
# Moody's Mega Math Challenge®

A contest for high school students

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## PREVIEW PAPER: AVERAGE

The judges noted that this submission had a poor executive summary. On question one, the team noted that their prediction for the mean sea level as a function of time had a negative slope, yet they predicted that the mean sea level will increase in time. On the plus side they indicated that predicting 100 years in advance is not ideal.

On question two, they defined a vulnerability index, but they integrated a function that is not well defined. It is not clear why they integrated the function. They also assumed that the temperature as a function of time is an exponential function.

With respect to question three, the team included a constant in their model, but they did not clearly define its value. Finally, the team added a little bit of humor at the end with their team's name. The pre-triage judges reacted differently in how they interpreted this.


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# Executive Summary

Our Nation's National Parks are filled with some of the most amazing natural beauty our world has to offer, but as the global climate is changing many parts of that beauty is put at risk. Although it is all still greatly unknown exactly how climate change will affect National Parks, analyzing data can help to paint a clearer picture of how the future will look. Through data on sea levels, weather and tourism, we have built three models designed to predict these things in 10, 20 and 50 years. To help The National Park Service when considering the best allocation of funds between the different National Parks

In order to accurately predict the future of the Parks. We began with calculating the projected risk factor of the five chosen parks. The risk factor relates to the possible loss of land due to sea levels rising, on a scale of low, medium, and high. Which resulted in Olympic National Park, Washington having the lowest risk factor and Padre Island, Texas having the highest. Meaning that when it comes to safety from rising sea levels Olympic National Park is the most worthy have having funds allocated towards. As there is little to no risk of a loss of property or human infrastructure over the next 50 years.

In terms of the second model we evaluated the trend of hurricanes in September in the locations of the National Parks on the East Coast. Which showed that Cape Hatteras, North Carolina was at the highest risk for detrimental hurricane damages, whereas Acadia National Park, Maine has the lowest risk of possible hurricane damages.

As for the third model we took into account the projected visitors in each park after 10, 20, and 50 years. The model showed overall that Olympic National Park had the highest visitor trend, and Padre Island had the lowest number of visitors projected for the future.

All of data leans towards the fact that Olympic National Park not only is the safest park to put money towards. Due to the fact it resulted in the lowest risk factor of all of the National Parks, it also scored highest in the projections of future visitors to the park. As for the largest risk, Padre Island not only is the most likely to be the first park with a large portion submerged underwater it also had the lowest trend of visitors over time.

In conclusion although climate change is an incredibly large problem facing National Parks by analyzing data we have the opportunity to plan and prepare the best ways to allocate funds in order to keep as many national parks as possible alive and thriving.

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# 1 Introduction

## 1.1 Background Information

Climate change is one of the largest problems looming in our future, especially in respect to National Parks where nature is the key focus. National Parks have been enjoyed by families all over the world for decades, but what happens when these parks are put at risk of erosion, and severe weather changes? To better understand the background of the problem, we have attached below a few descriptions of the current issues that the chosen parks are currently facing

Acadia National Park located in Bar Harbor, Maine is expected to have a temperature increase by 4 degrees fahrenheit over the next century[1]. Climate change is also causing an increase in annual precipitation. Due to these changes in weather patterns, sea levels have also risen causing the ecosystems that lay on the shore to be destroyed entirely or to be moved inland.

North Carolina's Cape Hatteras' sea levels have also risen and hurricanes have become more intense. Due to the rising sea levels, the NPS (National Park Service) moved the Cape Hatteras National Seashore lighthouse more inland in 1999, which is a direct example of climate change's effects on sea levels being detrimental to national parks[2].

Alaska's average annual temperature has also risen by 6.7 degrees fahrenheit in the past 67 years, with projections of up to a 32.6 degree fahrenheit increase over the next decade[3]. This would cause a detrimental rise in the sea levels surrounding Kenai Fjords leading to extensive erosion and the loss of the rocky shoreline. With such rise in sea levels, it will be incredibly difficult for tourists to enjoy the natural beauty that the park has to offer.

In 1982, the Olympic National Park had 266 glaciers. By 2012 the number had risen to 311 [4]. This is due to the increase in temperature causing the glaciers to break apart. It is predicted that the Pacific Northwest will rise by 3-9 degrees fahrenheit by the end of the century.

Similarly in Texas, the oceans are expected to rise 2-5 feet in the next century[5]. This increase will cause erosion to the sea shore, thus eliminating public access to the beach. The rise in sea level will cause Padre Island's to shrink significantly as a result of land erosion.

## 1.2 Problem Restatement

1) Build a mathematical model to determine a risk factor caused by changes in sea level by establishing ratings of high, medium, or low for each of the following five parks for the next 10, 20, and 50 years.
    - Acadia National Park, Maine
    - Cape Hatteras National Seashore, North Carolina
    - Kenai Fjords National Park, Alaska
    - Olympic National Park, Washington
    - Padre Island National Seashore, Texas

2) Develop a mathematical model that is capable of assigning a single climate vulnerability score to any NPS coastal unit. The model must take into account both the likelihood and severity of climate-related events occurring in the park within the next 50 years.

3) Incorporate the link between visitor statistics and the vulnerability scores into a model that predicts long-term changes in the amount of visitors each park receives. While keeping in mind other possible variables that may be considered a priority. So that this output can be used to advise NPS where their future financial resources should go.

# 2 Tides Of Change

One of the largest impending threats of climate change is the rising tides. Especially in national parks where the environment is the key means of bringing visitors to the park. The model below evaluates different risk factors related to changes in sea levels. It is split up into risk rating of low, medium, and high, with projections for the next 10, 20 and 50 years

**Acadia National Park, Maine**
**Cape Hatteras National Seashore, North Carolina**
**Kenai Fjords National Park, Alaska**
**Olympic National Park, Washington**
**Padre Island National Seashore, Texas**

## 2.2 Assumption And Simplifications

- **Assumption:** The sea level rise only counts towards oceans not lakes or rivers.
  **Justification:** For the most accurate model possible we focused only on sea levels rising in the ocean. Due to the difficulty of calculating exactly how rising sea levels' will affect lakes and rivers.

- **Assumption:** Risk factor is mostly dependent on sea level, ecosystems and biodiversity.
  **Justification:** There are countless possible risk factors for the quality of the model we are assuming that they are the only risks "worth" factoring in

- **Assumption:** High risk factor means ecosystems that are intertidal and subtidal, wetlands/estuaries, and beaches.

**Justification:** These ecosystems rely on the ocean level. If the sea levels also rise many beaches will be underwater and will not be able to have public access. Also beachfront homes would have to relocate or move back due to rising sea levels bringing higher wave heights.

- **Assumption:** Medium risk factor means ecosystems that are lakes and ponds, forests, rocky coast.

**Justification:** These ecosystems are at a moderate risk of problems related to climate change. Such as possible damages and loss of wildlife, but they wouldn't be completely detrimental to the park

- **Assumption:** Low risk factor means a mountain ecosystem
  **Justification:** Due to their height mountains are at little to no risk of being affected by climate change

- **Assumption:** That erosion does not affect elevation
  **Justification:** Due to the time constraints and amount of possible variables it is impractical to predict erosion. It also doesn't directly affect the posed question.

## 2.3 Definition Of Variables

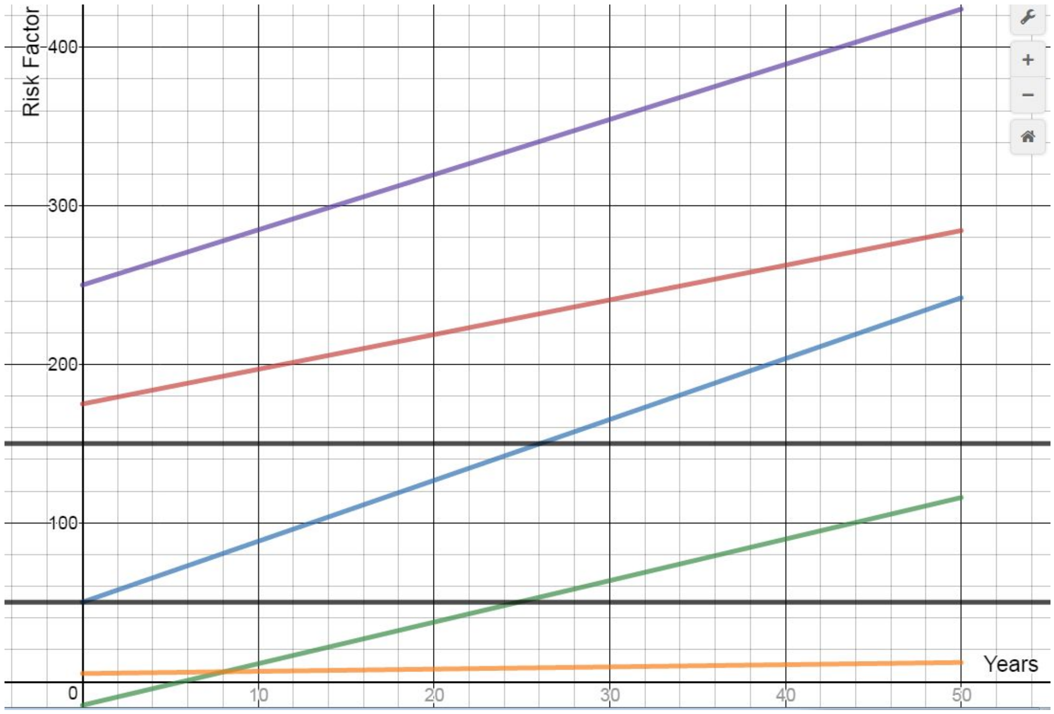
- **Elevation of the park**
  - Independant
- **Percentage of park submerged after X-years**
  - Dependant on elevation and ocean levels
- **Time**
  - Independent
- **Sea level**
  - dependant on time
- **Dollars worth of human infrastructure at risk of flooding**
  - Sea levels and time
- **Terrain type of park**
  - Independent variables
- **Elevation of park**
  - Independent variable

## 2.4 Solution

Based on the NPS data we determined that the rise in sea level was linear. As such the change in sea level is simply determined by a constant multiplied by time. The NPS data gave this constant in millimeters per year.

| | **Change Constant** | **10 Years** | **20 Years** | **50 Years** |
|---|---|---|---|---|
| **Bar Harbor, ME (Acadia)** | 2.178mm/year | 21.8mm | 43.6mm | 109mm |
| **Oregon Inlet Marina, NC (Cape Hatteras)** | 3.84mm/year | 38.4mm | 76.8mm | 192mm |
| **Seward, AK (Kenai Fjord)** | -2.62mm/year | -26.2mm | -52.4mm | -131mm |
| **Port Angeles, WA (Olympic)** | 0.14mm/year | 1.4mm | 2.8mm | 7mm |
| **Padre Island, TX** | 3.48mm/year | 34.8mm | 69.6mm | 174mm |

As can be seen in the results change in sea level can vary drastically among different locations. However we have reason to believe that this model breaks down as time goes on. This is because some scientists have predicted that the rate of sea level rise may become exponential in the future http://oceanservice.noaa.gov/facts/sealevel.html but the data collected so far does not seem to indicate this fact.




(Figure 1)

Legend:

Red = Acadia National Park

Purple = Padre Island National Seashore

Blue = Cape Hatteras National Seashore

Orange = Olympic National Park

Green = Kenai Fjords National Park

(The Change Constant for Kenai Fjords was multiplied by -1 as any sea level change can be deleterious)

When determining risk factor we considered biodiversity to be the most important factor. We took the linear functions for sea level rise and added or subtracted a biodiversity score that is based on the number of biomes and ecosystems that are likely to be affected by rising sea levels. Points were added for highly vulnerable ecosystems such as beaches and estuaries and subtracted for less vulnerable ecosystems such as mountains and forests.

| Biome | Biodiversity Score | Acadia | Padre | Hatteras | Olympic | Kenai |
|---|---|---|---|---|---|---|
| **Wetlands** | +50 | Yes | Yes | No | No | No |
| **Forest** | -10 | Yes | No | No | Yes | No |
| **Beach** | +50 | Yes | Yes | Yes | Yes | No |
| **Fjord** | +10 | No | No | No | No | Yes |
| **Mountains** | -25 | Yes | No | No | Yes | Yes |
| **Lagoon** | +100 | No | Yes | No | No | No |
| **Rocky Intertidal** | +100 | Yes | No | No | No | No |
| **Meadow** | -10 | No | No | No | Yes | No |
| **Mud Flats** | +50 | No | Yes | No | No | No |
| **Rocky Coasts** | +10 | Yes | No | No | No | No |
| **Total Score** | 325 | +175 | +250 | +50 | +5 | -15 |

(Figure 2)

# 3 The Coast Is Clear?

Our team developed a mathematical model that is capable of assigning a single climate vulnerability score to any NPS coastal unit. Our model takes into account both the likelihood and severity of climate-related events occurring in the park within the next 50 years.

## 3.2 Assumption And Simplifications

- **Assumption:** Hurricanes are mostly prevalent on the east coast
  **Justification:** Most west coast hurricanes head towards Asia. This can be seen on the cyclone formation maps provided by NOAA.

- **Assumption:** Hurricanes tend to strike specific areas
  **Justification:** Tracking historical hurricane paths show certain patterns. [6]

- **Assumption:** Hurricane intensity increases are a linear function of time.
- **Justification:** NOAA has predicted a 2 to 11% increase in average hurricane severity by 2100 but we did not have time to delve deeply into the trend of this increase so we used a linear trend for simplicity. [6]

- **Assumption:** The average increase in hurricane wind speed on the Saffir-Simpson Hurricane Wind Scale 0.065%/year
- **Justification:** Predicting weather is always spotty especially far in the future. This value is the arithmetic mean of upper and lower NOAA predictions.

- **Assumption:** The current average intensity of hurricanes on the Saffir-Simpson Hurricane Wind Scale is 2 for the year 2000
- **Justification:** If we had more time we would try to find the average value but the 2 can be substituted with the actual value in the model.

- **Assumption :** The most significant factors for hurricane danger are: likely paths, average return time, and hurricane wind speeds.
- **Justification:** Quite simply this data proved most easy to find in the time we had.

- **Assumption:** As hurricane intensity increases the damage done increases exponentially.
- **Justification:** As wind speeds increase it makes sense that more and more materials would be pushed beyond their breaking point.

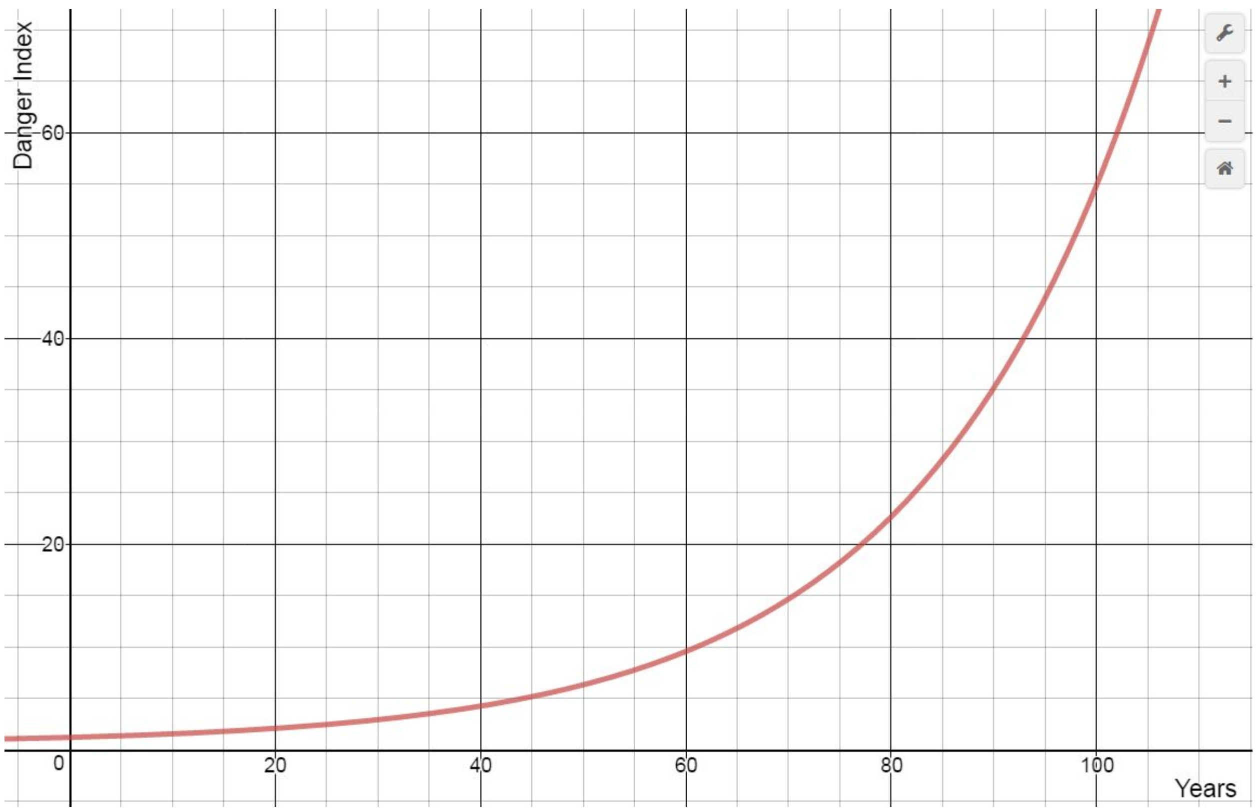
### 3.3 Solution

### Hurricane Risk

Based off of NOAA data September is the most active hurricane month. Our model uses Exclusively data from september because of the number of paths the hurricanes tend to follow is the greatest. Based off of this we used the likely, more likely, and most likely designations from NOAA. Every county on the east coast has a base hurricane risk associated with the above designations. The values go from 1 to 3 with 1 being likely and 3 being most likely. This base value is then divided by the average return time for hurricanes (also from NOAA). This constant is then multiplied by 1 plus the average intensity of hurricanes in the year 2000 raised to years since 2000 multiplied by the average annual increase in intensity.

$$Hurricane\ Danger\ Index = (P/R)(I^{T*0.065} + 1)$$

An example situation is shown for Cape Hatteras National Park. Where P=3, R=5, and I=2




(Figure 3)

### 3.4 Variables

- **Independent variable**

  Time

  The Predicted Path

  The intensity

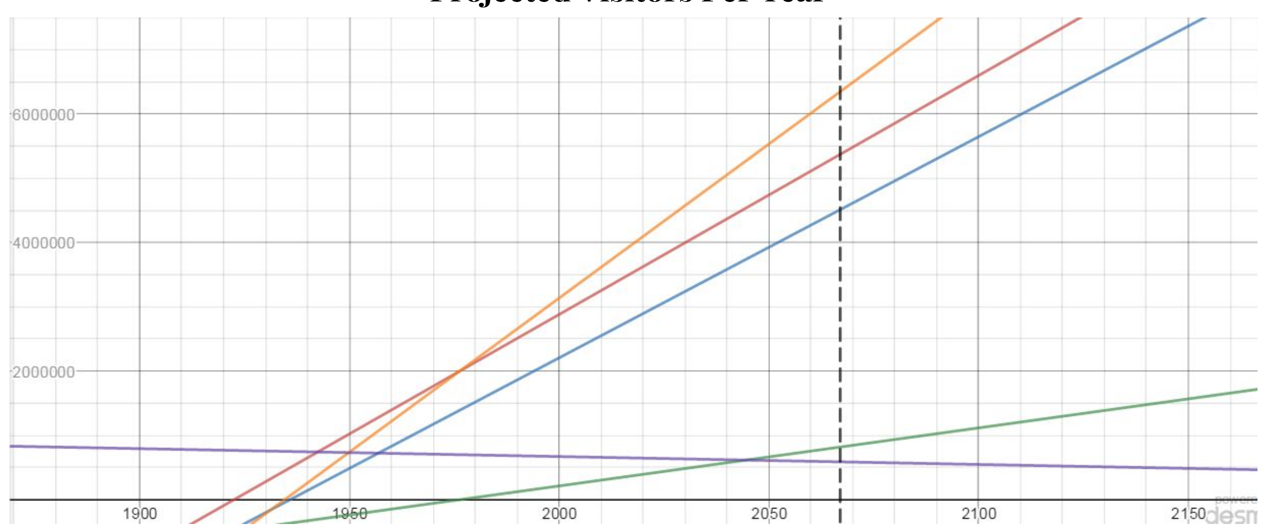
- **Dependent Variable**

  The hurricane index

# 4: Let Nature Take Its Course?

We considered incorporating visitor statistics and our vulnerability scores when deciding which parks could be a reasonable use of NPS monies. Keeping in mind other variables that may be considered priorities as we went, such as species and landmarks. To do this, we created a new model that predicts long-term changes in visitors for each park. We used this output to advise NPS where future financial resources should go.

**Projected Visitors Per Year**




(Figure 4)

Red = Acadia National Park

Purple = Padre Island National Seashore

Blue = Cape Hatteras National Seashore
Orange = Olympic National Park
Green = Kenai Fjords National Park

The equations follow a basic linear model (y=mx+b). We got the equations using a trend line, as all of the data points seem to go in one general direction or each park. The "m" is the average increase of visitors per year. The "b" is just the y intercept which was found through a yield line. As a quick example, in the Acadia National Park equation, "37190.438" would be considered the "m" variable, and "$7.15*10^7$" would be the "b" value. The "x" variable represents the year being projected, and the "y" would be the total projected visitors for that year.

Acadia- $y=37190.438*x-(7.15*10^7)$

Cape Hatteras- $y=34417.909*x-(6.663*10^7)$

Kenai Fjords- $y=9031.119*x-(1.785*10^7)$

Olympic- $y=47947.847*x-(9.276*10^7)$

Padre Island- $y= 1231*x+(3.132*10^6)$

| | Acadia | Cape Hatteras | Kenai Fjord | Olympia | Padre Island |
|---|---|---|---|---|---|
| **2016** | 3,303,393 | 2,411,711 | 346,534 | 3,390,221 | 634,012 |
| **2027** | 3,885,018 | 3,135,102 | 456,078 | 4,430,286 | 636,154 |
| **2037** | 4,256,922 | 3,479,281 | 546,389 | 4,909,764 | 623,842 |
| **2067** | 5,372,635 | 4,511,818 | 817,323 | 6,348,199 | 586,903 |

(Figure 5, Original Historical Data From NP)

## 4.2 Variables

- **Independent Variable**
  Years
- **Dependent Variable**
  Total Projected Visitors

## 4.3 Assumption And Simplifications

- **Assumption:** Higher level of natural beauty will cause a higher level of visitors to the park.
  **Justification:** People are naturally more attracted to nice looking.

- **Assumption:** More natural disasters that occur in the area of the park the less likely people will want to go there.

**Justification:** People will either believe it is unsafe to travel there or find it boring if they have to stay inside because of the weather.

- **Assumption:** The average amount of visitors would be linear
- **Justification:** Even though the number of visitors goes up and down it still follows a linear path.

- **Assumption:** No major event to cause a drop in visitors

**Justification:** Because it would be too complicated to account every major event that has happened since the parks have opened.

### 4.4 **Changes that would be made given more time:**

We would find a numerical matrix of elevations and show how much of it would be submerged using Matlab. We would create a more accurate (nonlinear) model of sea level change. We would define what the hurricane index means more in depth in the second model. Also more research to help it be more well defined. We would try to take into climate change into the effect for the last model to find out which parks will succeed or fail.

# 5 Conclusion

We created a model that shows how the sea level will rise in the next 50 years and whether each National Park is a high, medium, or low risk factor of being submerged. Our next model shows the risk factors based on severe weather events such as hurricanes. This model creates a Hurricane Danger Index that assesses hurricane risk based on variables such as location and average frequency.bib Last model shows where the NPS should spend their money.

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