OUR Journal: ODU Undergraduate Research Journal

Volume 3 *Crisis Communication & Climate Change* Article 3

2015

Studying the Effect of Sea-Level Rise on Infrastructure and Construction

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ABSTRACT

Climate Central, a nonprofit research organization that aims to provide the public with relevant and reliable information on climate change, developed an interactive application called the Risk Finder tool that launched in October of 2013. This tool collects data from several federal agencies, including NOAA, FEMA, and the EPA, and allows users to research sea-level rise and climate change in their specific state. In an effort to provide a user-friendly platform, Dan Rizza at Climate Central tasked an introductory Technical and Scientific writing course at Old Dominion University with conducting usability testing on the Risk Finder tool. Usability testing is the evaluation of a product by representative users, and in this case, refers to residents of Hampton Roads testing the Risk Finder tool and assessing its advantages and disadvantages. The primary investigators of the study are Dr. Daniel Richards and Mrs. Megan McKittrick. Students from the ENGL 231C course are also contributing to the study. The undergraduate students in ENGL 231C, led by Megan McKittrick, used systematic sampling from the Polk directories in the Old Dominion library to create a list of possible participants. The students then addressed envelopes and filled them with the appropriate content to be sent out a few days later. When the chosen participants tested the Risk Finder tool, specific approaches such as "productive usability" and "talk-aloud protocol" were used. These approaches allowed participants to have open use of the website while they spoke their decisions aloud, and patterns in the choices were then recorded by investigators in order to improve the website. These patterns also gave insight into which sea-level, rise-related issues users are most interested in, such as health risks and destruction of property. Sea-level rise will impact the current infrastructure and the construction of new property on the coasts, which has the potential to lead to a decline in the local economy. The Risk Finder tool would be useful in conveying such data to both city planners and the public, which would hopefully lead to policy change in affected areas.

The current state of environmental and ecological systems worldwide is a growing concern in today's society. The past few decades have seen a significant increase in fossil fuel production, which can be attributed to the growing population and an increase in developed countries and their emerging industries (Jackson Allen, 2015). This, along with other factors, has contributed to climate change and, therefore, rising sea levels. However, sea-level rise, while primarily a result of climate change, can also be attributed to natural changes in greenhouse gas levels (Williams, 2013). Multiple significant regional features must be considered as well, such as gravitational changes, changes in ocean circulation patterns and wind patterns, land subsidence or uplift depending on the isostatic adjustment of the earth's crust, sediment compaction or consolidation, and tectonic forces (Williams, 2013).

Sea-level rise will have a profound impact upon many aspects of life, but it will significantly impact coastal communities due to their proximity to the ocean. Projections show a dismal future for many

coastal communities as sea levels could rise as much as 2 meters by 2100 (Williams, 2013). These estimates show that coastlines will recede and low-lying areas along the coasts will have frequent oceanic inundation as sea levels rise, as well as physical impacts such as wetland inundation, increased tidal and storm surge flooding, and increased rates of shoreline change (Thatcher, Brock, & Pendleton, 2013).

In 2013, Climate Central created the Surging Seas Risk Finder Tool in response to the growing demand for information about the impact of sea-level rise on communities (Climate Central, 2014). The organization developed the interactive tool with city planners as the audience in mind, but they also wanted the product to be usable for the general public (Climate Central, 2014). Due to the numerous factors that contribute to coastal inundation, the Risk Finder Tool uses modeling and simulation to show users the effects of sea-level rise on a specific community. The Risk Finder Tool map also has sliding capability to allow users to change the rate themselves rather

than predicting it for them (Climate Central, 2014). The researchers studied the public's interaction with the tool and performed an assessment on the capabilities and limitations of the Risk Finder Tool. They also determined the public's interest in information about the impact of sea-level rise on building and infrastructure damage.

LITERATURE REVIEW

Estuary Destruction Due to Rising Sea Levels

Large scale reclamation projects near coastlines, in which disturbed land is rehabilitated into its former state, significantly change coastline configuration and subaqueous topography, therefore affecting tidal current and general tidal nature. After a reclamation project was proposed along one of China's shorelines, specifically the Jiaojiang estuary, numerical simulations were conducted to determine the effects of sea-level rise in that area (Sun et al., 2014). This study showed that sea-level rise does impact tidal levels and that due to the reclamation project, tidal levels significantly increased in

some parts of the area (Sun et al., 2014). Particularly, the reclamation project would change tidal volume into the estuarine entrance, raise tidal energy, and increase resistance along the channel (Sun et al., 2014).

In New South Wales, Australia, a case study was conducted on the Macleay River estuary and the effects of potential sea-level rise. The study concluded that sea-level rise will significantly flood parts of the landscape in the Macleay River estuary, which will destroy many ecological systems as well as urban structures (McGowan & Baker, 2014).

Modeling and Simulation as a Research Method

The use of modeling and simulation in predicting the future of climate change and sea-level rise is critical for researchers in those fields of expertise. Since it is impossible to know for certain how sea-level rise will impact communities, modeling and simulation provides a method that takes into account many factors that could possibly

contribute to the results. A study on the sea-level rise of the Norwegian coastline, sought to predict and analyze the effects of sea-level rise on buildings and construction (Almås & Hygen, 2012). The researchers were able to use this technology to demonstrate to the government how significant the damage would be to the coastline infrastructure (Almås & Hygen, 2012). In the Macleay estuary study, modeling and simulation technology was used to predict three scenarios for the year 2100 in order to highlight the uncertainties surrounding future sea levels: a best case scenario in which sea levels rose 90cm, a mid-case scenario in which sea levels rose 2.6m, and a worst case scenario in which sea levels rose 5m (McGowan & Baker, 2014).

Impact on Infrastructure

Building, housing, and land development along coastlines are at a severe risk for flooding and potential storm damage due to the rising sea levels. In the Norwegian coastline study, approximately 110,000

buildings were concluded to be situated less than 1m above normal sea level (Almås & Hygen, 2012). The categories of analysis used in the study were as follows: garages, temporary houses and boathouses, houses, cabins, office buildings, hotels and restaurants, and buildings for fishing and agriculture (Almås & Hygen, 2012). About 55% of these buildings were determined to be temporary housing that would not cost very much to demolish or rebuild, but the remaining categories were determined to be socially or economically important (Almås & Hygen, 2012). The researchers determined that the total costs for Norway on constructional measures to buildings alone are estimated to be as much as €725 million (Almås & Hygen, 2012).

In New South Wales, the Macleay River estuary study concluded that sea-level rise will significantly flood parts of the landscape in that area and precautionary approaches should be taken in future urban planning and construction (McGowan & Baker, 2014). In the United States of America, a study conducted by Thatcher, Brock, & Pendleton

analyzed the economic vulnerability of the United States' Gulf of Mexico shoreline. These researchers gathered data on the amount of infrastructure and population in a given area, along with local shoreline erosion rates and relative sea level rise rates. They concluded that climate change poses many challenges for the future management and development of the coastline and "long-term planning is particularly needed to enhance resiliency" (Thatcher et al., 2013).

Limitations of Current Research

As with most research, there are still many unknowns in this field of investigation, and there are currently gaps in the research due to multiple factors. First, there are no certainties on the exact amount of sea-level rise worldwide because of constantly fluctuating conditions. While there is a certainty that sea levels will continue to rise, numerical calculations and simulations will only be able to predict possibilities. Second, there is a definite focus on inundation in

predicted sea-level rise scenarios that contributes to the current gaps in research. There is a significant lack of research on other impacts of sea-level rise, such as extreme storm surge flooding and saltwater intrusion, and many vulnerability maps only take into account the inundation statistics and data. Future research needs to be conducted on the status of ice melting, soil erosion rates, and natural disasters in contributing to the increasing sea level rise as well.

The results of these studies are important for future reference, especially involving disaster prevention, construction, reclamation, and habitat restoration. They also prove that sea-level rise has had an impact on tidal levels, which then have an impact on storm surges and flooding. The technology of modeling and simulation used in these studies provides estimates on how much climate change and sea-level rise could potentially cost for a nation's coastline, which will be vital to future governmental policy. The damage to infrastructure due to flooding will not only impact the economy, but it will also put millions of people at risk for health problems and home displacement.

METHODS

The population for this study was collected using systematic sampling of the Polk directories in the Old Dominion University library. Systematic sampling of names and addresses was performed, and the resulting sample participants were solicited via a mail flyer, which prompted them for their contact information and availability for the study.

The participants who responded to the flyer, as shown in *Figure 1*, were brought to ODU to perform productive usability testing, in which both pre-test and post-test interviews about knowledge of climate change and overall thoughts on sea-level rise were conducted. While the participants were given full control of how they navigated the Surging Seas website and the Risk Finder tool, they were required to use think-aloud protocol in order for the researchers to hear their approaches and to conduct audio recording.

After the usability testing, the audio recording from each session was transcribed, and the final transcripts were coded for themes.

Figure 1:

Participant*	Gender	Age (Years)	Occupation
Tamara Wallace	Female	64	Corporate
Dan Evans	Male	63	Government
Mike Michener	Male	55	Federal/Civil
John Cameron	Male	67	Electric Technician

*The participants' names have been changed to ensure anonymity.

RESULTS

Generally, two major themes emerged from the coding. The first theme was Technical Problems, which included Statements about Technical Literacy, Website Navigation, and Website Terminology. The second theme was Risk Perceptions, which was then categorized into the sub-themes of Risks and Impacts of Risks. Overall, Risks Perceptions had a total of 97 coding instances before separating into the sub-themes, while Technical Problems had a total of 88 coding instances, as shown in

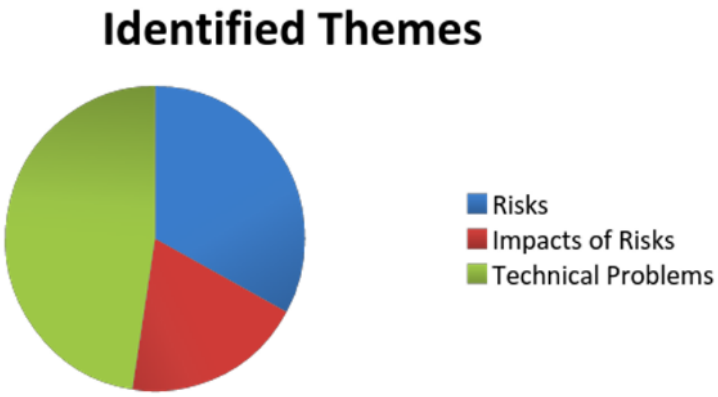

Figure 2:

Figure 2 and *Figure 3*. For this specific research report, only the results from Risks and Impacts of Risks will be analyzed.

Figure 3:

Theme	Number of Instances Coded
Risks	61
Impacts of Risks	36
Technical Problems	88

Risks

For coding purposes, the results for Risks were collected based on statements about climate change, flooding, and sea-level rise. In response to the question, "Is your perception of flooding as it relates to climate change alarm, concern, skeptical or other?" which was asked during the pre-test interview, all four participants responded that they were concerned about flooding risks in relation to climate change. Tamara Wallace stated, "I think it's all connected…. I don't remember us having these kinds of concerns when I was a little girl. It just seems to be growing as a concern, and I've heard about the sea

level rising." Dan Evans elaborated: "The fact of the matter is, we are going through a warming trend [and] seeing a rise, so a tidal event that 50 years ago may have been inconsequential now does create a consequence. It's a very real thing that we are going to need to pay attention to."

Impacts of Risks

For coding purposes, the results for Impacts of Risks were collected based on statements about the risks of flooding to family and transportation. Within five minutes of using the Risk Finder tool, each participant chose to view the 'Property Tab' on the map at least once. All participants also chose to view where they live specifically and assess the risk of flooding. John Cameron indicated that his concerns about Hampton Roads were "basically [the] loss of property and loss of life," and that "infrastructure may be important" as well.

Mike Michener discusses the impact of flooding on transportation: "The tunnels like to shut down when the water level

gets to a certain height. They have to shut the floodgates on them and then shut down the tunnels so you can't use them anymore, which is a big impact on transportation right now." Michener continued, "We've had some roads in Virginia Beach [and] some parts of town where you really can't drive when there's high water…. I do think it'd have a big impact on transportation [including] the damage to the roadways [and] the ability for people to get in and out of places safely. So, there's a public safety issue, I think. And then there's infrastructure damage that could come from high water. Certainly, buildings along the waterfront could be damaged more readily if there is higher water."

DISCUSSION

As expected, the major themes of the study involved the effects flooding and sea-level rise will have on the community. Particularly, the participants were interested in the impacts on transportation and infrastructure. When viewing the tool, most of the participants

viewed the impacts on hospitals, airports, and evacuation routes within the first ten minutes. Two out of the four participants also stated that they would use the Risk Finder tool to look at a given property's risk of flooding. This suggests that people might be more willing to instill policy change since flooding will affect aspects of daily life such as traveling to and from the workplace. Michener was particularly concerned about policy change and stated, "We have time still to make adjustments if we start making changes now to city planning and preparation, and then [we] also need to try and slow down the global impact of all the people in the world." Dan Evans also said, "[We need to] adjust the way we operate in order to prevent damage because as sea levels rise, it's only going to get worse…. Maybe we shouldn't be allowing development, and should we be trying to take a step back? ... Those buildings are in harm's way."

While the study was limited by the number of participants, and therefore generalizations can't be inferred, the study was intended to be qualitative and have a limited amount of participants. This

qualitative study helped the researchers generate improvements for the website while also understanding the perceptions on flooding shared by some residents of Hampton Roads.

CONCLUSION

Sea-level rise will impact the current infrastructure and the construction of new property on the coasts, which has the potential to lead to a decline in the local economy. The investigation of the Risk Finder tool will be valuable in conveying data to city planners while simultaneously educating the public on climate change in the future. The tool provides a simple way for the public to investigate climate change on their own and discuss it within their communities. This will be vital to policy change in affected areas and will hopefully have a big impact.

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Acknowledgements

I would like to thank Mrs. Megan McKittrick, Dr. Daniel Richards, the students of the Spring 2015 Climate Change Communication Undergraduate Research Learning Community, and Climate Central for their individual roles in this project and all of their assistance.