Is Florida Taking Sea Level Rise Seriously?

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Abstract: *Sea levels have been steadily rising, and projections indicate that this upsurge is accelerating. Florida is particularly prone to sea level rise and faces various detrimental consequences, including increased frequency and intensity of inundation and tropical cyclones, saltwater intrusion, erosion, and other associated issues. These challenges pose significant threats to the state's infrastructure, ecosystems, and communities, underscoring the urgent need for comprehensive measures to adapt to and mitigate the impacts of rising sea levels. This research investigates the current problems of sunny day flooding, tropical cyclones, saltwater intrusion, and the social and economic implications of those consequences of sea level rise in Florida. Additionally, it critically examines past and present responses aimed at mitigating the consequences of sea level rise, highlighting the urgent need for proactive and long-term solutions to effectively safeguard the economic and social well-being of the Sunshine State.*

Keywords: sea level rise, Florida, sunny day flooding, inundation, tropical cyclones, saltwater intrusion, adaptation strategies, economic, social effects

In April 2023, southeast Florida received outstanding amounts of rainfall, leaving the city of Fort Lauderdale with more than two feet of inundation and around two million people under flood warning. Videos shared on social media illustrated the extent of the heavy localized rainfall, causing flood waters to rise up to the tops of cars and residents to swim through flooded roads (O'Brien, 2023). The waters also moved around debris and entered houses, leading to mold and additional problems for residents ("Your Questions Answered," 2023). Due to heavy rain, the usually very busy Fort Lauderdale-Hollywood International Airport had to close its operations for two days, canceling hundreds of flights as the excessive rain had "turned [the airport's] runways and access roads into rivers" (Williams

& Rice, 2023, para. 2). The National Weather Service indicated that the rainfall represents a one-in-one thousand-year weather event (O'Brien, 2023), explaining why the sophisticated drainage systems of the area could not prevent flooding (Ramos, 2023).

However, according to experts, these events are part of a bigger problem of climate change and sea level rise. The combustion of fossil fuels, which provides us with energy and therefore was a significant contributor to the rapid changes in the living conditions in Florida over the course of the twentieth century, emits greenhouse gases into the atmosphere. The growing concentration of these gases leads to the greenhouse effect and higher surface temperatures on Earth. Thus, ice glaciers melt and ocean water volume expands, leading to rising sea levels, to which Florida is particularly vulnerable. Hence, what was a one-in-one-thousand-year weather event a century ago may now be a one-in-ten-year event. But the rising sea levels lead to several problems that go far beyond the days of heavy downpours described above. Higher sea levels have been shown to increase the frequency and intensity of inundation, tropical cyclones, saltwater intrusion, erosion, and other problems, which in turn have massive social and economic implications for Florida. Sea level rise and its consequences are exacerbating. Harold Wanless, the University of Miami chair of the Geology Department, suggests that Florida needs to adapt to its changing environment because "we are witnessing the beginning of the largest meltwater pulse in modern human history" (Rush, 2018, p. 76).

Strategies to adapt to Florida's changing environment are only recently being put into place, which demonstrates the reactive and short-term nature of most responses that have been implemented in the state. Although one may argue that sea level rise seems easy to handle, it poses a very complex and almost unmanageable issue for Florida, according to experts. It is uncertain whether the recent and future adaptation strategies

will effectively mitigate the rising consequences of sea level rise or worsen the problems in the long run.

This essay investigates the current problems of inundation, tropical cyclones, saltwater intrusion, and the social and economic implications of those consequences of sea level rise in Florida. Further, past and current responses to mitigate sea level rise are assessed to indicate the urgent need for proactive and long-term solutions to limit the negative economic and social implications of sea level rise.

Consequences of Sea Level Rise and Their Effects on Society in Florida

Researchers nearly unanimously agree that sea level rise is a crisis, but exact projections are hard to make as several variables affect the extent of sea level rise. By 2100, sea levels are projected to rise by 0.3 meters to 2.0 meters, with some projections even exceeding this range (Hauer et al., 2016; Tampa Bay Climate Science Advisory Panel, 2019). These projections pose a massive problem to Florida since much of the state lies below sea level, which makes the peninsula prone to accelerating sea level rise (Hauer et al., 2016). Researchers have focused their attention mainly on sunny day flooding, tropical cyclone threats, and saltwater intrusion because these are the most immediate and visible consequences of sea level rise, even though sea level rise poses several other consequences as well, such as the increased threat of erosion and health issues.

Sunny Day Flooding

According to an interview with William Sweet, an oceanographer from the National Oceanic Atmospheric Administration, the rate of "sunny day flooding" on the East Coast and Gulf Coast has already doubled in the last twenty years (Andrews, 2022). Sunny day flooding, or high tide flooding, is a term for floods that are not associated with a storm but instead through full moons or new moons. These floods are usually

not life-threatening, but due to sea level rise, they increasingly disrupt life in coastal communities as ocean waters repeatedly flood roads and basements (Andrews, 2022). Since Florida lies just above sea level and is a peninsula, it is particularly prone to such flooding (Rush, 2018). According to Rush (2018), inhabitants of the Shorecrest neighborhood in Miami experience sunny day flooding "just about every high tide" (p. 86). With the tide, saltwater rises above seawalls, damaging properties and infrastructure (Rush, 2018). While this used to happen only during storms, a full moon is now enough to create damage in neighborhoods like Shorecrest on a regular basis. Inhabitants of the middle-income community mourn the damages in their yards and their steadily declining property values. Robert Cisneros, an inhabitant of the neighborhood, told Rush (2018) that he "wanted to leave this house to [his] kids, but soon it's going to be worthless" (p. 88), demonstrating the increasing despair of the community. Cisneros' quote also reveals how the repeated floodings put not only a financial but also a psychological strain on coastal populations, as their lifestyle has rapidly changed with ongoing sea level rise. Rush (2018) paints a devastating picture of how the community has to deal with these changes and carry on with their daily lives when she describes how a woman wades ankle-deep through the streets with her skirt and shoes in her hands to make it to the bus stop–images that one might expect to see in a third-world country, but not minutes away from Miami Beach. And Shorecrest is just one of many communities that have been strained by repeated floodings.

Unfortunately, according to reports from 2022, the frequency of high tide floods will increase soon (Andrews, 2022). The 2022 *Sea Level Rise Technical Report* notes that high tide floodings will occur nationally on average between 45 and 70 days per year by 2050 (Sweet et al., 2022). Communities like Shorecrest, which have experienced far above average amounts of high tide floods in the past decade, will likely experience flooding frequencies exceeding 70 days per year. Property values there

and in similar places continue to plummet as the ocean water increasingly damages properties and the surrounding infrastructure. Shorecrest inhabitants reported that the city has not helped the community with short-term solutions such as raising the streets or installing pumps, as funding for these endeavors has been mostly reserved for the tourist-attracting beaches (Rush, 2018). With limited prospective solutions, it appears that the number of abandoned properties in Florida will rapidly increase over the following decades. According to Dr. Harold Wanless, nearly 60 percent of Miami-Dade County will be underwater by 2060 (Dyer, 2022). Ultimately, Wanless warns that sooner or later, a large part of the county will be underwater. As Wanless notes, "climate change is real. This isn't something that might happen" (Dyer, 2022).

Sea levels are projected to rise in the next decades, and researchers often talk about two scenarios by the year 2100: the 0.9-meter scenario and the 1.8-meter scenario (i.e. three and six feet). If we assume the worse of these two cases—in other words, a sea level rise of 1.8 meters by 2100—about 13.1 million Americans would be at risk of being affected by flooding, and more than six million of them would be Floridians (Hauer et al., 2016). Hauer et al. (2016) acknowledge that projections based on these data may have deviations, but the projected number of individuals at risk is immense even with downward deviations. While the number of people at risk would be significantly less with a sea level rise of 0.9 meters, there would still be several hundred thousand, if not millions, of people at risk in Florida alone (Hauer et al., 2016). No matter which scenario turns out to be true, if climate change is not prevented, sea levels will continue to rise and increasingly more Floridians will be strongly affected by this process.

The impacts of inundation will not only have massive effects on the living conditions of millions of Floridians, but also on the real estate market. Fu et al. (2016) examined the effects of flooding and saltwater intrusions on the real estate market

in Pinellas County and Hillsborough County. With cities like Tampa, Saint Petersburg, and Clearwater lying directly at the Gulf Coast and both counties housing more than 2.5 million inhabitants, the potential for infrastructure damage due to sea level rise is similar to the dangers in South Florida. According to Fu et al. (2016), "in 2050, it is estimated that the inundation of 3-foot sea level rise could cost Hillsborough and Pinellas County over 300 and 900 million dollars respectively for the real estate market alone" (p. 11). In addition, they project a historically relevant and significant change in their research. While properties with proximity to the coast are usually expensive, the prices for these properties will decrease (Fu et al., 2016). This development would have an immense impact on the future real estate market, city planning, and the infrastructure in Florida. Even with the standard deviation of the data given by Fu et al. (2016), one can reasonably infer that these estimates need to be treated with caution. Sea level rise, and therefore inundation, are influenced by several difficult-to-calculate factors, and due to the uncertainty of predictions, economic estimates like these are very complicated to ascertain. But even if sea levels rise less than three feet and the damage is less than projected, many residents in these counties will experience a tremendous financial loss as the value of their properties will decrease rapidly. As Miami's Shorecrest neighborhood illustrates, many people are already suffering major financial losses due to floodings. Early projections about sea level rise from the last century have thus become reality. And even if Dr. Harold Wanless's scientific projections do not occur as soon as he suggests, his predictions concerning inundation will become reality sooner or later, since climate change does not seem to be stopping in the near future.

Increased Threats from Tropical Cyclones

Another form of inundation is catalyzed by exacerbating natural disasters. Among scientists, it is well-known that the rising temperatures of climate change cause an increased

magnitude and frequency of natural disasters, especially tropical cyclones. A tropical cyclone is an umbrella term for tropical depressions, tropical storms, and hurricanes. According to Kossin et al. (2020), the probability for heavy tropical cyclones increased significantly between 1979 and 2017. This means that high-category hurricanes have become more probable over the last four decades. The rising temperatures of climate change increase the surface temperatures of the ocean waters. This leads to greater intensity of storm wind speeds and greater severity of the damages from those winds ("Hurricanes and Climate Change," n.d.). In addition, rising temperatures in the atmosphere lead to more water evaporation, increasing the amount of rainfall during a tropical storm or hurricane ("Miami, Florida Flood Factor Report," n.d.).

Sea level rise itself increases the damage of tropical cyclones even more by increasing the potential for hurricane-induced inundation, worsening the amount of damage caused by these natural disasters ("Hurricanes and Climate Change," n.d.). Surge simulations illustrate the extent to which climate change and sea level rise affect storm surges. In 2005, Hurricane Katrina put around 80 percent of New Orleans underwater; in some places, floods were more than thirty feet (nine meters) deep (U.S. Department of Commerce, n.d.). The cyclone accounted for $100 billion in damage, destroyed more than 23,000 homes around New Orleans alone, and directly caused more than 1,800 deaths, to say nothing of the indirect deaths that followed in the wake of the storm (Ambrose, 2021; Sims, 2017). According to former Environmental Protection Agency (EPA) Solid Waste and Emergency Response Analyst Hugh Kaufman, the costs for the cleanups alone were around $2 billion (Sims, 2017). The NOAA National Centers for Environmental Information (n.d.) also notes that the costs caused by the storm amount to $190 billion, making it the costliest storm in U.S. history. Furthermore, natural disasters like Hurricane Katrina have been shown to pose large-scale public health issues, reducing the quality of life

for people from the affected areas forever ("One Year After Katrina," 2006; Rhodes et al., 2010; Waddell et al., 2021).

Storm surge simulations show that "flood elevations would have been 15 to 60% lower c. 1900 than the conditions observed in 2005" (Irish et al., 2014). Flooding plays a significant role in damaging infrastructure, homes, and facilities, and lower flood elevations would have led to fewer damages, deaths, chronic diseases such as hypertension and respiratory issues, lifelong mental health issues such as post-traumatic stress disorder, and a lessened spread of infectious diseases (Waddell et al., 2021; Rhodes et al., 2010). And such long-term consequences hold true everywhere, not just in hurricane-prone areas of the country. For example, another study regarding flooding in New York City found that the frequency of Hurricane Sandy's flood heights tripled from 1800 to 2000 and will increase by around three to seventeen times from 2000 to 2100, depending on acceleration rates of sea level rise (Lin et al., 2016).

The intensity and frequency of wind speeds and flooding from tropical cyclones have increased because of climate change and sea level rise, and peer-reviewed predictions of those facts have been confirmed in recent years, most recently with Hurricane Ian in September 2022. In 2022, Hurricanes Ian and Nicole hit Florida directly. Hurricane Ian alone accounted for between $50 billion and $65 billion in private insured damages (Newburger, 2022). An interview with the Head of Catastrophe Perils at Swiss Re, Martin Bertogg, describes the extent of damages very well. According to Bertogg, a $20 billion loss through a natural disaster had never occurred before Hurricane Andrew in 1992. But now "there have been seven such hurricanes in just the past six years" (Newburger, 2022). While Bertogg acknowledges that inflation and wealth accumulation in Florida's coastal communities contribute to these statistical increases, climate change and sea level rise play a key role as well (Newburger, 2022). Hurricane Ian left more than 2.5 million Floridians without power and destroyed well-known beaches, landmarks, and

infrastructure (Brinkmann, 2022). Even now in 2023, nearly a year after Hurricane Ian's impact, the hurricane-induced devastation in Lee County is far from being cleaned up and corpses or just parts of them are still being recovered (Hudak, 2023; Wulfeck, 2023).

With further sea level rise, the previously mentioned effects will only worsen. Like in many other Florida counties, hurricane storm surge hazard zones are increasing due to sea level rise (Fears, 2017; Frazier et al., 2010; Hauer et al., 2016). In the case of Sarasota County, the consequence will be that future hurricane storm surge hazard zones will encompass "significant portions of the population, economic activity, and critical facilities" that are currently situated outside the existing hazard zones (Frazier et al., 2010, p. 490). Such changes can be expected along all coastal regions of Florida. Due to the increased susceptibility to tropical cyclones, hospitals and infrastructure necessary for transportation to hospitals or other critical facilities will not be accessible anymore. A scenario like this almost occurred in September of 2022. Hurricane Ian was projected to make landfall in the Sarasota-Tampa Bay area but changed direction at the last moment. Nevertheless, Tampa Bay is extremely flood-prone, making it the most vulnerable U.S. metropolitan area to tropical cyclones (Fears, 2017). Downtown Tampa lies directly at the bay and is right next to the Hillsborough River, and many buildings and properties in this area are not built to hurricane-proof standards. According to a Boston firm, a storm the size of Hurricane Katrina could lead to almost $200 billion in damages, making Tampa Bay one of the most vulnerable areas in the world for the consequences of hurricanes (Fears, 2017).

While the city's largest hospital, Tampa General Hospital, has taken protective measures against a Category 5 hurricane, even in the case of a lower-category hurricane, floodwaters would cut the hospital off from the city because it is located on Davis Island. This would leave many flood victims unable to access assistance in the event of a tropical cyclone in the future

(Fears, 2017). Also, higher threats of hurricanes and tropical storms increase the danger of erosion in municipal coastal cities because the effects of tropical storms and erosion are related to each other (Wang et al., 2006; Zhang et al., 2005). These risks will likely lead to decreasing values of real estate at the coastlines if no adaptations to the changing circumstances are made. As Fears has stated, a Category 5 hurricane hitting the Tampa Bay area has the potential to become the costliest hurricane in U.S. history (Fears, 2017; NOAA National Centers for Environmental Information, n.d.).

Saltwater Intrusion

Around the world, inundation through sunny day flooding or hurricanes is often countered with wells or similar barriers. Wells can pose a short-term solution against seawater flooding and the associated erosion and salinization of agricultural land, but such protective measures are minimally helpful against the threat from below: saltwater intrusion. The issue of saltwater intrusion has only recently begun to emerge as its effects had gone undetected until recently when the dramatic consequences on nature, agriculture, industry, and most importantly, health started to become overt (Lambrecht & Todd, 2020).

Especially in Florida, sea level rise has led to saltwater intrusion, which is saltwater being pushed or pulled into aquifers where fresh groundwater is stored (Water Resources Mission Area, 2019). Salt-contaminated water cannot be used for crop irrigation and human consumption, making saltwater intrusion very problematic for several communities in Florida (Water Resources Mission Area, 2019). Due to its "low topography" and "high water table," coastal Florida is highly vulnerable to saltwater intrusion (Czajkowski et al., 2018, p. 465). In other words, Florida's coastal cities lie just above or even below sea levels and have a high amount of soil that is completely saturated with water. Additionally, Florida's topography consists largely of karst substrate, which is very permeable. These factors make

coastal cities like Miami very prone to saltwater intrusion induced by sea level rise.

Especially in coastal and urban regions, groundwater supply issues negatively affect regional development, as other types of water sources are limited (Wen et al., 2019). Since groundwaters from aquifer systems are the primary source of water supply in most parts of Florida for both agricultural and human consumption, saltwater intrusion has a detrimental effect on Florida's economy (Barlow & Reichard, 2009; Czajkowski et al., 2018). Salt water entering the aquifers contaminates the groundwaters, causing shortages in water supplies for households, agriculture, and industry, especially in southeastern Florida (Barlow & Reichard, 2009). Saltwater contamination through sea level rise or geological processes has been exacerbated in northeastern and southeastern Florida through groundwater pumping and drainage canals, which are consequences of the water supply demands of these highly populated regions. Thus, areas around Jacksonville and Miami have been subject to "anomalous patterns of saltwater contamination that often are difficult to identify, explain, and monitor" (Barlow & Reichard, 2009, p. 251). With Florida's high reliance on groundwaters from aquifers, such contaminations are costly. Sea level rise simulations by Langevin and Zygnerski (2012) suggest that the amount of total dissolved solids (that is, the amount of organic and inorganic materials such as salts and metals) in groundwaters will exceed drinking water standards at some point between 2061 and 2072 in southeastern Florida.

Saltwater intrusion is becoming an issue in Florida, but there are already places that have experienced what the state of Florida is moving towards. Groundwater salinization through saltwater intrusion has likely led to heavy metal pollution in multiple coastal groundwaters around the world, which leads to significantly higher cancer risk when the water is ingested or even touched, and salinity itself has been linked to several health problems as well (Wen et al., 2019). Diseases associated

with excessive salinity exposure include, but are not limited to, skin disease, diarrheal diseases, hypertension, acute respiratory diseases, and miscarriage among pregnant women (Rakib et al., 2020).

A country strongly affected by saltwater intrusion is Bangladesh. Although it is not an industrialized country and does not have the resources Florida has, it is geographically not dissimilar. According to the World Health Organization (n.d.), fewer than two grams of sodium should be consumed daily. Daily sodium intake through drinking water alone went up to sixteen grams per day when drinking just two liters of water in coastal Bangladesh in 2011 (Khan et al., 2011). This alarming increase in sodium content poses a significant and escalating public health risk (Rakib et al., 2020). The extreme sodium levels and the resulting public health risk are a result of saltwater intrusion, increased inundation, and intensified tropical cyclones due to sea level rise. Even people who live 200 kilometers away from the ocean are affected, as the salt has now made its way inland through rivers. According to the Soil Resource Development Institute of the Bangladesh government, soil salinity has increased ten to twenty times in the southeastern Barisal division of Bangladesh, making a third of the land extremely saline and nearly useless for agriculture and driving water prices higher outside of the monsoon season (Montu, 2021).

Higher water prices, in turn, make people in lower economic classes go to extremes to fulfill their basic needs. The award-winning Bangladeshi journalist Rafiq Islam Montu describes the typical day of Aleya, who has to travel one and a half hours to bring one pitcher of water home; on a usual day, she has to make this effort twice. The depth of the water supply issues in the division of Barisal becomes clear when the author explains that "when guests drop in, the family does not worry about feeding them, but about supplying them with a glass of water" (Montu, 2021). As mentioned previously, Bangladesh is geographically somewhat similar to Florida. The coastal regions in

Bangladesh are flat, which make them very vulnerable to the consequences of sea level rise; in this sense, the geography is very similar to Florida (Montu, 2021). Since Florida has more financial resources to respond to sea level rise-induced issues, the extent of the consequences may vary, but water shortages like in Bangladesh are very likely to occur in Florida due to the salinization of Florida's water resources. Since Florida is so reliant on groundwater from aquifers, costly strategies will be required to maintain the many urban areas in Florida.

Salinization drives up water prices for households and agricultural products as the water needed for households or crop irrigation must either be piped from surface waters or far away groundwaters, or instead be desalinated. To mitigate the increasing saltwater intrusion in Florida, aquifer storage and recovery systems and desalination systems have been introduced. Since these systems make contaminated groundwater available again, they help cities like Jacksonville and Miami be less reliant on water imports. However, the costs for these technologies are still very high, and will necessarily be passed along to consumers (Barlow & Reichard, 2009; Lambrecht & Todd, 2020). As former Miami-Dade Water and Sewer Director Kevin Lynskey notes, "homeowners and businesses can expect their water and sewer bills to rise more than 5% every year through at least the next decade" (Lambrecht & Todd, 2020). An annual bill of $900 would increase to around $1,466 in just one decade, without considering inflation.

Additionally, water costs will rise for agricultural products. Saltwater intrusion has been a rising problem in several parts of the United States, one of them being the coastal plain in North Carolina. Many farmers like Dawson Pugh have already encountered large financial losses because their soil is becoming too saline for agriculture. Pugh's once-fertile farmland has been pockmarked with growing salty patches in just a couple of years. On these salt patches, nothing grows anymore, and "grass withered and died exposing expanses of bare, brown earth"

(Kaplan, 2019). Together with recent floods, which brought additional salinization to his land, saltwater intrusion cost him $2 million in five years. Due to the financial losses from the barren patches, Pugh stopped planting some of his fields entirely (Kaplan, 2019).

Similar things are happening in Maryland and California. Somerset County in Maryland lost about 850 acres of farmland to saltwater intrusion in just one decade (Biron, 2019). Additionally, the Public Policy Institute of California estimated that the Central Valley in California, known to be very fertile and useful for agricultural purposes, has already lost hundreds of thousands of acres and will lose five hundred thousand to one million acres of farmland due to water supply issues which are largely affected by saltwater intrusion (Lambrecht & Todd, 2020). The Executive Director of the Central Valley Salinity Coalition, Daniel Cozad, described the current issue as "the early stages of cancer" (Lambrecht & Todd, 2020). As of now, "you don't feel it, you don't see it and everything seems to be pretty normal," but if no one intervenes, the outcomes will be much worse soon (Lambrecht & Todd, 2020).

Florida's rising saltwater intrusion problem could strongly affect Florida's economy. According to Yuncong Li, professor of soil quality in the Soil and Water Sciences Department at the University of Florida, Florida's economy, and South Florida's economy in particular, is greatly influenced by the agricultural sector. Presently, Florida produces more than 300 different agricultural products, with 2020 revenue being around $7.4 billion (Bayabil & Yuncong, 2022). But 90 percent of South Florida's drinking water, which is used for agriculture, stems from groundwaters. The strong agricultural sector in Florida is at great risk due to saltwater intrusion, along with the combined effects of climatic changes and inundation. The gradual movement of saltwater inland, coupled with the fact that much of the farmland is situated near the ocean and the majority of crops in South Florida have a low tolerance for salinity, will result in

significant damage to the region's agricultural activities (Bayabil et al., 2022; Bayabil & Yuncong, 2022). These developments negatively impact the cost of agricultural production, which increases the prices of agricultural products and decreases profits for the industry (Bayabil et al., 2022).

Concerns have also risen over the dangers to nature, affecting humans in several other ways. Salt water has already led to the death of multiple vegetational species in Florida and is going to kill even more, resulting in "ghost forests" (Bayabil & Yuncong, 2022; U.S. Department of Agriculture Climate Hubs, n.d.). Rising sea levels and saltwater intrusion are therefore transforming diverse ecosystems into standing waters with only a few living species left (U.S. Department of Agriculture Climate Hubs, n.d.). This destruction of natural habitats leads to a greatly decreased diversity in plant and animal species, and this has several consequences for the state of Florida. The loss of coastal wetlands and mangroves in Florida carries significant implications for humans due to their crucial role in facilitating the process of carbon sequestration. A loss of these species leads to an increase of the amount of greenhouse gases in the atmosphere, exacerbating climate change and the consequences of sea level rise that Florida is already starting to struggle with (U.S. Department of Agriculture Climate Hubs, n.d.). Furthermore, coastal wetlands and mangroves help control inundation and storm surges, together with coral reefs and marshes. These nature-based defenses save the United States approximately $23.2 billion annually and saved $625 million during Hurricane Sandy in direct inundation damages (Narayan, 2017; Narayan, 2016). The loss of these natural protections in Florida is exacerbating vulnerability to sea level rise (Narayan, 2017). Considering that Florida is already one of the most vulnerable states in the U.S., the need for adaptation strategies would be even higher and costlier.

To battle the novel threat of saltwater intrusion, several adaptation measures have been introduced, but many of them

have long-term flaws that generate other problems. For example, one way that water managers have dealt with the issue of saltwater intrusion in South Florida is by creating a hydraulic gradient that promotes the continuous replenishment of the aquifers with fresh water. By maintaining a positive hydraulic gradient, the flow of fresh water from canals into the aquifer is encouraged. This process helps lower the saltwater intrusion risk of groundwaters. To mitigate the increasing threat of saltwater intrusion due to rising sea levels, water levels in South Florida will need to be raised over time (Carter et al., 2010). This solution has temporarily helped to prevent the risk of saltwater intrusion, but the heightened ground water levels increase the likelihood of flooding through high tides or natural disasters. This is turn leads to a higher risk for economic losses. This is because the capacity of the soil to absorb water is lower as water tables reach the surface faster. Efficient strategies to prevent sea level rise-induced saltwater intrusion have and will continue to increase economic losses through inundation and tropical cyclones. Water managers in South Florida are challenged with conflicting demands of freshwater needs for the population and economy and flood control to prevent large economic losses (Czajkowski et al., 2018). This seemingly unsolvable dilemma is a result of sea level rise.

Sea Level Rise in Florida's Near Future

Considering the consequences of sea level rise, Florida will become a less desirable place to live in the upcoming decades. Inundation, increased threats through tropical cyclones, and saltwater intrusion are only some of the severe effects of sea level rise that especially impact residents of coastal municipal regions. Other issues include, but are not limited to, erosion, marsh migration, and public health problems. Together with the consequences of climate change like droughts and wildfires, Florida is becoming a less desirable place to live, even if no crisis is breaking out (Quintana, 2021). To prevent sea level rise most

effectively, the root cause of the problem, greenhouse gas emissions, must be combated. An impactful approach to achieve this is by emphasizing the utilization of renewable energy instead of fossil fuels. However, Floridians would have to rely on the cooperation of the entire world population for this approach to be effective, which is not likely in the near term. Therefore, simply decreasing greenhouse gas emissions in the U.S. is good, but not sufficient enough to combat the threats posed by sea level rise. Instead, strategies to combat the symptoms of the problem need to be put into place as soon as possible to protect Florida.

The visible and future effects of inundation alone have led to large amounts of money being paid to adapt to the threats posed by rising sea levels. Adaptation strategies have been in place for years, but these do not benefit everybody equally. The city of Miami offers an excellent example. In 2009, Broward, Miami-Dade, Monroe, and Palm Beach counties formed the Southeast Florida Regional Climate Change Compact to combat the consequences of climate change collaboratively (Southeast Florida Regional Climate Compact, n.d.). Collaborative efforts of neighboring regions have been shown to save costs; these collaborative efforts ensure a quick and effective response to threats imposed by sea level rise and climate change (Boehnke et al., 2019; Council of Europe et al., 2010). The project has been praised by former president Barack Obama and was evaluated as successful, but not everybody has benefited from these efforts (Nickerson, 2020; Southeast Florida Regional Climate Compact, n.d.).

For example, Rush (2018) spoke to several residents of areas affected by sea level rise in Miami-Dade County to gather insights about the challenges associated with sea level rise. According to her research, communities of people of middle and low income "tend to receive disproportionately low funding for adaptation, resiliency, and relocation" (Rush, 2018). Most of the funding and adaptation strategies in place primarily aim to help retain property in beach regions in order to keep Florida's

tourism economy alive (Rush, 2018). Tourism is Florida's fourth biggest employer (Rockpoint Analytics, 2020). Therefore, these endeavors make sense, but will lead people of low income to be forced to sell their property in the near future. As Rush (2018) illustrates, people of low income are most likely the ones who sell their property the soonest. Their properties are already losing value at a faster rate due to increased flooding and little governmental support. In other words, tourists and the rich will stay, while the poor will have to migrate. The loss of value for most of these people is probably already inevitable due to the interplay of supply and demand.

In order to counteract Florida's worsening problems from sea level rise more effectively, Florida's current governor Ron DeSantis signed the Flooding & Sea Level Rise Act in March 2021, which created the Resilient Florida Grant Program. The bill includes "a $100 million per year starting in 2022-2023 to mitigate the effects of flooding and sea level rise" and $12.5 million funding for an initiative to protect coral reefs ("Governor Ron DeSantis Signs Bill," 2021; Murphy, 2021). Together with $500 million in federal funding for resilience projects in Florida, the state has now started to act against the consequences of sea level rise, especially flooding ("Governor Ron DeSantis Signs Bill," 2021). In addition, a flood vulnerability assessment is to take place regularly so that the risks and effects associated with sea level rise can be determined for different parts of Florida ("Governor Ron DeSantis Signs Bill," 2021). A regular flood vulnerability assessment will help to target adaptation strategies to the most threatened regions of Florida (C40 Cities Climate Leadership Group & C40 Knowledge Hub, n.d.), and allocating the funds to vulnerable locations can eliminate the inequity caused by past inappropriate funding. It is questionable, however, whether Florida's legislators will place more emphasis on restoring natural habitats and supporting low- and middle-income communities like Miami's Shorecrest community or will focus on keeping high-value properties and tourism alive as

they have in the past. Legislative measures need to be taken to make sure that the funding is allocated in a fair way.

The Flooding & Sea Level Rise Act is already quite late, as apparent from the experiences of various communities described by Rush (2018). The late governmental response serves as evidence of how reactive sea level rise prevention efforts have been in Florida. Most responses are put into place after consequences are already threatening people and the state economy. Governor DeSantis calls himself "not a global warming person" and contends that he is concerned with the effects rather than the causes of climate change and sea level rise (Green, 2022). These statements further demonstrate Florida's reactive response to sea level rise, but there is still hope.

What Can Be Done Moving Forward

There are roughly three categories for addressing sea level rise that will have an immediate impact for Florida: improving coastal defenses to reduce the likelihood and severity of flooding (protection), designing buildings and infrastructure to reduce the impacts of a flooding event, and preparing for managed retreat from at-risk areas (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2022).

There are three major types of protection: hard protection, sediment-based protection, and ecosystem-based protection. Hard protection, a strategy involving barriers, dikes, and seawalls to protect coastal territories from flooding is projected to be widely used on the Atlantic Coast and Gulf of Mexico in the near future (Gittman et al., 2015). Hard protection reduces the likelihood and severity of flooding because it reduces the amount of inundation damage. It has been shown to be economically efficient, but it creates a tremendous amount of long-term problems (Intergovernmental Panel on Climate Change, 2022). Particularly in southeast Florida with its unique topography, hard protection could have severe consequences. The implementation of dikes, barriers, and seawalls is related to

the deterioration or loss of intertidal habitats such as marshes, known as coastal squeeze (Doody, 2004). The loss of marshes and similar vegetation leads to worsened "provision of nursery habitat for commercially and recreationally valuable fish and crustaceans, filtration of nutrients and pollutants from terrestrial runoff, carbon burial, and erosion protection" (Gittman et al., 2015, p. 306). These consequences actually exacerbate the effects of climate change and sea level rise in the long term. The porous limestone in Florida makes the areas around Miami particularly prone to be flooded from below by rising groundwaters as an effect of the protective measures taken (Bloetscher et al., 2011 as cited in Intergovernmental Panel on Climate Change, 2022). This kind of flooding is long-lasting, and standing waters not only interfere with people's daily lives and economic activities but can also result in mosquito infestation and septic system failure (Bacher, n.d.; Gittman et al., 2015; Intergovernmental Panel on Climate Change, 2022).

Aside from hard protection, other protection strategies exist. Sediment-based protection, like dunes and beach and shore nourishment, and ecosystem-based adaptation through the creation of wetlands, marshes, and mangroves are alternative protective strategies to hard protection. Both sediment-based and ecosystem-based strategies also serve as flood defenses to lower the likelihood and severity of inundation and its consequences. Sediment-based protection is a cheap and effective protective alternative because the needed sand is close to the locations of demand. Large-scale sediment-based protection efforts have been used to mitigate sea level rise in other parts of the world, but the strategy has some drawbacks. When developing practices such as beach nourishment, the local ecosystem needs to be strongly considered to make sediment-based protection effective long-term, which drives costs and implementation time up (Intergovernmental Panel on Climate Change, 2022). Sediment-based protection has been used in Miami, but as previously discussed, it led to economic inequity (Rush, 2018). Still, sediment-based

protection is a less invasive strategy that has been shown to work in the short term. Ecosystem-based protection is even less invasive. This strategy aims to protect and restore ecosystems that help mitigate the negative consequences of sea level rise to protect coastal and inland populations. Although ecosystem-based protection requires appropriate environmental conditions for effective implementation, Florida's subtropical climate and vegetation align with these conditions (Intergovernmental Panel on Climate Change, 2022). Ecosystem-based protection is increasingly gaining global recognition, and Florida's Flooding & Sea Level Rise Act has allocated funding towards an initiative fostering coral reef resilience and protection ("Governor Ron DeSantis Signs Bill," 2021; Intergovernmental Panel on Climate Change, 2022). However, it is unclear whether the funding is sufficient and how effective this protection measure is long-term (Intergovernmental Panel on Climate Change, 2022).

While protection measures can cause controversy, there exists a consensus that accommodation should be an important component of adaptation efforts. Accommodation refers to a variety of strategies that foster resiliency against the consequences of sea level rise. Examples include "flood proofing [building flood resistant buildings] and raising buildings, implementing drainage systems, land use changes as well as EWS [Early Warning Systems], emergency planning, setback zones and insurance schemes" (Intergovernmental Panel on Climate Change, 2022, section 4.4.2.5.1). Accommodation has been used across the United States to adapt to sea level rise. The city of Tampa invested $251 million for stormwater improvements with a large amount being spent to upgrade pump stations and other infrastructure following significant floods that occurred in 2015 and 2016 (Frago, 2021). However, the increasing sea levels along Tampa's shoreline pose a potential challenge as they may submerge the outlets of the pumps eventually (Crownhart, 2021). These projections demonstrate a challenge with many accommodation programs. It is costly to maintain the pump-

ing or sewer systems and improve them to keep up with rising sea levels. A recent example illustrating the costs associated with such endeavors is a projection of the costs to modernize Detroit's sewer system completely. The system is used to deal with steadily increasing stormwater floods and is expected to amount to over $17 billion. From that point on, pump stations would have to be upgraded regularly (Crownhart, 2021). High-impact accommodation strategies cost a massive amount of money, but they are potentially impactful in addressing current conditions with slowly rising sea levels. Accommodation strategies can serve as short-term solutions but cannot completely prevent inundation or saltwater intrusion, especially in the long term (Intergovernmental Panel on Climate Change, 2022).

The approach with the longest history is advance, which involves extending the land area by constructing into the sea or ocean, often on a higher altitude level. Historically, it has been used in coastal areas due to land scarcity, population pressure, and functional reasons such as to build harbors, but advance can also serve as a response to sea level rise in the future or support other adaptation strategies. While there is no clear consensus about the projected costs, the implementation of advancing into the sea is considered effective as this approach "can provide predictable levels of safety" (Intergovernmental Panel on Climate Change, 2022, section 4.4.2.4.4). However, despite the benefits, advance is accompanied with several drawbacks. For instance, during the last three decades, around 50 percent of the land gained through advance has been lost again. Further, advance has been shown to increase the risk of erosion, groundwater salinization, loss of coastal ecosystems and habitats, and more. While advancing into the sea seems to be a beneficial short-term solution in densely populated coastal areas, it has large long-term drawbacks (Intergovernmental Panel on Climate Change, 2022).

Another option that is increasingly discussed around the world is managed retreat, which is a supervised and coordinat-

ed movement of people and assets away from the coastal hazard zones (Intergovernmental Panel on Climate Change, 2022). If greenhouse emissions are not reduced and sea level rise does not stop, managed retreat will likely become necessary in various places around the world, including Florida (Carey, 2020). Managed retreat represents a proactive approach and has various benefits compared to displacement, which refers to a forced or involuntary (and thus reactive) movement due to environmental factors (Intergovernmental Panel on Climate Change, 2022). Managed retreat presents a solution that requires less social and economic demands than waiting until previously mentioned short-term solutions fail and displacement is happening (Lawrence, 2020). Even though managed retreat is recommended by many researchers, it has largely been left out of government planning worldwide due to several issues (Dannenberg et al., 2019).

First, relocating people is "not about moving houses, it's about moving lives" (McNamara & Des Combes, 2015, p. 317). The quote underscores the emotional and psychological toll of displacing people due to sea level rise. Mandating relocation goes beyond simply changing people's physical residences. It involves a fundamental alteration of their basis of life with its social connections, cultural ties, and daily routines. Managed retreat can also change the social fabric of a community, which is why care must be taken to ensure that managed retreat is designed fairly (Dannenberg et al., 2019). But that care also makes the costly endeavor even more expensive and must be factored into the cost-benefit analysis often mentioned by Dannenberg et al. (2019). Another widely expressed concern is inequality between communities of different socioeconomic statuses. The concern is that wealthier individuals are preferred when relocated, while low-income communities are either not relocated at all or relocated to places where inundation will still affect them (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2022). Strong collaboration between organizations, businesses,

people, cities, and governments must occur to make managed retreat work. Due to the extensive issues with managed retreat, it has not been widely considered.

A wide range of adaptation strategies are available to help Florida cope with sea level rise. Even though the state government is reacting late, the flood vulnerability assessment is a logical first step to determine optimal strategies and invest money effectively. However, most available adaptation strategies are reactive in nature and all of them provide just a short-term solution. They help battle the consequences of sea level rise instead of the causes, which buys Florida time, but does not solve the problem. Adaptation strategies will decrease in effectiveness and increase in cost in the long term as sea levels rise, leading to even greater problems in the future. Therefore, the ultimate long-term goal should be to target climate change itself. Florida alone cannot reduce greenhouse gas emissions of the entire world, which is why adaptation strategies need to be implemented for the time being. But investing into renewable energy resources is the only way to handle the cause of sea level rise. Several cities in Florida have committed to drawing their energy from renewable sources only by 2050, but as of 2021, only six percent of Florida's in-state electricity net was fueled by renewable resources (Schorsch, 2022; U.S. Energy Information Administration, 2023). Several governments around the earth have failed to achieve their set climate change-related goals in the past, so it is also questionable whether the cities will reach their goals. However, one thing that is certain is that sea levels will rise, and consequences of this process will threaten an increasing amount of people. If Florida does not act proactively and effectively enough, the paradise of Florida will soon be only a memory.

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