Moody's Mega Math Challenge 2017

Johns Creek High School –

Team # 9120 Alpharetta, Georgia

Coach: Julie Meert

Students: Daniel Bodea, Alex Hammond, Anshul Tusnial, Akhil Vaidya, Jamie Wang

Moody's Mega Math Challenge Third Place, $10,000 Team Prize

From Sea to Shining Sea

Team #9120

Contents

Executive Summary

For many years, the U.S. National Park Service (NPS) has pioneered the protection of our nation's most valuable natural resources and landscapes. From the vast wilderness to storied landmarks, the NPS is responsible for maintaining and safeguarding the natural legacy of the United States, ensuring that future generations can enjoy the unique environmental beauties of the country. Global changes in climate, however, threaten the security and future viability of these resources.

In order to aid the NPS in determining the proper course of action in response to climate-related changes, we first created a model to determine the risk of changes in sea levels for five different representative national parks for the next 10, 20, and 50 years. Our model was based on a conical design that allowed us to determine the land area of each national park destroyed by rising sea levels using the surface area of the conical figure. We calculated the percentage of park destroyed and classified a range of percentages as high, medium, and low within each time interval. This model is unique in its ability to accurately account for coastal areas and reflect the actual surface area of each park instead of basic acreage.

To establish a vulnerability index, we first establish expectations of risk by considering lost surface area. We took into account three main factors: flooding (from Part 1), wildfires, and hurricanes, which are all applicable to these coastal parks. These parks are more susceptible to hurricanes and flooding since they are on the coast. To create our index, we took the expected surface area lost and divided it by the total surface area of the conic park. We then ranked the different parks according to this index, effectively demonstrating the relative impact climate change events will have on each park.

Considering the previously formed vulnerability scale, we developed a model to establish appropriate investment levels for the NPS based on visitation to each of the five parks for the next 50 years. In this model, the total damage to the park derived from Part II is multiplied by the number of visitors for each park over the same 50-year time span. This number is then divided by the total sum of the five numbers to standardize the values into a percentage. Consequently, these percentages represent the fraction of financial resources that each park should receive. To this end, this model effectively builds off of the model created in Question 2 by combining the visitation and vulnerability as factors in the investment of financial resources for the NPS.

Based on this evaluation, Padre Island National Seashore needs the highest proportion of financial funds (86.87%) and the Kenai Fjords National Park will not be allocated any of the funds. With these models, the NPS has a means to determine the effect of climate-related changes and how to continue the preservation of our nation's natural resources in the future.

Background

The U.S. National Park Service (NPS) is a federal agency that is primarily responsible for the administration of national parks and historic sites across the United States. Global climate changes critically endanger these natural landmarks.

Over the last 50 years, average global temperatures have increased at the fastest rate in recorded history. Anthropogenic global warming is the result of accumulated carbon dioxide, air pollutants, and greenhouse gases that absorb sunlight and trap heat in the Earth's atmosphere. These increases in global temperature have had severe effects on the environment including rises in sea levels, increased ocean temperature, and glacial retreat [1,2].

In response, the NPS is taking steps to gauge the potential risk from global change factors and protect our national parks from any damage that could hinder the visitor experience.

Restatement of the Problem

Given the global change factors that are likely to affect park resources and the visitor experience, we were asked to develop models in response to the following problems for Acadia National Park, Cape Hatteras National Seashore, Kenai Fjords National Park, Olympic National Park, and Padre Island National Seashore:

- Create a mathematical model to evaluate whether each of the five national parks is at a high, medium, or low risk of sea level changes for the next 10, 20, and 50 years.
- Determine the risk of other climate-related events including wildfires, hurricanes, and floods. From that risk data, develop a vulnerability score model applicable to each of the national parks.
- Using visitor statistics and the vulnerability scores, build a model to predict trends in visitor attendance and make recommendations to the NPS about future investment for each of the parks.

Part I: Tides of Change

I. Restatement of the Problem

One of the primary effects of global climate change is the rise in sea levels. There are three environmental factors that result in a change in global sea levels: thermal expansion, addition of water mass, and tectonic plate movement. The first two factors are a direct result of temperature changes as increased heat causes thermal expansion and causes glaciers to melt, adding water mass to bodies of water around the world [3].

Even small increases in sea levels can have a widespread impact on the surrounding environment. As seawater reaches further inland, it can cause erosion, wetland flooding, agricultural soil contamination, and habitat loss. Most studies concur that sea levels will continue to rise in the future, with the Intergovernmental Panel on Climate Change predicting that ocean levels will rise between 11 and 38 inches by 2100 [4].

It is important for the NPS to determine the risk of sea level change in the areas of their jurisdiction to ensure the preservation of important natural resources.

II. Assumptions

1) The only three factors that account for a significant change in global sea levels are thermal expansion, addition of water mass (through melting glaciers), and changing depths from movement in the Earth’s crust, as per [3].
2) We assume that effects of tectonic plate movement on sea levels are negligible, because it takes millions of years for a noticeable impact in ocean basins [19].
3) Area of the national park is a uniform conical shape with base equal to the total acreage of the park and height equal to the height of the highest peak of the park. This is a valid assumption because although distribution of the land area and heights is often variable and unpredictable, parks generally follow a conical form from border to peak, given insufficient topographical maps and park surface measurements.
4) Mean sea level change for the five national parks given is constant, based on the past 30 years of given station data.
5) Data obtained from the NPS provided an accurate measurement of mean sea levels and acreage.
6) Data obtained from the National Weather Service provided an accurate measurement of monetary damage from flooding.
7) The parks each have an equal inherent value to the nation based on the idea that their designation as a national park justifies their value to the country.

III. Developing the Model

To establish a baseline for our model, we start out first with an equation for the rise in sea level. Since we assume MSL, the mean sea level rise per year, to be constant, this equation is a linear function of time:

$$H(t) = MSL \times t.$$

Then we define the initial surface area of the national park to be the surface area of the cone whose base has area equal to the acreage of the park and whose height is the height of the highest peak of the park. We define r_1 to be the radius of the base of the cone, and h to be the height of the cone. Then the area of the base is given by

$$A_B = \pi {r_1}^2$$

and the surface area of the cone is given by

$$A_i = \pi r_1 \sqrt{h^2 + {r_1}^2}.$$

After the sea level rises, we assume that the portion of the cone from the base to height $H(t)$ is submerged and rendered unusable. The portion of the cone that is still usable now has a base that is $H(t)$ higher than the previous base and has radius r_2. The new usable surface area of the cone is given by

$$A_f = \pi r_2 \sqrt{[h - H(t)]^2 + {r_2}^2},$$

where $[h - H(t)]$ gives the new height of the cone, and r_2 is calculated by

$$r_2 = r_1 - \frac{H r_1}{h}.$$

The above relationship follows from the relation between the diagonals of the old and new cones.

Then the area of destroyed surface (surface rendered unusable) is given by

$$A_D = A_i - A_f.$$

However, note that only a portion of the park is bordered by shoreline, and only that portion of the cone will be flooded and rendered unusable. That portion is given by the fraction

$$p = \frac{L}{2\sqrt{\pi A_B}},$$

where L is the length of the shoreline of the park. Then, the proportion of the initial area that is destroyed is given by

$$R_D = p \frac{A_D}{A_i}.$$

IV. Data and Calculated Values

Figure 1A: Specified Measurements of NPS Units

Data (symbol) (unit)	**Acadia National Park**	**Cape Hatteras National Seashore**	**Kenai Fjords National Park**	**Olympic National Park**	**Padre Island National Seashore**
Peak Height	1530	10	6450	7965	45

(h) (ft)					
Seashore length (L) (ft)	316800	369600	2112000	385440	369600
Mean Sea Level Rise (MSL) (ft/yr)	.007146	.01260	–.008596	.0004593	.01142
Area (A_B) (sq. ft.)	2136705120	1065913200	29188684800	40200652800	5826585600
Surface Area (A_i) (sq. ft.)	55,915,748, 980,000	19,633,962,28 0,000	2,826,097,57 5,000,000	4,570,066,75 5,000,000	250,926,618, 800,000

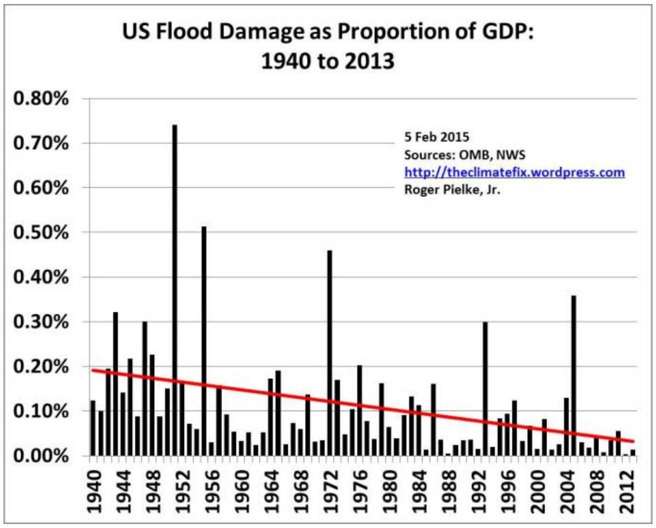
Figure 1B: Percentage of Park Damaged in 10, 20, and 50 years

Results (R_D) (% of park damaged)	**Acadia National Park**	**Cape Hatteras National Seashore**	**Kenai Fjords National Park**	**Olympic National Park**	**Padre National Seashore**
10 years	.0181%	7.997%	–.0093%	.00006254%	.6924%
20 years	.0361%	15.89%	–.0186%	.0001251%	1.383%
50 years	.0903%	38.97%	–.0465%	.0003127%	3.44%

V. Risk Level Classifications

To establish risk for sea level change for each national park, we classified each national park as high, medium, or low level of risk. To relate damage between parks, we assumed that all national parks have an equal inherent value. This means that damage done to parks as a proportion of the total area of the park is of equal value between parks. Then we found values to quantify typical rates of flood damage, using flood damage as a percent of GDP to determine the typical value of flood damage.

Figure 1C: U.S. Flood Damage as a Proportion of GDP from 1940 to 2013 (source: OMB, NWS)



From this graph we determined that flood damage that accounts for less than .05%, the current historical average, of the total is abnormally low. We also determined that any higher rate of flood damage that has been recorded can be considered medium, while any rates of flood damage above recorded rates are abnormally high. Therefore any values less than .05% are low, any between .05% and .75% are medium, and any higher than .75% are high.

VI. Results.

After 10 years, Acadia National Park, Kenai Fjords National Park, and Olympic National Park are at low risk. Padre National Seashore is at medium risk. Cape Hatteras National Seashore is at high risk.

After 20 years, Acadia National Park, Kenai Fjords National Park, and Olympic National Park are at low risk. There are no parks at medium risk. Cape Hatteras National Seashore and Padre National Seashore are at high risk.

After 50 years, Kenai Fjords National Park and Olympic National Park are at low risk. Acadia National Park is at medium risk. Cape Hatteras National Seashore and Padre National Seashore are at high risk.

VII. Conclusions

Based on the developed model, we classified the risk level of each park after 10, 20, and 50 years.
The negative values from Kenai Fjords National Park signifies that the sea level is not rising at that location, and therefore there is no predicted risk of sea level rise.

While our model reflects a close estimate to the actual topography of each park, the conical assumption does not account for topographical inconsistencies in the parks. Also, the assumption of constant mean sea levels does not account for possible changes in MSL over time. We also assumed that all parks are of equal intrinsic value to the nation, which may not necessarily true based on different visitation patterns and investments.

Our model, however, does effectively evaluate the risk of sea level change for each national park based on a conical design that accurately accounts for the amount of coastal area destroyed within each park. Further, our model allows for height distribution and reflects a close estimate to the actual topography of each park. Our data from the NPS and National Weather Administration also allows us to consider actual surface area rather than the base acreage from a satellite view. This model can be applied to any national park in the United States with coastal area and is therefore a capable tool in determining the risk of changes in sea levels around the nation.

Part II: The Coast Is Clear

I. Restatement of the Problem

In addition to the rising sea levels, there are many other climate-related events that could have significant impact on NPS coastal units. The United States is at risk for a variety of natural disasters across the spectrum of NPS coastal units, including hurricanes, wildfires, and earthquakes. These, along with the risk of changing sea levels, have the potential to inflict severe damage within these units, adding to their vulnerability. The effects of hurricanes wildfires, and earthquakes can wildly range from sediment erosion, forest degradation, wind damage, habitat destruction, air pollution, and human death [6,7,8]. While these additional climate-related events are not directly impacted by climate change, the rise in global temperatures has been connected to the increased frequency of natural disasters [9].

With the large variety of climate-related events, it can be difficult to determine the vulnerability of the NPS coastal units. For this reason, assigning each unit a numerical evaluation based on the individual combined risk of the coastal units would provide a base standard for the NPS to compare between various regions.

II. Assumptions

1) Damages are mainly a result of flooding from sea level rise, wildfires, and hurricanes. All other disaster impacts as a result of climate change are negligible. This is a valid assumption because they occur more frequently with a rise in global temperatures and cause the majority of land damage (i.e., national park resources) [13].

2) The five different national parks are representative of the wide diversity in landscapes and environments because of their wide berth across the United States, covering all coasts.
3) We assume that effects of tectonic plate movement on sea levels are negligible, because it takes millions of years for a noticeable impact in ocean basins [19].
4) Wildfire-Specific Assumptions
    a) A Class G fire has an upper bound of 10,000 acres of damage, since an infinite upper bound is statistically impossible, given countermeasures.
    b) All wildfires within their class are uniform, which is given through the law of large numbers.
    c) A Class A wildfire does .125 acres of damage (the midpoint of the [0, .25] interval), a Class B wildfire does 4.875 acres of damage (the midpoint of the (.25, 10] interval), a Class C wildfire does 55 acres of damage (10, 100], a Class D wildfire does 200 acres of damage [100, 300], a Class E wildfire does 650 acres of damage (100, 1000], a Class F wildfire does 3000 acres of damage (1000, 5000], and a Class G wildfire does 7500 acres of damage (5000, 10000]. This can be assumed because the law of large numbers and the Central Limit Theorem mean that large data sets approach normalcy, meaning they are evenly distributed around a mean.
    d) Land is not reused after being burned down within our 50-year time period, due to factors including the inherent risk of repeated deforestation and the time required for reforestation to occur. That is, we assume forests to be a non-renewable resource in our time frame.
5) Hurricane-Specific Assumptions
    a) Damage caused by hurricanes directly corresponds to their level on the Saffir–Simpson scale by the potential damage factors given by the NOAA [11].
        i) These factors are scaled down based on monetary values of Hurricane Arthur's destruction of Cape Hatteras related to the monetary values of median damages from category 2 hurricanes given by the NOAA [21,11]. That is, a category 2 hurricane will be said to damage .4% of a given national park.
    b) Tropical storms and all other sub-category 1 hurricanes do a minimal amount of damage, making their potential impact 0 [11,12].
    c) The number of hurricanes of per year have increased linearly since the base year 1851. [14]
6) If the sea level recedes (MLS negative), then the newly exposed park land is used by the park; since not all national park land is monitored and tidied, any land exposed is now part of that park.

III. Developing the Model

We define the expectation (risk) of x as

$$E(x) = P_x \times P(x),$$

where P_x is the magnitude, given by acres lost, and $P(x)$ is the weight we assign to the magnitude, the probability of that event occurring.

We then derive the total expected acres lost after *y* number of years, due to flooding (sea level rises calculated in Part 1), wildfires, and hurricanes.

$$\sum_{k=1}^{50} E(x) = E_{flood,k} + E_{wildfire,k} + E_{hurricane,k}.$$

To solve for flooding, we used a distribution to weigh the relative risks of flooding occurring (Part I). The mean of the 142 way stations used to measure MSL in mm/year is 1.771 mm/year, with a standard deviation of 3.768 mm/year (NOAA). We use this data to create a Gaussian distribution that we use to weigh the flooding risks from increased sea levels. We obtained the acre loss from Part I by inputting the park-specific details. Based on these givens, we can make our probability plot X ~ N(1.771, 3.768):

$$G(x, MSL) = \frac{1}{\sqrt{2\pi * 3.768^2}} e^{\frac{-x^2}{2*3.768^2}},$$

where *x* is the MSL value.

Based on this, the probability of a certain range of MSL values is given by

$$\int_{MSL_{low}}^{MSL_{high}} CDF[G(x, MSL)]\, dMSL,$$

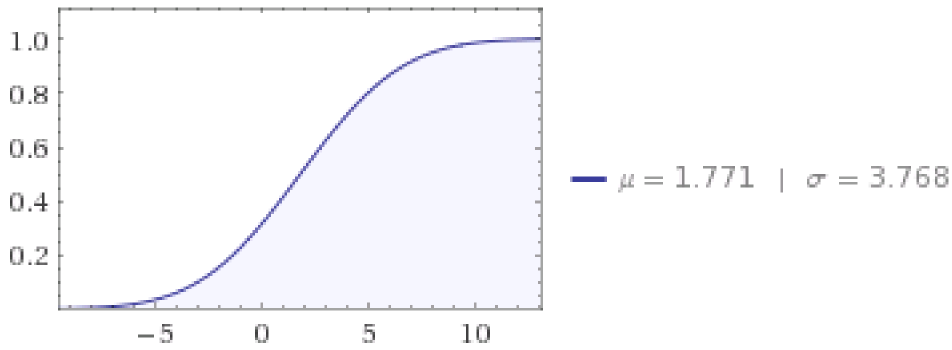
where CDF is the cumulative distribution function evaluated between the two MSL points.

We look at NOAA Tides and Currents information for the 142 coastal national parks that have had information collected on mean sea levels (MSL) rises and drops [20]. The scatterplot given by the data from the NOAA station trends affords us a predictive cumulative density function (contingent on the Part 1 assumption that MSL trends are linear and unchanging, as they are, based on a range of [22, 118] years of data). The CDF is plotted as

$$M(x) = CDF[dist, x],$$

with *dist* referring to the distribution of the average data.

Figure 2B: Plot of CDF - Probability given MSL value



The CDF can be used as a predictive weighing value against the acres lost due to sea level increases because the NHS data provides a 95% confidence interval within which the MSL trends were contained. Given this data, and our assumption that the trends continue into the future, the CDF is predictive. We can then use the MSL range from MSL_i to MSL_f.

$$CDF[dist, MSL_f] - CDF[dist, MSL_i],$$

which allows us to use the following equation to get the inter-CDF value:

$$\frac{1}{\sqrt{2\pi * 3.768^2}} \int_{-\infty}^{MSL_f} e^{\frac{-(MSL-1.771)^2}{2*3.768^2}} dMSL - \frac{1}{\sqrt{2\pi * 3.768^2}} \int_{-\infty}^{MSL_i} e^{\frac{-(MSL-1.771)^2}{2*3.768^2}} dMSL.$$

We then multiplied this calculated value by the square feet lost after 50 years (Figure 1B), scaling the park area lost from Part I because they represented the likelihood that the national park would have an MSL within that range. This value is the expectation of flooding, taking into account risk and magnitude. The following data is the expected acreage flooding of each of the five parks.

Figure 2C: Expected Acreage of Flooding for National Park Units

E_{flood} - sq ft lost to flooding after 50 years	**Acadia National Park**	**Cape Hatteras National Seashore**	**Kenai Fjords National Park**	**Olympic National Park**	**Padre National Seashore**
E_{flood}	2.33e+9	1.69e+12	-9.71e+10	2.61e+09	1.23e+12

To solve for the expectation of the wildfires, we looked at overall trends in national park acres destroyed by wildfire. We found that in the past few years, the average intensity, duration, and area covered of a wildfire have increased six-fold. These kinds of increases show an increasing trend of wildfire destruction and acres destroyed [23].

We derived that the Kenai Fjords distribution of fires was 95 Class A fires, the weakest type, doing an estimated .125 acres of damage (Alaska Interagency Coordination Center Situation Report), by taking the total acre damage (11.2 acres) and dividing it by the number of fires (95) [22].

The expectation of wildfire damage over the next 50 years, given by calculating acre loss multiplied by the likelihood of the damage happening, is

$$F_{total} = \int_{32}^{82} F_d(t) \times D_c \, dt,$$

where F_{total} is the total fire damage over the next 50 years, with a lower bound of 32 since the data begins in 1975, and we want to be predictive of calendar years 2017 to 2067. $F_d(t)$ is the fire damage (sq ft) in year y. D_c is the damage probability constant (**P**(event occurs)) given by

$$\frac{fire\ damage\ in\ park\ X\ over\ last\ 20\ years}{total\ fire\ damage\ in\ US\ over\ last\ 20\ years},$$

which is an accurate measure of probability since it is the likelihood of obtaining a favored event, out of total potential outcomes. Fire damage in park X over the last 20 years was given by assumption that a Class A wildfire is uniform and does .125 acres of damage (the midpoint of the [0, .25] interval), a Class B wildfire is uniform and does 4.875 acres of damage (the midpoint of the ([.25, 10] interval), and so on. We then looked at the given NPS data that provided the numbers of instances of wildfires and their classifications. Total fire damage in the U.S. over the last 20 years was calculated according to the National Interagency Fire Center data provided by wildland fires [18].

This is the expectation of the wildfire damage since it takes into account the likelihood of the event and the expected cost. The severity for the function is given by $F_d(t)$, which is a measure of the total square foot damage to the park. The D_c represents the probability of fire damage occurring, out of potential fire damage that occurs.

Figure 2D: Expected Damage from Wildfires of National Park Units

$E_{wildfire}$ - sq ft lost to wildfires – past 20 years	**Acadia National Park**	**Cape Hatteras National Seashore**	**Kenai Fjords National Park**	**Olympic National Park**	**Padre National Seashore**
$E_{wildfire}$	2.01e+05	1.38e+05	9.17e+04	1.68e+07	7.13e+07

To solve for the expectation of hurricanes, we calculate the sum of the risks of each category of hurricane for the park. To calculate the risk for a specific category, we multiply the category's probability of occurring by the damage it does (in square feet).

To calculate the hurricane's expected damage, we use the following equation:

$$E_{hurricane} = \frac{total\ number\ of\ hurricanes\ of\ category\ Z\ that\ have\ ever\ hit\ the\ park}{total\ number\ of\ hurricanes} \times \frac{\int_0^x f(x)}{x},$$

where *x* is the number of years since the base year, 1851, and *f(x)* is the function of the number of hurricanes depending on year. The quotient *f(x)/x* amounts to a multiplier that scales the probability of occurrence with respect to the increase in hurricanes per year. *f(x)* is given by the following equation, derived from a linear regression of values representing the number of hurricanes each year since 1851 from [16]:

$$f(x) = 0.0401x + 5.9906 .$$

This tells us the number of hurricanes that occur in any given year after the base year, assuming that the ratio between the number of hurricanes in a year and number of years since 1851 is linear. This assumption is valid due to the r^2 value of the linear regression, which is greater than the r^2 values of other possible regressions, including polynomial and power regressions.

To quantify the amount of damage each category of hurricane does, we make two assumptions: First, that the NOAA data regarding the relative damages of each category of hurricane is correct [11].

H1: 1, H2: 10, H3: 50, H4: 250, H5: 500.

Second, a category 5 storm does catastrophic damage, and will therefore destroy half of the park [12]. Then, dividing each category's relative damage by the maximum relative damage imparted by a category 5 storm (500), we obtain percentage values of

H1: 0.02%, H2: 0.4%, H3: 2.0%, H4: 10%, H5: 20%

demonstrating the amount of the park that is damaged. We multiply the above percentages by the acreage of the park to determine the number of damaged acres. Then, multiplying the probability and the number of damaged acres, we obtain the risk for the specific category. Adding together the risks from each specific category, we obtain the overall risk from hurricanes for the park, a value in potential damaged acres. Then

$$E(hurricane) = \frac{total\ number\ of\ hurricanes\ of\ category\ Z\ that\ have\ hit\ the\ park\ since\ 1995}{total\ number\ of\ hurricanes\ since\ 1995} \times \frac{\int_0^x (0.0401x + 5.9906)\,dx}{x}.$$

This follows from the fact that the ratio of the total number of hurricanes of a certain category to have hit the park to the total number of hurricanes gives the probability of a hurricane to have hit the park in the base year, and the ratio of $\int f(x)$ to x gives the scale factor that scales the probability from the base year to x years after 1851. Since 1995, there have been four H1 and six H2 storms striking Cape Hatteras, and one H1, one H2, and one H4 storm striking Padre Island, out of a total 129 hurricanes making landfall in the world through that time period.

Figure 2F: Expected Damage of Hurricanes in National Park Units

$E_{hurricane}$ - sq ft lost to hurricane after 50 years	**Acadia National Park**	**Cape Hatteras National Seashore**	**Kenai Fjords National Park**	**Olympic National Park**	**Padre National Seashore**
$E_{hurricane}$	0	1.95e+12	0	0	1.02e+14

Our $\mathbf{E_{total}}$ model is given by

$$\sum_{k=1}^{y} E(total) = E_{flood,k} + E_{wildfire,k} + E_{hurricane,k} =$$

$$\left[\left(\frac{1}{\sqrt{2\pi * 3.768^2}}\int_{-\infty}^{MSL_f} e^{\frac{-(MSL-1.771)^2}{2*3.768^2}} dMSL - \frac{1}{\sqrt{2\pi * 3.768^2}}\int_{-\infty}^{MSL_i} e^{\frac{-(MSL-1.771)^2}{2*3.768^2}} dMSL\right) * \frac{\boldsymbol{L} * A_{\boldsymbol{d}}}{\mathbf{2}\sqrt{\boldsymbol{\pi} \boldsymbol{A_B}}}\right] +$$

$$\left[\int_{32}^{32+t} F_d(t) * D_c \, dt ,\right]$$

$$+ \left[\frac{total\ number\ of\ hurricanes\ of\ category\ that\ have\ hit\ the\ park\ since\ 1995}{total\ number\ of\ hurricanes\ since\ 1995} \times \frac{\int_0^x (0.0401x + 5.9906)\, dx}{x}\right],$$

where y is the amount of years into the future, MSL_f is the larger MSL in the 95% confidence interval of recorded sea levels, MSL_i is the smaller MSL in the 95% confidence interval, L is length of shoreline of the park, A_D is the area of destroyed surface, A_B is the area of the base, t is the desired timeframe into the future, $F_d(t)$ is the wildfire damage for year t, D_c is the fire damage constant, and x is the amount of years since 1851. The final surface area of national parks lost is given below.

Figure 2H: Total Potential Damage in National Park Units

Total Potential Damage (E_{total})	**Acadia National Park**	**Cape Hatteras National Seashore**	**Kenai Fjords National Park**	**Olympic National Park**	**Padre National Seashore**
E_{total}	2.33e+09	3.64e+12	–9.71e+10	2.62e+09	1.03e+14
SA_{total}	55,915,748,980,000	19,633,962,280,000	2,826,097,575,000,000	4,570,066,755,000,000	250,926,618,800,000
β	4.167e-05	0.1854	0	5.733e-07	.4105

We assign a vulnerability score from 0 to 1, where the closer to 1 the value is, the higher the innate risk, because the vulnerability score, β, is derived from

$$\beta = \frac{E_{total}}{SA_{total}}.$$

If β returns a negative value, the vulnerability score is set to 0, since there is no risk. This makes sense, since Kenai Fjords is predicted to continuously drop in sea level, giving it more land.

IV. Conclusion

From β, we can see that Padre National Seashore is the most climate-vulnerable, with 41% of the park being destroyed after 50 years. The second most at-risk is Cape Hatteras, with 18.54% of the park destroyed. After that, we have Acadia National Park, Olympic National Park, and the Kenai Fjords National Park with 0 vulnerability score.

This vulnerability index is applicable to all NPS units as it is based on conic coastal units that are susceptible to flooding, wildfires, and hurricanes. The wildfires, however, were negligible, which made sense, since the parks are coastal, meaning they are in more danger of flooding and hurricanes than land-based fire. Possible errors with the model include the decision to forego replenished land, or possible fixing of the landmasses after disasters occur. We assume that the landmass is Bernoulli in nature, where it is either in a state of use or is not, and cannot be repurposed.

While the model does not evaluate the full extent of damage and overlooks possible replenishment of land, it accurately evaluates the total amount of damage done by events related directly to climate change. However, it does not account for damage that would have occurred independent of climate change, inflating the overall damage estimations.

Part III: Let Nature Take Its Course?

I. Restatement of the Problem

In FY 2015, the budget for the National Parks Service (NPS) was $3.4 billion and resulting economic activity generated by NPS reaches nearly $16 billion. Oftentimes, however, the appropriated budget is insufficient to cover the full maintenance and preservation of the land under administration of NPS. Moreover, visitation to the national parks topped nearly 300 million people in 2015 and is expected to increase in the future [10].

In the case that the NPS is unable to fully maintain and repair their administered land, we were tasked with creating a model that could incorporate the previous vulnerability scale into a model that reflects trends in visitation.

II. Assumptions

1) NPS will allocate revenue to the places with the most visitors and most vulnerability.
2) We assume that all national park services accumulate their revenue and the NPS has full discretion on where to allocate revenue.
3) Assume the division of funds are for funds beyond standard fixed operation costs.
4) Valuable assets and resources are uniformly distributed across the national park.
5) All national parks are chosen arbitrarily based on value to people, so we assume all parks are equal in intrinsic value.

III. Developing the Model

Using the given visitor models, we developed linear lines of best fit for each of the five parks. Given the model for damage within the next 50 years, we projected the total number of visitors up until the year 2067. We integrate the visitors per year formula and add base year 2016 to get total visitors for 50 years.

We find an arbitrary value (P_{park}) that we then use to determine the amount of funds allocated to each park. Since the funds allocation depends solely on the number of visitors and the potential future damage, the formula for P_{park} is

$$P_{park} = E_{total} \times V_{total}.$$

To standardize the values and calculate the distribution among the five parks, we would sum each of the values to get the total value P_{total}. Then the proportion

$$P_{park}/P_{total}$$

gives the proportion of funds the NPS should allocate to the given park.

IV. Results

Figure 3A: Visitors and Total Potential Damage for National Park Units

	Acadia National Park	**Cape Hatteras National Seashore**	**Kenai Fjords National Park**	**Olympic National Park**	**Padre National Seashore**
Visitors per year (formula)	–1819.75*x + 6131554.04	22480.94*x - 42775558.91	9031.12*x - 17851292.32	21844.73*x - 40632467.62	–3549.59*x + 7762342.95
Total visitors for next 50 years (V_{total})	12.3 mil	12.8 mil	1.8 mil	17.1 mil	3.0 mil
Vulnerability Index (β)	4.167e-05	0.1854	0	5.733e-7	.4105
Percent Funds allocated	0.01%	13.10%	0.00%	0.01%	86.87%

V. Conclusions

According to our calculations, the NPS should allocate the majority of its funds to Padre National Seashore in order to prevent future damage from climate change.

While our initial P_{park} is based on arbitrary values without a set scale, our model definitively evaluates the appropriate level of investment for each park through the calculated percentages. Also, this model could be more effectively represented by a higher order function instead of the linear basis we developed it around.

Our model, however, does properly evaluate the allocation of resources for each national park, and it takes into account the effect a growth in population has on the funds. Moreover, it incorporates the modeling work completed in Parts I and II by including the vulnerability of each park to various climate-related changes in these calculations. In this way, the model represents a simple way to standardize P_{park} in relation to the whole and create a means to allocate financial resources to the various national park units.

References

[1] MacMillan, Amanda. "Global Warming 101." National Resources Defense Council. National Resources Defense Council, 21 Dec. 2016. Web. 25 Feb. 2017. <https://www.nrdc.org/stories/global-warming-101>.

[2] "Climate Change Evidence: How Do We Know?" NASA. NASA, 23 Feb. 2017. Web. 25 Feb. 2017. <https://climate.nasa.gov/evidence/>.

[3] "Delaware Department of Natural Resources and Environmental Control." Delaware Department of Natural Resources and Environmental Control. State of Delaware, n.d. Web. 25 Feb. 2017. <http://www.dnrec.delaware.gov/Pages/Portal.aspx>.

[4] "Sea Level Rise." National Geographic. National Geographic, 24 Feb. 2017. Web. 25 Feb. 2017. <http://www.nationalgeographic.com/environment/global-warming/sea-level-rise/>.

[5]"The Precipitous Decline in US Flood Damage as a Percentage of GDP." The Climate Fix. N.p., 05 Feb. 2015. Web. 25 Feb. 2017. <https://theclimatefix.wordpress.com/2015/02/05/the-precipitous-decline-in-us-flood-damage-as-a-percentage-of-gdp/>

[6] "Effects of a Hurricane." Hurricane - The One-Eyed Monster. N.p., n.d. Web. 25 Feb. 2017. <http://teachertech.rice.edu/Participants/louviere/hurricanes/effects.html>.

[7] "Forest Fire/Wildfire Protection." Colorado Firecamp. Congressional Research Service, n.d. Web. 25 Feb. 2017. <http://www.coloradofirecamp.com/congressional_research/forest-fire-wildfire-effects.htm>.

[8] "Earthquake Effects." Earthquake Effects. N.p., n.d. Web. 25 Feb. 2017. <http://eqseis.geosc.psu.edu/~cammon/HTML/Classes/IntroQuakes/Notes/earthquake_effects.html>

[9] "Understanding the Link Between Climate Change and Extreme Weather." EPA. Environmental Protection Agency, 19 Oct. 2016. Web. 25 Feb. 2017. <https://www.epa.gov/climate-change-science/understanding-link-between-climate-change-and-extreme-weather>

[10] Selby, W. Gardner. "National Park Service Budget Less than Austin City Budget." Politifact. N.p., 24 June 2016. Web. 25 Feb. 2017. <http://www.politifact.com/texas/statements/2016/jun/24/jonathan-jarvis/national-park-service-director-correct-its-budget-/>.

[11] Landsea, Chris. "TCFAQ D5): How Does the Damage That Hurricanes Cause Increase as a Function of Wind Speed?" Atlantic Oceanographic and Meteorological Laboratories. National Oceanic and Atmospheric Administration, n.d. Web. 25 Feb. 2017. <http://www.aoml.noaa.gov/hrd/tcfaq/D5.html>.

[12] US Department of Commerce, NOAA, National Weather Service. "Saffir-Simpson Hurricane Wind Scale." NOAA's National Weather Service, 07 Nov. 2004. Web. 25 Feb. 2017. <http://www.prh.noaa.gov/cphc/pages/aboutsshs.php>.
[13] Meyers, Joe. "Which Natural Disasters Hit Most Frequently?" *World Economic Forum*. World Economic Forum, 5 Jan. 2016. Web. <https://www.weforum.org/agenda/2016/01/which-natural-disasters-hit-most-frequently/>.
[14] "TCFAQ E11) How Many Tropical Cyclones Have There Been Each Year in the Atlantic Basin?" Atlantic Oceanographic and Meteorological Laboratories. N.p., n.d. Web. 25 Feb. 2017.
[15] "Interior Department Releases Report Detailing $40 Billion of National Park Assets at Risk from Sea Level Rise." U.S. Department of the Interior. N.p., 26 Apr. 2016. Web. 25 Feb. 2017.
[16] "Is Global Warming Fueling Increased Wildfire Risks?" Union of Concerned Scientists. Union of Concerned Scientists, n.d. Web. 25 Feb. 2017.
[17] "How Many Hurricanes Have There Been in Each Month?" Atlantic Oceanographic and Meteorological Laboratories. N.p., n.d. Web. 25 Feb. 2017.
[18] Rate Limited. N.p., n.d. Web. 25 Feb. 2017. <http://wildland-fires.findthedata.com/>.
[19] "CU Sea Level Research Group." Do You Account for Plate Tectonics in the Global Mean Sea Level Trend? | CU Sea Level Research Group. N.p., n.d. Web. 25 Feb. 2017. <http://sealevel.colorado.edu/content/do-you-account-plate-tectonics-global-mean-sea-level-trend>.
[20] "Sea Level Trends - U.S. Stations Linear Mean Sea Level (MSL) Trends and Standard Errors in Mm/yr and Feet/century." Sea Level Trends - U.S. Stations Linear Mean Sea Level (MSL) Trends and Standard Errors in Mm/yr and Feet/century. N.p., n.d. Web. 25 Feb. 2017. <https://tidesandcurrents.noaa.gov/sltrends/mslUSTrendsTable.htm;jsessionid=EE0EEE5936238F5B1C3B45D01A812346>.
[21] Hampton, Jeff. "Hurricane Arthur Damage More Economic than Physical." Virginian-Pilot. N.p., 05 July 2014. Web. 25 Feb. 2017. <http://pilotonline.com/news/local/weather/storms/hurricane-arthur-damage-more-economic-than-physical/article_a6578ebe-876f-5c2c-8335-e7e7c274c42c.html>.
[22] "Alaska Interagency Coordination Center Situation Report." N.p., 2 Nov. 2016. Web. <https://fire.ak.blm.gov/content/aicc/sitreport/current.pdf+>.
[23] "Cultural Programs of National Park Service Reorganized." Anthropology News 23.6 (1982): 1. Web. 25 Feb. 2017.