An Analysis of the Distribution of Costs and Possible Social Justice Implications of Global Warming in the Richmond Metro Area

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Summer 2007
Introduction

As much current research has shown, global warming is becoming increasingly accepted as inevitable and likely to impact people around the globe. In light of its global significance, many studies have been done to show potential environmental impacts of increasing global temperatures, such as rises in sea level, changes in weather patterns and ecosystem shifts and species extinctions. This global phenomenon may have tremendous negative effects on individual communities. This project focused on some potential effects on local Richmond communities and explored the question of whether the social burdens of global warming in Richmond would be evenly distributed among all classes and races or more highly concentrated among particular socioeconomic groups.
Increased Flooding of the James River

• Sea level rise is expected to be one of the major effects to all mid-Atlantic states, with the “Climate Change 2007” report by the Intergovernmental Panel on Climate Change (IPCC) estimating a rise between 9-88 cm.

• Because of the “backwater effect” in which river drainage into the ocean is slow due to this sea-level rise, a moderate sea-level increase can cause increased flooding even as far inland as the Richmond Area.
Tide data from June 2006-June 2007 from these two points was used to determine the strength of the backwater effect and estimate how much the James River would rise in Richmond due to an increase in sea level at Sewell’s Point. The daily data points were graphed with the height of the high tide where the James River meets the Atlantic Ocean on one axis and the height of the high tide in Richmond on the other. The slope of the line can be used to approximate how much the James River would rise in Richmond due to sea-level rise.
This is a graph of all 365 days, the slope is .98, indicating that the James River in Richmond would rise almost the same amount as sea-level. However, there are several days that don’t fit this equation very well due to large precipitation events that raised the water level in Richmond. As a result, the slope is distorted and only 75% of the data points fall within 30% of the line.
After removing the top five percent of the highest tides in Richmond (since they are largely due to precipitation events and not the relationship to sea-level rise), the new line has a slope of .84 with roughly 80% of the points falling within 25% of the expected.
This graph uses the median tide heights as data points instead of high tides, and the slope matches the one from high tide, .85. The data is convincing enough to make the preliminary assumption that an increase in sea-level would increase the height of the James river in Richmond by a comparable amount.
The IPCC estimates of sea level rise of 8-88 cm are equivalent to 3.5 to 35 inches. Going with a moderate example of 8 inches, we could approximate the rise in Richmond at about 7 inches based on the .85 slope in the previous graph.
This graph shows the likelihood of the James River reaching a specific stage height in any given year, the blue dots are based on historical conditions and the black dots based on the current year’s conditions. The graph shows that there is a 3.75% chance of exceeding the flood stage (12 ft) in any given year.
The potential seven inch rise in the James river would raise the flood risk to 4.75% in any given year according to the previous diagram. For the data analyzed, the water level exceeded the flood stage 5 times and was within 7 inches two more times, so an increase in sea level of only 8 inches could have caused the James River to flood two extra times last year.
• The following slide will show a map of income levels in the entire Richmond metro area overlaid with the James River floodplain. The counties denoted by blue arrows are in the floodplain and the counties denoted by the white arrows are not in the floodplain.

• Note: The small picture in the lower right hand corner of the next slide is a screen print out of the GIS analysis and highlights the block groups that lie within the James River floodplain.
While the previous slide showed a lower overall mean income for residents within the floodplain, this may largely be due to the fact that a lot of the inner city is in the floodplain and inner city incomes are generally lower than the suburban counties. The next slide shows a map of only the inner city and analyzes the income levels within the floodplain and outside the floodplain for only inner city.
No significant differences in income were found between inner city residents in the floodplain and inner city residents outside of the flood plain. However, the census block group data are not specific enough for a detailed analysis and there is potential for further study here.
This map just shows the population density of the different block groups in Richmond overlaid with the floodplain. The most populated area of the center city is not in the floodplain, but several areas within the floodplain do have a medium population density.
Change in Tree Species

- The Natural Resources Defense Council’s Report on Global Warming in the Mid-Atlantic reported that a rapid shift in major tree types may occur. If new conditions harm existing tree species, the light gaps that open up in the forest could lead to invasive species taking hold and certain trees that are favored by the new conditions may become dominant and reduce diversity.

Why it’s important to Richmond:

A 2007 report by the Virginia Department of Forestry shows that the forest industry is a 29.4 billion dollar industry in Virginia, ranks first in manufacturing jobs and pay, and timber is the number one agricultural crop in Virginia.
• In order to determine how the forests changed in the Richmond area, I used the climate change atlas recently created by the USFS. The atlas incorporates over a decades worth of research to model how each major Eastern US tree species would change in prevalence in response to two different degrees of global warming (“high and “low” 
• The next slide shows an example print out of the Climate Change Atlas for Virginia Pine. The left picture shows the current prevalence and the right slide shows the predicted prevalence based on three different models and a “low” degree of global warming.
Climate Scenario Menu

Choose Climate Scenario from Menu

Current FLA

Climate Scenario Menu

Choose Climate Scenario from Menu

Avg. of 3 GCMs - Low

Animate Scenarios
Using the model, I evaluated the prevalence of each Virginia tree in the Richmond metro area on a scale of 1-10. Then, each tree was also given a prevalence value in the Richmond metro area after a “low” degree of global warming. The before and after values were compared and the most significant species in the Richmond area were identified.

The diagram on the next slide shows the most significant tree species in the Richmond area and the change in prevalence on this ten point scale.
The right six species are softwood, the rest are hardwood species. Post Oak and Shortleaf Pine are likely to become the dominant species, with Sweet Gum and Loblolly Pine also remaining very prevalent.
Effects on the Timber Industry

-In general, there will likely have to be a shift in the Richmond lumber industry to the use of more softwood species (right now the industry is split about evenly).

  - oaks dominate the hardwood trade and almost all of the oaks decrease in prevalence
  - the loblolly and shortleaf pines that dominate the softwood trade increase in importance.

- The younger trees that take over will also be less valuable than the older more mature trees that are present now.

- The reduction in diversity will increase susceptibility to disease and parasites, making the timber industry more vulnerable.
Other costs

• Trees provide filtering services valued at 900 million dollars annually removing five major pollutants (carbon dioxide, sulfur dioxide, nitrogen oxides, ozone and particulates) from the air

• Older mature trees protect water quality and prevent erosion and siltation better than younger trees

• Older mature trees can mitigate effects of storm water, so without them, flooding may be worse as well
Endangered Species/Species of Concern most affected by change in dominant tree species

- Refinesque’s Eastern Big Eared Bat
  - Mature red maples are primary habitat
- Barking Tree Frog
  - Virginia Pine is primary habitat
- Wren
  - Prefers oaks and older trees
- Brown Creeper
  - Prefers hardwood habitats
The data for the map on the following slide came from the Virginia Department of Conservation and Recreation’s Forest Economics Model that estimates the economics value of all of Virginia’s forest. The numbers show the value of forests on a 1-5 scale for each of the counties around Richmond. Chesterfield had the highest average economic value.
City of Richmond: 2.46

Chesterfield 3.17

Hanover 3.11

Henrico 2.86

City of Richmond: 2.46

Charles City 3.02
Air Quality

• Ground Level Ozone formation depends on sunlight and heat:
  • OH + CO → H + CO2
  • H + O2 → HO2
  • HO2 + NO → OH + NO2
  • NO2 + sunlight → NO + O
  • O + O2 → O3

• Health effects include irritation of the respiratory system, decreased lung function, aggravation of asthma and increased susceptibility to respiratory infections
This slide shows the non-attainment history for Virginia. Richmond is one of the areas that has had problems with ozone in the past.
This chart from the Virginia Department of Environmental Quality shows the average number of times each year that Richmond exceeded the national air quality standards for ozone. As is reflected in the chart, the air quality has improved in Richmond over the last decade, but there is still a problem with ozone pollution in the city.
This chart shows the effect of temperature on ozone formation under two different emission scenarios. The effect of temperature on ozone formation is much stronger under higher emissions. Since inner city Richmond has higher emissions than anywhere else in Virginia the temperature change will have a much greater effect in Richmond.
These correlations from Norfolk and Richmond show how Richmond’s ozone is more reliant on temperature than Norfolk.
This chart from the Virginia Department of Environmental Quality shows the likelihood on any given day of exceeding the national standards for ozone at three different temperatures. The chart shows that Richmond is the most likely to exceed ozone standards at any temperature.
According to the previous chart, an increase from 32 degrees Celsius to 36 degrees Celsius can increase the probability of exceedance in any given day from 36% to 48%. The IPCC estimates an increase in temperature between 1 and 6 degrees Celsius, so this four degree change is a reasonable estimate. If we conservatively assume that only July and August are susceptible to ozone formation, a 12% increase in probability each day for 61 days could mean an extra 8 high ozone days a year.
• The next slide shows two examples of an Appalachian Lee Trough. An Appalachian Lee Trough is an axis of low pressure is usually oriented south-southwest to north-northeast. An ALT is triggered by the mountains to the west and the flat eastern coastal and occurs under weather conditions that are favorable to ozone formation, including high pressure overhead. The conditions combine to lead to the development of a narrow belt of high ozone along and east of the trough axis. ALT’s can be a serious problem for the east end of Richmond because If the axis of the trough is overlaid on the high emissions I-95 Corridor, very high ozone can result.
The orange band in the picture above shows the high ozone in the trough, though usually a trough would be located more east than this.

The dotted orange line below indicates the location of the Appalachian Lee Trough.

August 1, 2002
This diagram shows the extremely high ozone levels possible in inner city Richmond.
The figure above shows the different ozone monitoring sites in Richmond and their design values. A design value is the three year average of the 4th highest ozone level each year. Hanover county has the highest design value and over the past 15 years has had the highest number of exceedances for all four counties 10 times. Chesterfield has the lowest design value and has consistently had the lowest number of exceedances.
• Since ozone is a regional pollutant, it is not possible to get any more specific than county level. While inner-city and Henrico (the two lowest income areas) are more at risk than Chesterfield, Goochland and Powhatan, Hanover is the most at risk, and it is the wealthiest county in the region. No definitive statements can be made from this data about spatial environmental justice issues. However, there may be environmental justice issues centered on susceptible populations.
### Asthma Prevalence

<table>
<thead>
<tr>
<th>Virginia</th>
<th>White</th>
<th>Black</th>
<th>Multi-racial</th>
<th>Other</th>
<th>Hispanic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime</td>
<td>11.60%</td>
<td>14.40%</td>
<td>23.60%</td>
<td>5.20%</td>
<td>13.20%</td>
</tr>
<tr>
<td>Current</td>
<td>7.10%</td>
<td>9.40%</td>
<td>14.90%</td>
<td>3%</td>
<td>11.80%</td>
</tr>
</tbody>
</table>

For example, children with asthma are going to be more affected by higher ozone levels than healthy children and or adults. It has long been suggested that there is already an environmental justice problem in Richmond regarding lower income children developing asthma with higher frequency than wealthier children. The census data above shows that Caucasians have lower rates of asthma in Virginia than other races. In addition, the elderly would be more adversely affected by increased ozone.
Summary:
The three most significant effects of global warming to Richmond are:

- the increased flooding risks of the James River due to sea-level rise
- the redistribution of tree dominance in forest ecosystems
- the potential for increased ground level ozone pollution

The environmental justice implications of each issue differ since each of these issues has a different potential distribution of costs:
• Inner city Richmond, Goochland, Powhatan and Charles City are affected by increased flooding, but whether or not there are environmental justice implications within these counties will require smaller data sets.

• The distribution of the costs of the change in tree species cannot be determined because it affects anybody economically invested in the timber industry and anybody that places a high value on Virginia’s natural habitats and wildlife, both hard populations to identify.

• The air pollution is likely to affect Hanover worst, followed by inner city Richmond, Henrico and Charles City. However, the burden within these counties may fall heavily on lower-income children with asthma and the elderly.
If we combine these results spatially:

- Goochland and Powhatan are in the James River Floodplain, but don’t have as many air pollution problems.
- Hanover has the worst problem with air pollution, but doesn’t have the James River running through it.
- The City of Richmond and Charles City both have to deal with both of these problems, and also are the two lowest income areas, but more research is needed with more refined data sets on income to make any concrete conclusions on the environmental justice implications of global warming.