurs outside of the inundation zone.

MODEL BUILDING

Inundation Maps

A large part of the calculations for our model are based on inundation maps, which show the areas of a city predicted to be flooded by tsunami waves. These maps incorporate location of fault lines, ocean floor topography, shoreline terrain, and elevation. Whenever possible, we used inundation maps published by NOAA or another government agency. These maps, however, only exist for tsunami-risk areas, such as California, Oregon, Hawaii, and Alaska. For other areas of the US, we created our own inundation maps by overlaying topographical, elevation, and flood-risk maps. For example, no inundation map existed for Charleston, so we combined Map 1 (Topographical) and Map 2 (Standard) to produce Map 3 (inundation).
Once we had an inundation map for each area (see Appendix A), we measured the area of each inundation zone.


Map 1


Map 2


Map 3

Devastation in Terms of Human Life

We assessed a tsunami's risk to human life by evaluating the thoroughness of the city's tsunami response plan and the feasibility of the evacuation plans described. To do this, we first created a 9-point rubric to use in the evaluation of each city's tsunami response plan. Because several of the cities did not have tsunami-specific response plans, we evaluated their general emergency response plans for the same criteria, assuming that in the event of a tsunami, a city would put this plan into effect. Our rubric considered the following points to be the most important:

1. Knowledge of Inundation Zones/Flood Zones
2. Recognition of Distant vs. Local Tsunamis and Plans for both
3. Detection of Incoming Tsunamis
4. Notification of the Public
    a. TV
    b. Radio
    c. Internet/SMS Alerts
    d. Languages Other than English
5. Notification of Response Groups
    a. Highway Patrol
    b. Coast Guard
    c. Fire and/or Police Departments
6. Evacuation of At-Risk Areas
7. Public Awareness
8. Damage Assessment (after the tsunami)
    a. Removal of Debris
    b. Disposal of hazardous materials
    c. Assistance for residents
9. Training of Response Groups/Testing of Response Plan

We found each city or area's tsunami (or general emergency) response plan online and read them, recording the number of points each plan addressed. A plan had to address all subtopics of a point to receive that point. Then we subtracted the number of points addressed from the number of possible points to find the number of points not addressed (summarized in Table 1).

Table 1: Thoroughness of Emergency Plans

City (Emergency Plan Read)	Points Addressed (out of 9)	Points Not Addressed (out of 9)
San Francisco (City and County of San Francisco Emergency Response Plan: Tsunami Response Annex)	8	1

Hilo (Hawaii County Multi-Hazard Mitigation Plan)	7	2
New Orleans (City of New Orleans Comprehensive Emergency Management Plan)	7	2
Charleston (South Carolina Tsunami Response Plan)	7	2
New York (New York City Emergency Response and Evacuation Plans in the Event of a Weather-Related Emergency)	2	7
Boston (Ready Boston Brochure)	4	5
Seaside (Tsunami Evacuation Map)	7	2

Next, we determined the practicality of a city's evacuation plan by further examining its evacuation plans, as well as the population to be evacuated and the distance to safe ground.
We used the following rubric to award point values to evacuation plans:

1. Basic Instruction- Move Inland and to Higher Ground
2. Assistance to Evacuees (Public Transportation)
3. Special Assistance for Disabled People
4. Traffic Control
5. Set-Up of Shelters for Evacuees

A point was award if the issue was addressed and thoroughly answered (for example, naming the locations of shelters and the intersections to be monitored). A ½ point was awarded if the issue was addressed but left unanswered (for example, stating that shelters would be set up and traffic would be monitored, but not identifying where). After recording the number of points addressed, we found the number of points not addressed (summarized in Table 2).

Table 2: Thoroughness of Evacuation Plan

City	Points Addressed (Out of 5)	Points Not Addressed (out of 5)
San Francisco	5	0
Hilo	5	0
New Orleans	5	0
Charleston	2.5	2.5
New York	2	3
Boston	5	0
Seaside	2.5	2.5

We combined the city's response and evacuation data into Table 3 with the population to be evacuated and the furthest distance an evacuee must travel to reach safe land. The population to be evacuated was found by multiplying the area of the inundation zone by the population density of the city. The furthest distance for evacuees to travel was found by measuring the longest distance from an inundated area to a safe area on the map. For each category, human risk increases as the value increases because missing components of response and evacuation plans, more people trying to evacuate, and farther distances to travel all increase the difficulty of evacuation and the likelihood a resident is injured or killed while evacuating.

Table 3: Human Devastation Category Totals

City	Emergency Response Plan Points Not Addressed (Out of 9)	Evacuation Plan Points Not Addressed (Out of 5)	Population to be Evacuated (People)	Furthest Distance for Evacuees to Travel (Feet)
San Francisco	1	0	71,674	4,593
Hilo	2	0	2,899	5,000
New Orleans	2	0	106,798	40,127
Charleston	2	2.5	2,555	2,608
New York	7	3	3,039,868	33,000
Boston	5	0	6,804	1,450

Seaside	2	2.5	2,235	5,454

<u>Devastation in Terms of Property Value</u>

To calculate the cost of property destroyed by a tsunami, we calculated the cost of all property in the inundation zone. This was done by adding the cost of houses to the cost of other major buildings (i.e. hospitals, golf courses, hotels, and schools).
To find the cost of damage to houses, we first found the number of houses in the inundation zone by multiplying the area of the inundation zone by the city's average house density. We then multiplied the number of houses by the average cost of a house in the region.
For example, San Francisco's inundation zone is 4.137 mi^2, its housing density is 7,421 houses/mi^2, and the average cost of a house is $433,000. Thus, the total value of all houses in the inundation zone is

$$4.137\,\text{mi}^2 \times 7421\,\frac{\text{houses}}{\text{mi}^2} = 2893 \text{ houses } \times \$433000 = \$1,252,669,000 .$$

These calculations were repeated for each city, adjusting the values for each city's unique inundation zone area, house density, and average house value (see Appendix B).

Then, we calculated the value of other major buildings in the inundation area. We used Google Maps to examine zoomed-in maps of the city and record any major buildings in the inundation area. Examples of "major buildings" are zoos, hotels, schools, universities, golf courses, hospitals and museums. Restaurants, small public buildings (i.e. post offices and libraries), and shops were not considered major buildings. We recorded the number of each type of building found in the inundation area and used their proportionate worth to calculate their value.

We decided to assume the value of a business or building is proportionate to the value of the houses around it because house price is a good indicator of the economic status of an area. People living in a region with high home values are making higher incomes, and thus have more money to spend on businesses in the area, whether they are zoos, hotels, or schools.
Proportionate worth was determined by comparing the cost per square foot to build the building and the cost per square foot to build a house. For example, the approximate cost per square foot to build a house is $25.30, and the approximate cost per square foot to build a hotel is $250. $250 divided by $25.30, is roughly 10, so a hotel is worth about 10 houses. We repeated this process for each type of building, and found that

- A "big building" (museum, aquarium, golf club) is worth 3.5 times the average house's worth.
- An elementary, middle, or high school is worth 6 times the average house's worth.
- A hotel is worth 10 times the average house's worth.
- A fire or police station is worth 10 times the average house's worth.
- A university is worth 9 times the average house's worth.
- A hospital is worth 8 times the average house's worth.
- An airport is worth 10 times the average house's worth.

For Hilo, the average house was worth $282,895, and there were 981 houses, 13 hotels, 4 schools, and 3 "big buildings" in the inundation zone.

$$\left(981 \text{ houses} \times \frac{\$282895}{1 \text{ house}}\right) + \left(13 \text{ hotels} \times 10\,\frac{\text{houses}}{\text{hotel}} \times \frac{\$282895}{1 \text{ house}}\right) + \left(4 \text{ schools} \times 6\,\frac{\text{houses}}{\text{school}} \times \frac{\$282895}{1 \text{ house}}\right) + \left(3.5 \text{ "big buildings"} \times 6\,\frac{\text{houses}}{\text{"big building"}} \times \frac{\$282895}{1 \text{ house}}\right)$$

=$324,056,222.50 = total cost of property in Hilo's inundation zone. This process was repeated for each city (see Appendix B). The total property values in each city's inundation zone are summarized in Table 4.

Table 4: Inundation Zone Property Values

City	Property Value in Inundation Zone
San Francisco	$13,335,750,500
Hilo	$324,056,222.5
New Orleans	$26,986,048,613
Charleston	$239,285,438
New York	627,009,000,000
Boston	$1,238,148,450
Seaside	$303,490,000

Devastation in Terms of Social Impact

To quantify the social impact of the devastation caused by a tsunami, we devised a point system ranking the importance of various buildings. To be considered socially important, a building must be necessary to the survival and function of the city. A building's social importance is then determined by the number of people it serves and the importance of its function. A house only serves one family, so its damage has a small social impact, while a hospital serves many people and has a critical function, so its social impact is large.

- 1 house = $^{1}/_{10}$ point
- 1 school or university = 3 points
- 1 fire or police station = 5 points
- 1 hospital = 10 points

We then calculated the total social impact points (summarized in Table 5) in a city's inundation zone (once again assuming that all buildings in the inundation zone are completely destroyed) by counting the number of each type of building and multiplying it by that building's social importance.
For example, Seaside's inundation zone contains 1451 houses, 2 schools, 2 fire/police stations, and 1 hospital, which equals a social impact of

$$\left(1451\text{ houses}\times\frac{0.1\text{ points}}{1\text{ house}}\right)+\left(2\text{ schools}\times\frac{3\text{ points}}{1\text{ school}}\right)+\left(2\text{ police stations}\times\frac{5\text{ points}}{1\text{ police station}}\right)+\left(1\text{ hospital}\times\frac{10\text{ points}}{1\text{ hospital}}\right)$$

=171.

Table 5: Social Impact of Tsunami

City	Tsunami's Social Impact
San Francisco	3,070
Hilo	110
New Orleans	10,296
Charleston	119
New York	116,558
Boston	311
Seaside	171

Our Model

For our final model, we combined the 3 aspects of devastation (human life, property value, and social impact) into one 100-point scale that ranks the city's level of devastation after a tsunami, where 0 points is no devastation and 100 points is the complete destruction of the city. Human life and property value were each weighted for 2/5 of the overall devastation, and social impact was weighted for 1/5. Thus, the tsunami could cause up to 40 points of human life devastation, 40 points of property devastation, and 20 points of social devastation in a city.

To calculate the total human devastation points, we combined the 4 categories of human risk (the thoroughness of the city's response plan, the thoroughness of the city's evacuation plan, the number of people who need to evacuate, and the farthest distance a person needs to travel to safe ground) into one value, which could range from 0 to 40 points, 0 being no risk to human life and 40 being almost impossible survival. Thus, each category of human risk for a city could range from 0 to 10 points.

Because each missing component of a city's response or emergency plan translates to higher risk for the residents, we found what proportion of points each city had not addressed by dividing the points not addressed by the number of total number of points (9). Then, we multiplied this value by 10, because 10 is the maximum number of points for this subcategory. We repeated these calculations for each city's evacuation plan thoroughness, but these values were divided by 5 because there were 5 possible points.

In terms of feasibility of evacuation, the more people that must evacuate and the farther they must go, the longer it will take and the more dangerous it will be, thus increasing risk to human life. We found the proportion of the city's population that needs to be evacuated by dividing the population needed to be evacuated by the city's total population. We divided by the total city population because the larger the proportion of the city's population that needs to be evacuated, the less resources the city has to dedicate to each individual. This value was also multiplied by 10 to comply with the 10 point scale. The feasibility of walking distance was adjusted to the 10 point scale by finding the proportion of necessary walking to the possible distance that could be walked, which was defined as 47,520 feet, the distance the average person can walk in 3 hours because a typical distant tsunami will be detected 3 hours before it hits the shore. This was then multiplied by 10, because of the 10 possible points for the category.

We totaled these 4 values to find the city's human devastation value out of the 40 point scale.

For example, here are the calculations to find New York's human devastation value (the rest of the calculations can be found in Appendix C):

New York did not address 7 of the 9 points in its emergency response plan, which converts to

$\frac{7 \text{ points not addressed}}{9 \text{ possible points}} \times 10 = 7.78$ human devastation points.

New York did not address 3 of the 5 points in its evacuation plan, which converts to

$\frac{3 \text{ points not addressed}}{5 \text{ possible points}} \times 10 = 6$ human devastation points.

New York needs to evacuate 3,039,868 of its 8,363,710 people, which converts to

$\frac{3039868 \text{ people}}{8363710 \text{ total people}} \times 10 = 3.64$ human devastation points.

New York's farthest walking evacuees need to travel 33,000 feet, and the total possible evacuation distance is 47,520 feet, which converts to $\frac{33000\text{ feet}}{47520\text{ possible feet}} \times 10 = 6.94$ human devastation points. Thus, New York's total human devastation score is 7.78+6+3.64+6.94=24.36 points. Table 6 shows the human devastation points for each city, assuming the tsunami has affected the whole inundation zone.

Table 6: Human Devastation Points

City	Human Devastation Points (40 possible)
San Francisco	2.96
Hilo	3.99
New Orleans	14.01
Charleston	7.97
New York	24.36
Boston	5.97
Seaside	12.16

To adjust property damage to the devastation scale, we had to manipulate the cost of property damage to be between the values of 0 and 40. To do this, we first decided that the main proportion should be between the property damage and the GDP (gross domestic product) of the city. Because we were not able to find the GDP of each city, we made a proportion between the square mileage of the state and city and the GDP of the state and city. The generic proportion we used is as follows:

$$\frac{state\, mi^2}{city\, mi^2} = \frac{state\, GDP}{city\, GDP}$$

Next we found the GDP of the area by multiplying the ratio of the area of the damage to the area of the city by the GDP of each city. After we found those values for the cities, we divided the property damage by the GDP of the area.

We then needed to convert those values into points that would represent the property cost devastation. If an area's point value were to be 40, the maximum destruction would occur, in other words, the whole city would be destroyed. We found the average GDP of the area by dividing the GDP of the United States by 19,355 cities to get the GDP per city: 73188 billion dollars. We divided the maximum property damage by the average GDP per city, which is $988,312. We then divided the property damage in an inundation zone by the GDP of the city and multiplied that number by 40 and divided by 988,312 to find the property cost devastation points.

Table 7: Property Cost Devastation Points

City	Damaged: City Area (sq mi)	Proportion	GDP of city ($ bil)	GDP of the area	Property Damage ($ bil)	Property /GDP	Property Cost Devastation Points
San Francisco	4.137: 46	0.08993	0.54470	0.04899	13.33570	272.22687	11.38502
Hilo	3.324: 54	0.06156	0.53686	0.03305	0.32406	9.80593	0.41010

New Orleans	86.12: 180	0.47844	0.91824	0.43932	26.98605	61.42623	2.56896
Charleston	2.212: 96	0.02304	0.49862	0.01149	0.23929	20.82737	0.87104
New York	110.24: 303	0.36383	7.34496	2.67231	627.00937	234.63232	9.81274
Boston	.541: 48	0.01127	2.23462	0.02519	1.23815	49.16010	2.05596
Seaside	1.378: 4	0.34450	0.00673	0.00232	0.30349	130.85347	5.47253
Max		1	0.73188	0.73188	700	988.31215	40

For example, to find the point value of Seaside, we found the proportion of the damage area to the city area to be 1.378 to 4. When dividing those numbers, the value is .345. Next the GDP of the city is found by using the proportion:

$$\frac{95,996.79\,mi^2}{4\,mi^2} = \frac{\$161.573\,billion}{x}$$

$$x \approx \$.0067324\,billion$$

Afterwards, we found the GDP of the area by multiplying the GDP of the city, $.0067 billion, by the proportion of damaged area to the area of the city, .345. That value comes to approximately $.00232 billion. We then calculated another ratio of the property damages to the GDP of the area. For Seaside, the value comes to about 130.85. Finally we made a proportion between the maximum value of property to GDP and the 40 point range, so that the value under 40 points for Seaside is about 5.3 points.

We converted the social impact values to the 20-point scale by finding the proportion of social impact to the maximum potential social impact. The maximum potential social impact, or the social impact value if all socially important buildings in a city were destroyed, was found by researching the total number of homes, schools, universities, hospitals, and police and fire stations for the city and calculating their total social impact value.

For example, the city of Charleston contains a total of 44,143 homes, 107 schools, 12 universities, 6 hospitals, and 20 fire and police stations. This is equivalent to a social value of

$$\left(44143\text{ houses}\times\frac{0.1\text{ points}}{1\text{ house}}\right)+\left(107\text{ schools}\times\frac{3\text{ points}}{1\text{ school}}\right)+\left(12\text{ universities}\times\frac{3\text{ points}}{1\text{ university}}\right)+\left(6\text{ hospitals}\times\frac{10\text{ points}}{1\text{ hospital}}\right)+\left(20\text{ fire and police stations}\times\frac{5\text{ points}}{1\text{ station}}\right)=$$

4,913. Thus, if all of Charleston were destroyed, the social impact would be 4,913.

We then found the proportion by dividing a tsunami's social impact by the maximum potential social impact, and then multiplied this proportion by 20 to find the number of social impact points (summarized in Table 8).

For Charleston, this was $\frac{119\text{ social impact}}{4913\text{ maximum potential social impact}} = 0.0241\times 20\text{ points}=0.483\text{ points}$

Table 8: Social Impact Points

City	Tsunami's Social Impact	Maximum Potential Social Impact	Proportion $\left(\frac{\text{Tsunami's Social Impact}}{\text{Maximum Potential Impact}}\right)$	Social Impact Points
San Francisco	3,070	12367.5	0.248231251	4.964625
Hilo	110	1725.8	0.063738556	1.274771
New Orleans	10,296	22182.1	0.464158037	9.283161
Charleston	119	4931.3	0.024131568	0.482631
New York	116,558	327457.2	0.355948808	7.118976
Boston	311	26158.5	0.011889061	0.237781
Seaside	171	457.1	0.374097572	7.481951

Table 9 shows the devastation points for each category, as well as the total devastation points for each city, assuming the tsunami has affected the whole inundation zone.

Table 9: Total Devastation Points

City	Human Points	Cost Points	Social Points	Total Points
San Francisco	2.96	11.38502	4.97	19.31
Hilo	3.99	0.4101	1.28	5.675
New Orleans	14.01	2.56896	9.28	25.862
Charleston	7.97	0.87104	0.483	9.324
New York	24.36	9.81274	7.12	41.292
Boston	5.97	2.05596	0.238	8.264
Seaside	12.16	5.47253	7.48	25.114

<u>Applying Our Model to Tsunamis of Various Magnitudes</u>

Up until this point, we have made the assumption that the tsunami affects all of the inundation zone, which is only true of the most severe tsunamis, and is normally not the case. To apply our devastation scale to tsunamis off all magnitudes, we created a formula relating the magnitude of the earthquake causing the tsunami, the magnitude of the tsunami itself, and the proportion of inundation zone the tsunami damages.

While researching, we found a model used by scientists in the Pacific Ocean that predicts the amount of damage a tsunami will cause based on the magnitude of the earthquake. They had chosen to describe the tsunami's destruction as magnitudes from -1 to 4. We found that what they referred to as a tsunami with the magnitude of 0 would affect 1/10 of an inundation area, what they referred to as a tsunami of magnitude 1 would affect 2/5 of the inundation area, and what they referred to as a tsunami of magnitude 4 would affect all of the inundation zone. Additionally, we calculated the run up predicted by each magnitude with respect to the amount of the inundation zone affected. We found that a run-up of 30 would cover the entire inundation zone, so it would be caused by a tsunami with a magnitude of 5.

Using this same logic, a run up of 24 would be caused by a magnitude of 4, and a run up of 18 would be caused by a tsunami with a magnitude of 3.

Their original equation was $t = 2.61e - 18.44$, where *t*= the magnitude of the tsunami and *e* = the magnitude of the earthquake. To find our equation, we solved for *e* when *t* = 0, 1, and 4. We adjusted these points so *t* would range from 0 to 5, and the area of the inundation zone that is affected is *t**20%. Thus a magnitude 0 tsunami would cause no damage to the inundation zone, and a magnitude 5 (or higher) tsunami would cause damage to 100% of the inundation zone. To create this new formula, we took the points (e, t), (7.06, 0), (7.45, 1), and (8.60, 4) and changed the tsunami magnitudes to 1, 2, and 5 so the range of tsunami magnitude values would be from 0-5 (instead of -1-4). We then did a linear regression of the new points (7.06, 1), (7.45, 2), and (8.60, 5) to find the new equation, which is $t = 3.049e - 21.341$. For this equation, if $t \leq 0$ then the earthquake does not cause a tsunami and if $t \geq 5$, t should be rounded down to 5 as the tsunami will cause damage in all of the inundation area.

To predict the number of devastation points a tsunami would cause based on the magnitude of the earthquake, one would multiply the number of total points if the whole inundation zone is affected by the proportion of the inundation zone affected. A mathematical model of this process is $\frac{t}{5} \bullet P = D$, where t is the magnitude of the tsunami, P is the number of points if the tsunami affected the whole inundation are, and D is the number of destruction points for the tsunami. If t is less than or equal to 5, so no rounding is required, $D = \frac{3.049e - 21.341}{5} P$.

TESTING OF OUR MODEL

To test our model, we chose two historical tsunamis and their corresponding earthquake magnitudes to get the effects of a part of the inundation zone. Using the 2004 tsunami in Thailand and the 1994 tsunami on the Java coast, we figured out the percentage of the inundation zone that would be affected.

In the 2004 tsunami in Thailand, the magnitude of the earthquake was 9.1. When solving for t using the magnitude of the equation, we found that the tsunami would affect 100% of the inundation zone. The damage to resorts and small towns in Thailand amount to about $15 billion of damage. When looking at the inundation area of the 2004 tsunami, it covered what would be the predicted as the general inundation zone of Thailand so the tsunami did affect the entire inundation zone, as predicted by our equation.

In 1994 on the coast of Java, an earthquake with a magnitude of 7.8 caused a tsunami. Our model would predict the tsunami to have a magnitude of about 2.44 and affect about 48.8% of the inundation zone. In our model we found that a tsunami with a magnitude of what we describe as 5 would have a run-up of 30 meters. A run-up of 14 m was experienced in Java, which corresponds to a tsunami with a magnitude between 2 and 3.

CONCLUSION

Our model, based on a 100-point devastation scale, computes the amount of devastation a tsunami will cause to a city, taking into account human devastation, property devastation, and social devastation. Complete destruction would result in a city receiving 100 points; no damage would result in a city receiving 0 points. Each city’s devastation point value quantifies the amount of damage it would suffer from a tsunami. New York's high devastation points make sense; the city has no tsunami response plans, a large population to evacuate, and a large amount of property close to the water. In the same way, Hilo's low score makes sense; they have a smaller total value of property in the inundation zone and, accustomed to tsunamis, have extensive response and evacuation plans in place.

While cities cannot control many factors of tsunamis, our model shows that they can reduce the effects of damage. Having thorough response and evacuation plans reduces the risk of human threat, and minimizing important or expensive buildings in the inundation zone also reduces damage. Furthermore, specific areas of the inundation zone are affected depending on the magnitude of the earthquake causing the tsunami, so cities can plan for tsunamis of various severities as well.

STRENGTHS AND WEAKNESSES OF OUR MODEL

Strengths of Our Model

- We take three aspects of devastation into account: risk to human lives, monetary cost, and social impact.
- Our model can be used to compare the potential tsunami devastation on any coastal city.
- Despite differences in size and location, our model directly and quantitatively compares the devastation of the seven various cities.
- Our model can predict the devastation of a tsunami on a city given the magnitude of the earthquake.

Weaknesses of Our Model

- The property values, which were based buildings' proportionate worth of houses, are not completely accurate.
- Property value does not take any small businesses or buildings, such as restaurants and small stores into account, or the cost of any personal belongings, cars, boats, etc that may also be destroyed.
- We assume all the property in an inundation zone would be destroyed, which may not be the case.
- Cities/areas may have tsunami response plans that we are unaware of.
- We do not distinguish between a local and distant tsunami when calculating human risk. A local tsunami gives less warning, so human risk would be significantly higher.
- We found the GDP of cities by using the GDP of the United States. This was not a correct assumption because some cities, example New York City, represent a larger amount of the GDP of the United States than other, such as Seaside.
- The Tsunami magnitude

Tsunamis in New York- And We Don't Mean Sushi!

What would you do if a tsunami hit New York City? Not possible? Think again. Tsunamis are caused by earthquakes underwater or near the coastline. While they occur most often in the Pacific Ocean, they can occur in the Atlantic Ocean as well.

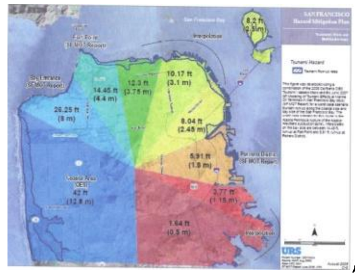
Recent mathematical modeling has shown New York City is not prepared for a tsunami; out of seven cities compared, New York will suffer the most devastation in terms of human risk, damaged property value, and social impact. Even a distant tsunami, which can be detected over three hours before the tsunami hits the coast, would cause serious damage to New York City and would pose a substantial threat to the lives of residents.

Despite recognizing tsunamis as a potentially dangerous natural disaster, New York doesn't have a tsunami-specific response plan or evacuation strategy, or even a prediction of the inundation zones (areas affected directly by the tsunami). In fact, out of the nine categories used to evaluate the New York tsunami emergency response plan, New York only addressed two: flood zones and notifying response groups, completely neglecting public awareness, damage assessment after the tsunami, training of response groups, and separate strategies for distant and local tsunamis. The New York City evacuation plan is also flawed, only addressing 2 of the possible 5 points. Furthermore, the number of people that need to be evacuated and the furthest distant from safe ground add to New York's embarrassing score of 24 out of 40 possible human devastation points- and a score of 40 means that every person in the inundation zone has a serious risk of their life being taken. As far as property damages go, if New York City was hit by a tsunami, the cost of damages would be about 627 billion dollars! This translates to 10 out of 40 possible property damage points. This may seem low, but other cities had as low as 0.41 out of 40 points- clearly New York could do better! Finally, the tsunami would hit a variety of socially important buildings, contributing 7 out of 20 social impact points. When totaling up the score, we found that New York receives a devastation score of 41.3 out of 100 points- the highest of all the cities compared!

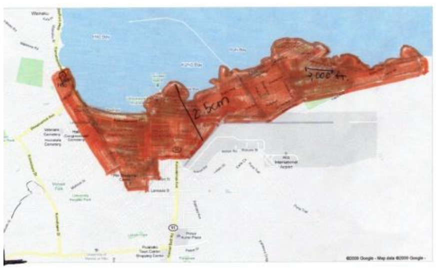
So what would we suggest to do to make this score lower? The city of New York definitely has to make some major changes. For one, constructing and publishing an inundation map would make sure that people know where the places of danger would be if a tsunami occurs. The city also needs to make a more comprehensive plan of evacuation, including escape traffic routes and shelters for evacuees. Though New York cannot change the location of expensive property or socially important buildings, residents should keep in mind the location of inundation zone and what social and financial effects it will have on them. But for now, the next time your building shakes, we suggest you head for higher ground.

Appendix A: Inundation Maps

Inundation Map 1: San Francisco

 produced using , 

Inundation Map 2: Hilo

 produced using 

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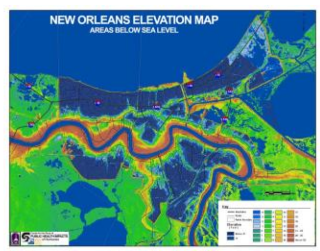
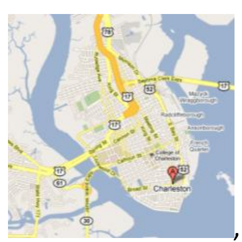
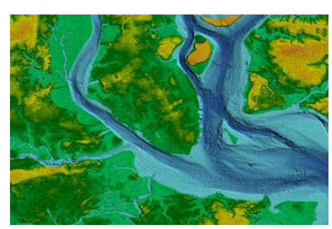
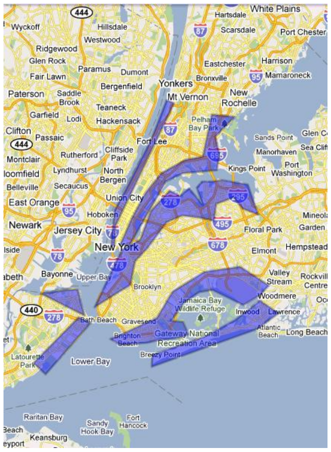
Inundation Map 3: New Orleans

 produced using 

Inundation Map 4: Charleston

 produced using , 

Inundation Map 5: New York



Produced using

Inundation Map 6: Boston

produced using

Inundation Map 7: Seaside

Appendix B

To calculate the total value of the houses in the inundation area, we multiplied across this table.

Chart 1	Inundation Area (mi^2)	Housing Density (houses/mi^2)	Average Cost of a House	Total Value of Houses
San Francisco	4.137	7421	\$433000	\$13293533000
Seaside	1.378	1053	\$155000	\$224905000
Hilo	3.324	295	\$282895	\$277519995
Boston	0.541	5202	\$425700	\$1197919800
Charleston	2.212	455	\$233006	\$224344036
New Orleans	86.12	1191	\$262785	\$26953594665
New York	110.24	10553	\$538800	\$626820000000

Charts 2-4 represent values for Inundation Zone.

Chart 2 shows the values of each type of place using proportionate worth

Chart 2	House Value (\$)	Hotel Value (\$)	School Value (\$)	Big Building Value (\$)	Fire and Police Station Value (\$)	Hospital (\$)	Airport (\$)	University (\$)
San Francisco	433000	4330000	2598000	2598000	4330000	3464000	4330000	3897000
Hilo	282895	2828950	1697370	1697370	2828950	2263160	2828950	2546055
New Orleans	262785	2627850	1576710	1576710	2627850	2102280	2627850	2365065
Charleston	223006	2230060	1338036	1338036	2230060	1784048	2230060	2007054
New York City	538800	5388000	3232800	3232800	5388000	4310400	5388000	4849200
Boston	425700	4257000	2554200	2554200	4257000	3405600	4257000	3831300
Seaside	155000	1550000	930000	930000	1550000	1240000	1550000	1395000

Chart 3 shows the number of each type of property in the inundation zone.

Chart 3	Houses	Hotels	Schools	Big Buildings	Fire and Police Stations	Hospitals	Airports	University
San Francisco	30701	0	8	5	0	0	0	0
Hilo	981	13	4	3	0	0	0	0
New Orleans	102569	0	14	15	0	3	2	3
Charleston	1006	4	1	2	0	1	0	1
New York City	1163363	0	19	15	0	19	2	5
Boston	2814	6	0	3	0	3	0	0
Seaside	1451	2	46	2	2	1	0	0

Chart 4 shows the total added values of each category. This was found by multiplying the number of each category by their property worth.

Chart 4	Cost of Homes (\$)	Cost of Hotels (\$)	Cost of Schools (\$)	Cost of Big Buildings (\$)	Cost of Fire and Police Stations (\$)	Cost of Hospitals (\$)	Cost of Airports (\$)	Cost of Universities (\$)
San Francisco	13293533000	0	20784000	12990000	0	0	0	0
Hilo	277519995	36776350	6789480	5092110	0	0	0	0
New Orleans	26953594665	0	22073940	23650650	0	6306840	5255700	7095195
Charleston	224344036	8920240	1338036	2676072	0	1784048	0	2007054
New York City	6.2682E+11	0	61423200	48492000	0	81897600	10776000	24246000
Boston	1197919800	25542000	0	7662600	0	10216800	0	0
Seaside	224905000	3100000	42780000	1860000	3100000	1240000	0	0

Appendix C

To calculate the total human devastation points if the tsunami affected the whole inundation zone, we found the sum of the points assessed for the city's emergency plan, evacuation plan, number of evacuees, and distance to safe ground.

	Emergency Response Plan (out of 9)	Evacuation Plan (out of 5)	Population of Evacuated Area	Population of City	Furthest Distance for Evacuees to Travel (ft)	Points for Emergency Plan	Points for Evacuation Plan	Points for Number of Evacuees	Points for Distance to safer area	Total Human Devastation Points
San Francisco	1	0	71674	808976	4593	1.111	0	0.886	0.967	2.964
Hilo	2	0	28999	40759	5000	2.222	0	7.115	1.052	10.389
New Orleans	2	0	106798	311853	40127	2.222	0	3.425	8.444	14.091
Charleston	2	2.5	2555	126567	2608	2.222	5	0.202	0.549	7.973
New York	7	3	3039868	8363710	33000	7.778	6	3.635	6.944	24.357
Boston	5	0	6804	609023	1450	5.556	0	0.112	0.305	5.972
Seaside	2	2.5	2235	5900	5454	2.222	5	3.788	1.18	12.158

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