RISING ABOVE: DETERMINING APPROPRIATE, COMMUNITY-SPECIFIC RESPONSES TO SEA LEVEL RISE IN GALVESTON BAY, TX

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I. THE VULNERABILITY OF GALVESTON BAY TO SLR

Galveston Bay has one of the highest vulnerabilities to large storms and sea level rise (SLR) in the country due to its natural properties, high population pressures, and costly infrastructure.[4] SLR is described as an "enormously complex public policy problem" because beaches have a dynamic nature while laws are static.[5] A single shoreline, like that of Galveston Bay, will advance and retreat at various times in geologic history, and at a certain point some beaches will be eroding while others will be accreting. Changes in sea level affect these constant changes. The rate of SLR increased in the last two hundred years due to global climate change and anthropogenic activities, and it is now a driver of shoreline retreat in many locations.[6] Additionally, human migration patterns are further stressing coastal environments.[7]

The current predominant shoreline protection paradigm emphasizes shoreline hardening as the primary mode to combat SLR. At least 14,000 miles of the United States' coast has been armored, and one-third of the coast could be hardened by 2100 if trends continue.[8] In recent years, however, there has been recognition of the benefits that natural shorelines offer. This has resulted in a push towards utilizing living shorelines, a green infrastructure approach. There are

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[4] Katie K. Arkema et al., *Coastal Habitats Shield People and Property from Sea-Level Rise and Storms*, 3 NATURE CLIMATE CHANGE 913–918 (2013).
[5] Meg Caldwell & Craig Holt Segall, *No Day at the Beach: Sea Level Rise, Ecosystem Loss, and Public Access Along the California Coast*, 34 ECOLOGY L. Q. 533 (2007).
[6] R.G.D. Davidson-Arnott, *Conceptual Model of the Effects of Sea Level Rise on Sandy Coasts*, 21 J. OF COASTAL RES. 1166-72 (2005).
[7] Jennifer Weeks, *Coastal Development: Is Over-building Putting Coastal Regions at Risk?*, 23 CQ RESEARCHER 181 (2013).
[8] Roberta Kwok, *Rise of 'Shoreline Hardening' Threatens Coastal Ecosystems*, CONSERVATION, Aug. 6, 2015, *available at* http://www.conservationmagazine.org/2015/08/rise-of-shoreline-hardening-threatens-coastal-ecosystems/ (last visited June 20, 2018).

many benefits to protecting the connectivity of land and sea in such a way. A better understanding of the potential results from these protective measures will increase the knowledge of coastal communities in the Galveston Bay area and thus enable them to respond to SLR in the most appropriate manner.

SLR is directly tied to a warming atmosphere due to anthropogenic activities.[9] Large-scale anthropogenic releases of greenhouse gases began with the Industrial Revolution.[10] If, as it happened until modern times, there was no infrastructure installed in coastal areas, then wetland habitats would simply migrate inland. However, the installation of immobile structures along the dynamic land/sea interface creates a net loss of coastal habitats and environments in a process called coastal squeeze.[11] Coastal squeeze occurs when wetland environments lose their areal extent due to being sandwiched between rising seas and structures; this restriction limits marshes' ability to vertically accrete or migrate inland and has led to a greater risk of inundation and erosion. An estimated 10% of Galveston Bay's shorelines are already armored and thus, are subject to coastal squeeze.[12]

Development-induced coastal squeeze shrank Galveston Bay's wetlands. Marsh losses can cause a negative feedback loop whereby habitat conversion results in an alteration of ecosystem services. At the global scale, wetland habitats, including marshes, are carbon sinks, and their destruction releases significant amounts of carbon into the atmosphere, which in turn exacerbates SLR.[13] This process can leave humans more vulnerable to storms and erosion. Thus, the protection of marshes and other wetlands is one of the easiest and simplest solutions to initiate adaptation to SLR and mitigate climate change impacts.[14]

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[9] INTERGOVERMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: SYNTHESIS REPORT (2014), http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf (last visited June 20, 2018).
[10] Johan Rockström et al., *A Safe Operating Space for Humanity*, 461 NATURE 472–475 (2009).
[11] Dante D. Torio & Gail L. Chmura, *Assessing Coastal Squeeze of Tidal Wetlands*, 290 J. OF COASTAL RES.1049–1061 (2013).
[12] TEX. COMM'N ON ENVTL. QUALITY, GALVESTON BAY ESTUARY PROGRAM, THE STATE OF THE BAY: A CHARACTERIZATION OF THE GALVESTON BAY ECOSYSTEM (2011) https://www.researchgate.net/publication/261759345_State_of_the_bay_A_characterization_of_the_Galveston_Bay_ecosystem_Third_Edition (last visited June 20, 2018).
[13] Gail L. Chmura, *What Do We Need to Assess the Sustainability of the Tidal Salt Marsh Carbon Sink?*, 83 OCEAN & COASTAL MGMT. 25–31 (2013).
[14] Carlos M. Duarte et al., *The Role of Coastal Plant Communities for Climate Change Mitigation and Adaptation*, NATURE CLIMATE CHANGE 961–968 (2013).

This negative feedback loop partially occurs because people settle coastal areas without enough consideration of environmental issues.[15] Coastal development affects Texas in general and Galveston Bay in particular. A quarter (25%) of Texas's population lives in its eighteen coastal counties, and 75% of that 25% lives on the west side of Galveston Bay.[16] Texas had a 154% increase in coastal counties' population density from 1960-2008, and the Galveston Bay watershed is expected to be home to eighteen million people by 2040.[17]

Furthermore, the anthropogenic additions to atmospheric gasses will continue trapping solar thermal energy, leading to additional SLR. It is estimated that, given a 2 m rise in sea level, 2.4% of the global population could be displaced by 2100 due to the inundation of infrastructure in urban landscapes.[18] As of this writing, that is approximately 180,000,000 people.

Galveston Bay is a very important region both from an ecologic and anthropogenic perspective. It is a shallow estuary with protective barrier islands, and the Environmental Protection Agency's National Estuary Program distinguished it as an estuary of national significance.[19] It is the most biologically productive estuary in Texas, has the second largest fisheries production of any estuary in the United States, and is a hub for birdwatchers.[20] An estimated 75% of North America's bird species pass through the bay including endangered species such as the piping plover.[21] The Central Flyway, a path for an estimated 400

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[15] Gordon McGranahan et al., *The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones*, 19 ENV'T AND URBANIZATION 17–37 (2007).
[16] William Merrell et al., *The Ike Dike: A Coastal Barrier Protecting the Houston/Galveston Region from Hurricane Storm Surge*, Presentation at Texas Hurricane Center 2013 Conference (Aug. 2, 2013) (proceedings available at http://hurricane.egr.uh.edu/sites/hurricane.egr.uh.edu/files/files/2013/8-speakers-2013.pdf) (last visited June 20, 2018).
[17] STEVEN G. WILSON & THOMAS R. FISCHETTI, U.S. BUREAU OF THE CENSUS, COASTLINE POPULATION TRENDS IN THE UNITED STATES 1960 TO 2008 (2010), https://www.census.gov/library/publications/2010/demo/p25-1139.html (last visited June 20, 2018).
[18] R. J. Nicholls et al., *Sea-level Rise and its Possible Impacts Given a 'Beyond 4 C World' in the Twenty-first Century*, 369 PHIL. TRANSACTIONS OF THE ROYAL SOC'Y: MATHEMATICAL, PHYSICAL AND ENGINEERING SCI. 161–181 (2010).
[19] BIOGEOCHEMISTRY OF GULF OF MEXICO ESTUARIES (Thomas S. Bianchi, Jonathan R. Pennock & Robert Reece Twilley eds., 1999).
[20] For More Information on Galveston Bay, *see Discover Galveston Bay*, GALVESTON BAY ESTUARY PROGRAM, http://www.gbep.state.tx.us/discover-galveston-bay/ (last visited June 20, 2018).
[21] Arkema, *supra* note 4.

species of migratory birds, cuts through the region as does the Great Coastal Birding Trail, which offers 500 miles of sites for birdwatchers.[22]

SLR's damage potential rises as assets and population increase in coastal zones. Galveston Bay has high concentrations of both partially because it is home to one of the United States' primary oil and gas hubs. Galveston Bay is a significant metropolis due to its industry, trade, and petrochemical importance. Houston, located northwest of the bay, is the fifth largest city in the United States. The Port of Houston is the largest port in the country in regards to foreign tonnage and second in overall tonnage, and the Gulf Intracoastal Waterway runs through the bay.[23] The region is home to the United States' largest concentration of oil refineries; the region produces approximately 26% of the United States' gasoline, 42% of base chemicals, and 60% of jet fuel.[24] That infrastructure is worth an estimated $100 billion,[25] and the ports generate hundreds of thousands of jobs annually.[26] Galveston Bay also has the "third largest concentration of privately-owned marinas" in the country.[27] Because of this economic infrastructure, SLR in Galveston Bay has the potential to damage the economies of both Texas and the United States. Potential socioeconomic impacts of SLR include the loss of property and coastal habitats; increased flood risk and loss of life; damage to infrastructure; loss of tourism, recreation and transportation functions; loss of cultural resources and values; and impacts on agriculture and aquaculture.[28]

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[22] PAUL A. JOHNSGARD, WINGS OVER THE GREAT PLAINS: BIRD MIGRATIONS IN THE CENTRAL FLYWAY (Zea E-Books 2012); Marge Lindsay, *The Great Texas Coastal Birding Trail: A Tool for Avitourism*, *in* CORNELL LAB OF ORNITHOLOGY, STRATEGIES FOR BIRD CONSERVATION: THE PARTNERS IN FLIGHT PLANNING PROCESS (Rick Bonney, et al., eds. 1999), http://www.birds.cornell.edu/pifcapemay/lindsay.htm (last visited June 20, 2018).

[23] Kiah Collier, *Houston has the Busiest Seaport in the U.S.,* HOUSTON CHRON., May 23, 2013, http://www.chron.com/discoverhouston/article/Houston-has-the-busiest-seaport-in-the-US-4486844.php (last visited June 20, 2018).

[24] Duff Wilson et al., *Special Report: Why Metro Houston Fears the Next Big Storm*, REUTERS, Nov. 24, 2014, http://www.reuters.com/article/us-sealevel-fixes-galveston-specialrepor-idUSKCN0J81IM20141124 (last visited June 20, 2018).

[25] *Id.*

[26] *Overview Facts*, PORT OF HOUSTON, http://porthouston.wpengine.com/wp-content/uploads/2016/11/Port-of-Houston9689-Port-Fact-Sheet.pdf (last visited June 20, 2018).

[27] *Discover Galveston Bay*, *supra* note 20.

[28] Robert J. Nicholls & Jason A Lowe, *Benefits of Mitigation of Climate Change for Coastal Areas*, 14 GLOBAL ENVTL. CHANGE 229–244 (2004).

Additionally, SLR in Galveston Bay is projected to impact infrastructure such as roads, railroads, airports, houses, private businesses and public buildings.[29]

The Galveston Bay region is extremely vulnerable to SLR because of its natural properties including low elevation, low relief, and small tidal range. These all mean that small changes in sea level have relatively large effects. Broad areas of land less than 2 m above sea level extend inland nearly ten miles from the shoreline, and, additionally, the land is sinking in many places. Galveston's Pier 21 tidal gauge measured a relative SLR rate of 6.4 mm per year, most of which is due to subsidence.[30]

Subsidence is another characteristic that increases Galveston Bay's vulnerability to SLR. Galveston Bay's relative SLR rate of about 6 mm per year stands in stark contrast to the global eustatic average of 2 mm per year. Subsidence occurs when the land surface lowers relative to a fixed datum due to natural processes or anthropogenic causes. The area around Galveston Bay is subsiding to a small degree because of natural sediment compaction and tectonics.[31] The predominant cause of subsidence in the region, however, is groundwater and oil and gas extractions, which initiate geologic fault movements.[32] The extractions result in a lack of volume and internal pressure, which causes the land to gradually and consistently sink, threatening both built and natural environments. Over a thirty-year period, nearly 5,000 square miles of land subsided at least 15 cm with some areas subsiding more than 3 m; additionally, more than 31 sq. miles of land was permanently inundated.[33]

The neighborhood of Brownwood is one that succumbed to subsidence.[34] No houses exist today in the once-affluent neighborhood because of subsidence

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[29] Mukesh Subedee et al., *Investigating the Environmental and Socioeconomic Impacts of Sea Level Rise in the Galveston Bay, Texas Region*, Poster Presented at Ocean Science Meeting (Feb. 21-26, 2016).

[30] NAT'L OCEANIC & ATMOSPHERIC ADMIN., SEA LEVEL VARIATIONS OF THE UNITED STATES 1854-2006 (2009), https://tidesandcurrnts.noaa.gov/publications/Tech_rpt_53.pdf (last visited June 20, 2018).

[31] Jeffrey G. Paine, *Subsidence of the Texas Coast: Inferences from Historical and Late Pleistocene Sea Levels*, 222 TECTONOPHYSICS 445–458 (1993).

[32] William W. White & Robert A. Morton, *Wetland Losses Related to Fault Movement and Hydrocarbon Production, Southeastern Texas Coast*, 13 J. OF COASTAL RES. 1305–1320 (1997), *available at* http://www.jstor.org/stable/4298740 (last visited June 20, 2018).

[33] *Subsidence & Groundwater Regulation FAQs*, HARRIS-GALVESTON SUBSIDENCE DISTRICT, http://hgsubsidence.org/frequently-asked-questions/subsidence-groundwater-regulation-faqs (last visited June 20, 2018).

[34] DEVIN L. GALLOWAY ET AL., U.S. GEOLOGICAL SURVEY CIRCULAR 1182, HOUSTON-GALVESTON, TEXAS: MANAGING COASTAL SUBSIDENCE (2015).

and SLR.[35] The area north of Galveston Bay along the Houston Ship Channel, originally was inundated only by hurricanes and large storms. Over time, however, the land subsided by more than 3 m and even mild storms, wind, and high tides caused the inundation of houses. Groundwater extraction peaked in 1970, and in response, the Houston-Galveston Subsidence District was created in 1975 to minimize subsidence in the region through the regulation of groundwater withdrawal.[36] They have been largely successful as evidenced by the fact that subsidence rates are lessening. [37] However, the Brownwood neighborhood was abandoned in 1983, with many houses bought by the Federal Emergency Management Agency (FEMA), and the neighborhood turned into wetland habitats by the Baytown Nature Center.

Historical lessons provide evidence that coastal systems respond rapidly to change. Although the geomorphology of coastal areas has changed throughout geologic time, these changes have all been exacerbated by anthropogenic processes; humans are now the dominant force of coastal change.[38] An ongoing increase in SLR rate will continue to severely impact low gradient coasts, especially since the reaction time of policy makers tends to be slow. A lack of government policy and regulation will cause future financial losses due to climate change, including sea level rise coupled with large storms.

Galveston has a history of severe hurricanes, and it is a matter of when, not if, a future storm hits. Two hurricanes, the Galveston Hurricane of 1900 and Hurricane Ike in 2008, highlight how vulnerable Galveston Bay is to large storms. It is important to emphasize that hurricanes on top of a higher sea level would be much worse than the same storm occurring at lower sea levels.

The Hurricane of 1900 was the deadliest natural disaster to ever hit the United States, killing between 6,000 and 12,000 people. That hurricane also eroded the shoreline by 100 m in some places and demolished hundreds of structures.[39] In response to the hurricane, the Galveston Seawall was designed and constructed and the elevation of the eastern portion of Galveston Island was raised.

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[35] *Id.*
[36] *Id.*
[37] Jiangbo Yu et al., *Is There Deep-Seated Subsidence in the Houston-Galveston Area?*, 2014 INT'L J. OF GEOPHYSICS 1 (2014).
[38] P.M. Vitousek, *Human Domination of Earth's Ecosystems*, 277 SCI. 494 (1997).
[39] ALBERT BARTLETT DAVIS, GALVESTON'S BULWARK AGAINST THE SEA: HISTORY OF THE GALVESTON SEAWALL (1981).

Hurricane Ike was the third costliest storm in United States history with 121 deaths and estimated financial losses of $21.3 billion.[40] Ike made landfall over Galveston in September 2008. It was a category two hurricane with maximum sustained winds of almost 110 miles per hour. Storm surge raised water levels in parts of Galveston Bay by over 10 m.[41] Damages to houses caused by flooding cost an estimated $2.74 billion.[42] Ike affected every industry in the area including health care, agriculture, fishing and tourism as well as the ecology of the surrounding wetlands and water environments. For instance, sediments deposited on oyster beds killed the reefs and impacted the surrounding fishing grounds. In addition, all of the United States was impacted by damage to oil and gas refineries.[43] The U.S. Department of Energy closed fourteen oil refineries in the region because of Ike, which caused cascading effects such as increased gas prices and gas shortages across the United States.[44] The cost to repair erosion damages, dredge waterways, and repair infrastructure to navigable waterways, ports and coastlines cost Texas $2.4 billion.[45] Lastly, the Port of Galveston had damages from saltwater and sediment deposits.

The impact of the Hurricane of 1900 indicates the historical vulnerability of the region to big storms, and Hurricane Ike indicates that the vulnerability has not decreased over time. In fact, a FEMA report warns that land subsidence, erosion and SLR may cause increased hazards and that greater damage may be incurred from similar storms in the future.[46] The region is not just vulnerable to large storms, however; the cumulative costs of storm surge damage from smaller,

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[40] FED. EMERGENCY MGMT. AGENCY, FEMA P-757, MITIGATION ASSESSMENT TEAM REPORT: HURRICANE IKE IN TEXAS AND LOUISIANA: BUILDING PERFORMANCE OBSERVATIONS, RECOMMENDATIONS, AND TECHNICAL GUIDANCE (2009), https://www.fema.gov/media-library-data/20130726-1648-20490-9826/fema757.pdf [hereinafter MITIGATION ASSESSMENT TEAM REPORT] (last visited June 20, 2018).

[41] *Hurricane Ike Storm Surge Inundation Maps*, HARRIS CNTY. FLOOD CONTROL DIST., https://www.hcfcd.org/media/1242/ike_stormsurge-inundation_maps.pdf (last visited June 20, 2018).

[42] FED. EMERGENCY MGMT. AGENCY, HURRICANE IKE IMPACT REPORT (2008), https://www.fema.gov/pdf/hazard/hurricane/2008/ike/impact_report.pdf [hereinafter HURRICANE IKE IMPACT REPORT] (last visited June 20, 2018).

[43] *Hurricane Effects on Oil and Natural Gas Production Depend on Storm Trajectory, Strength*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/todayinenergy/detail.php?id=11491&src=email (last visited June 20, 2018).

[44] MITIGATION ASSESSMENT TEAM REPORT, *supra* note 40.

[45] HURRICANE IKE IMPACT REPORT, *supra* note 42.

[46] MITIGATION ASSESSMENT TEAM REPORT, *supra* note 40.

more frequent storms as sea level rises could be just as great as a single big storm.[47]

The Texas coast in general and Galveston Bay in particular are at a high to very high risk of adverse SLR impacts. As damaging as the Hurricane of 1900 and Hurricane Ike were, the same storms would be more damaging if they occurred from a SLR-induced higher water platform.[48] This is because SLR itself is not the direct threat to human life, but rather it is the storm surge on top of SLR that has the potential to cause widespread damage. By raising the level from which waves "attack" the shore, SLR enables a greater rate of erosion. Combined with storms and hurricanes that are forecasted to be stronger due to climate change, storm surge will cause even more erosion by reaching higher on the land/sea interface.[49]

As of 2014, 1.6 million people lived in the Galveston Bay region's hurricane evacuation zones and another million are predicted to move into the area by 2035.[50] With current roads and other limitations, it would take over thirty-six hours to evacuate the residents out of the hurricane evacuation zones, a process often fraught with chaos and other issues.[51] Many residents choose not to leave and are endangered, and those who do evacuate leave billions of dollars' worth of infrastructure and property behind. Hurricanes striking the coast when sea level is even higher will place even more people at risk, which thus emphasizes the need to plan for higher sea levels and the direct and indirect hazards it causes.[52]

II. LEARNING TO LIVE WITH SEA LEVEL RISE IN GALVESTON BAY

Additional study is necessary to gain a broader understanding of SLR impacts, but it is not feasible to wait to gain a complete understanding of the system before

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[47] Natalya N. Warner & Philippe E. Tissot, *Storm Flooding Sensitivity to Sea Level Rise for Galveston Bay, Texas*, 44 OCEAN ENGINEERING 23 (2012).
[48] Mir Emad Mousavi et al., *Global Warming and Hurricanes: The Potential Impact of Hurricane Intensification and Sea Level Rise on Coastal Flooding*, 104 CLIMATE CHANGE 575 (2010).
[49] Stephen P. Leatherman, Keqi Zhang & Bruce C. Douglas, *Sea Level Rise Shown to Drive Coastal Erosion*, 81 EOS 437 (2000).
[50] SSPEED CTR. OF RICE UNIV., SSPEED CENTER PHASE III: DEVELOPING A HOUSTON-GALVESTON AREA PROTECTION SYSTEM (2014).
[51] SSPEED CTR. OF RICE UNIV., SSPEED CENTER 2014 REPORT (2014) http://doctorflood.rice.edu/sspeed/downloads/HE_Final_Report_2014.pdf (last visited July 3, 2018).
[52] Maarten K. Van Aalst, *The Impacts of Climate Change on the Risk of Natural Disasters*, 30 DISASTERS 5 (2006).

determining how to adapt.[53] This section discusses current laws in Texas that address SLR and issues that must be considered when developing policy options. A brief discussion of several response options is also included.

A. Gulf-Facing Beaches

Texas has some of the most progressive laws of any Gulf state when it comes to protecting Gulf of Mexico-facing beaches. These laws include the Texas Open Beaches Act of 1959 (TOBA) and the Dune Protection Act (DPA). TOBA indirectly provided statutory protection of the shifting boundaries of beaches by requiring public access to the shore. DPA[54] prevents construction on sand dunes. Texas also has a program called the Texas Coastal Erosion Planning and Response Act of 1999,[55] which aims to prepare the state for SLR. It is a statewide program designed to fund projects that battle erosion in critical Gulf- and bay-facing areas along the coast. It emphasizes the use of dune restoration and beach nourishment coupled with monitoring and studies to prevent the shoreline from retreating.[56] It also funds the removal of structures that are located on public beaches.

DPA requires each county with a Gulf-facing beach to establish a line along beach dunes no further landward than 1,000 feet from the mean high tide line (MHTL).[57] A permit must be obtained in order to partake in any activities that disturb the dunes seaward of this "dune protection line." This prevents development from intruding on the beach, thus protecting the beach and dune system. Local legislation in Texas can enact additional setback rules that prevent development, the most stringent of which is Nueces County. Nueces County disallows most construction from the seaward edge of the dune at the line of vegetation landward to 350 feet.[58] These progressive laws protect Gulf-facing beaches and maintain the ecosystem services they provide, buffering the effects of SLR.

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[53] Sandra S. Nichols & Carl Bruch, *New Frameworks for Managing Dynamic Coasts: Legal and Policy Tools for Adapting U.S. Coastal Zone Management to Climate Change*, 1 SEA GRANT L. & POL'Y J. 19 (2008), http://www.nsglc.olemiss.edu/sglpj/Vol1No1/2Nichols.pdf (last visited June 20, 2018).
[54] TEX. ADMIN. CODE ANN. § 31.15.3.
[55] TEX. NAT. RES. CODE ANN. §§ 33.603-33.608.
[56] *Id.* §33.607.
[57] *Id.* § 63.012.
[58] Richard McLaughlin, *Rolling Easements as a Response to Sea Level Rise in Coastal Texas: Current Status of the Law After Severance v. Patterson*, 26 J. OF LAND USE & ENVTL. L. 365 (2011), *available at* http://www.jstor.org/stable/42842969 (last visited June 20, 2018).

TOBA was enacted in 1959, and the courts' interpretation of the law's public access requirements led to the development of a "rolling easement doctrine," which allows the public to use the beach seaward of the vegetated dune line as it moves due to natural forces.[59] Rolling easements ensure access to sandy beaches migrate inland as the water level rises. Texas courts have also applied custom-based laws to justify rolling easements because, in order for them to be useful and "reflect the reality of the public's actual use of the beach, [the easements] must migrate as did the customary use from which it arose."[60]

Courts have also held that not allowing the public's use to shift with the changing contours of the beach could cause the public's use to entirely disappear.[61] This finding enables the law to be used as a method to combat SLR. Rolling easements restrict development seaward of the easement's landward boundary and provide the rationale for the removal of structures that are located seaward of the landward boundary.[62] They also prevent the installation of any artificial armoring, and existing houses or other structures are subject to removal when erosion or other processes move the vegetation line landward of the structures.[63] This not only guarantees the public's right to Texas's Gulf-facing beaches, but it also protects the sandy beach from erosion due to artificial armoring.

TOBA was weakened by the 2012 *Severance v. Patterson* court case involving a home in Galveston.[64] That property was listed in 1999 by the Texas General Land Office as seaward of the vegetation line and was found in 2004 to be wholly or partially on public beach, but because it was not a hazard the Land Office granted a two-year moratorium on removal.[65] At the time of purchase in 2005, the owner received a disclosure notice that the house was located in vulnerable locations and could be subject to removal by the state. Later that year, Hurricane Rita eroded the beach considerably, and a notice sent to the owner in 2006 stated that the house was subject to removal because it was on the public easement. The owner sued the Texas Land Commissioner with assistance from the Pacific Legal Foundation.

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[59] *Id.*
[60] Caldwell & Segall, *supra* note 5..
[61] McLaughlin, *supra* note 58.
[62] JAMES G. TITUS, CLIMATE READY ESTUARIES, ROLLING EASEMENTS (2011).
[63] *Id.*
[64] Severance v. Patterson, 370 S.W.3d 705 (Tex. 2012).
[65] *Id*.

The Texas Supreme Court held that "Texas does not recognize a 'rolling' easement," and found that structures are only subject to removal under TOBA when imperceptible erosion causes the loss.[66] The court asserted that there was a distinction between avulsion, which are "sudden occurrences," and erosion, which occurs "imperceptibly."[67] It held that, in this case, despite evidence of years of imperceptible erosion, the overnight erosion caused by Hurricane Rita was avulsive, and thus, TOBA did not apply.[68]

The distinctions between avulsion and erosion, while important in a legal context, have limited value in applied science. This finding demonstrates an unclear understanding of geology and natural processes; the ocean and thus shoreline are dynamic and constantly changing. The distinction between erosion and avulsion is ambiguous and effectively requires the reestablishment of easements after each hurricane season. Additionally, it guarantees that the State will be involved in expensive court cases with individual landowners for years to come. Lastly and most importantly, it "defeats the purpose of [T]OBA: to maintain public beach access."[69]

The *Severance* decision had immediate consequences beginning with the cancellation of a $40 million beach nourishment project in West Galveston.[70] The project was cancelled because public funds are not permitted to be used to benefit private homeowners, and there was confusion regarding whether a public easement existed on the beach in question, as believed prior to *Severance*, or whether *Severance* did away with the easement.

In 2013, House Bill (HB) 3459 was enacted giving the Texas General Land (GLO) Commissioner the ability to determine whether avulsion or erosion occurred in certain cases.[71] It offers a three-year moratorium to allow the area to settle naturally; during that time, the public easement is 200 feet from mean low tide line.[72] After that period of time, the commissioner may be advised by the

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[66] *Id*. at 724.
[67] Angela Howe, *Texas Open Beaches - The TX Supreme Court Refuses to 'Roll with It' in West Beach*, GALVESTON SURFRIDER FOUND., Nov. 8, 2010, http://www.surfrider.org/coastal-blog/entry/texas-open-beaches-the-tx-supreme-court-refuses-to-roll-with-it-in-west-bea (last visited June 20, 2018).
[68] *Severance*, 370 S.W.3d at 724-25.
[69] Severance v. Patterson, 566 F.3d 490, 504-05 (5th Cir. 2009) (Wiener, J., dissenting).
[70] Harvey Rice, *Mayor Faults 'blow to Galveston' after State Halts Beach Project*, HOUSTON CHRONICLE, Nov. 15, 2010, https://www.chron.com/business/real-estate/article/Mayor-faults-blow-to-Galveston-after-state-1708528.php (last visited June 20, 2018).
[71] TEX. NAT. RES. CODE ANN. § 61.0171.
[72] *Id.*

Bureau of Economic Geology of the University of Texas to determine whether the change was avulsive or if it was "within the normal rate of erosion."[73] If determined to be erosive, the public easement will roll to the vegetation line. As long as the commissioner listens to the science, this bill is a step towards protecting Texas's beaches and public access to them. A commissioner who errs on the side of private property rights, however, could limit public access to Texas's beaches and potentially cause the loss of beaches through coastal squeeze.

B. Bay-Facing Shorelines

Although Texas's Gulf-facing beaches are shielded by progressive laws, Texas's 3,300 miles of bay-facing shorelines have much less protection. In these areas, private property regulation may be subject only to the owner's will. Texas law provides the GLO with jurisdiction only on public lands that are below the MHTL. If a rising sea is triggering erosion, the landowner must get the land surveyed.[74] Armoring may then be installed as long as it is just above the MHTL and thus not on public lands, regardless of whether coastal squeeze will cause the loss of wetland habitats and their ecosystem services, which benefit everyone. The only protection bay-facing wetlands and beaches have in Texas are federal laws such as the Clean Water Act (CWA) Section 404, which protects coastal wetlands, or any incorporated city ordinances, if applicable.[75]

Unincorporated communities, which are under state law, do not have the legal authority to protect coastal habitats as no state laws exist to protect wetland habitats.[76] As such, there are very few protections for unincorporated, undeveloped bay-facing properties. Incorporated cities should enact their own protections for bay-facing wetland habitats; protection under the law could then spread from community to community. The lack of regulation for bay-facing properties stands in stark contrast to the progressive protection given to Gulf-facing beaches by TOBA and DPA.

C. Takings Issues

The Fifth Amendment of the Bill of Rights to the U. S. Constitution states that "private property [shall] not be taken for public use, without just

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[73] TEX. GEN. LAND OFFICE & TEX. VETERANS' LAND BD., STRATEGIC PLAN FOR THE FISCAL YEARS OF 2015-2019 (2014).
[74] TEX. GEN. LAND OFFICE, RESIDENTIAL APPLICATION PACKET (2013).
[75] 33 U.S.C. § 1344.
[76] 52 TEX. JUR. 3D MUN. CORPORATIONS § 139; 8B TEX. JUR. PL & PR. FORMS § 176:2 (2d ed.).

compensation," and thus, it aims to prevent the federal, state or local government from infringing upon an individual's private property without due compensation. Any government action that deprives a landowner of the full utility of his or her property without compensation may be considered a taking.[77]

By their nature, legal protections for wetland habitats usually prevent the landowner from using his or her property in some way.[78] For instance, the prohibition on armoring means that the areal extent of privately owned uplands may be decreased due to erosion. Should this type of regulation be considered a taking since the government is preventing the landowner from protecting what is legally his or hers? It depends upon how individual laws are written and what type of impact they may have on the owner's use of the property. Policies today must be cognizant of this, and laws and regulations need to be written in such a way that minimizes the probability that the state will be involved in costly litigation expenses and payouts for takings.

A consideration in takings cases is investment-backed expectations.[79] Coastal residents' expectations can be tempered through real estate listings notices and disclosure requirements that inform and warn the potential buyer of the effects of SLR, which can influence investment-backed expectations and thus minimize takings claims.[80] Under Texas state law, Natural Resource Code Section 61.025 requires that all individuals buying land "in close proximity" to a Gulf-facing beach sign a "Disclosure Notice Concerning Legal and Economic Risks of Purchasing Coastal Real Property Near a Beach." This document informs the buyer of "potential risks of economic loss" for coastal properties. It also informs the buyer that he or she may be financially responsible for removing the structure if it becomes located on the public beach due to erosion or storm events. Adopting similar notices in bay-facing areas would be politically controversial and is arguably unrealistic given Texas's political attitudes.

Because the Fifth Amendment was designed to protect the private property owner from the government and not forces of nature, policies can minimize the risk of takings by emphasizing that coastal and bayfront protections are in response to forces of nature and are not designed for government profit at the

[77] Nichols & Bruch, *supra* note 53.
[78] James G. Titus, *Rising Seas, Coastal Erosion, and the Takings Clause: How to Save Wetlands and Beaches Without Hurting Property Owners*, 57 MD. L. REV. 1279 (1998).
[79] Margaret E. Peloso & Margaret R. Caldwell, *Dynamic Property Rights: The Public Trust Doctrine and Takings in a Changing Climate*, 30 STAN. ENVTL. L. J. 51 (2011).
[80] Nichols & Bruch, *supra* note 53.

expense of private landowners. Policies should explicitly state the "background principles' attributes" of the new regulation.[81]

At present, Texas seems to hold an "ignore the problem" perspective to some degree, particularly in regards to bay-facing shorelines. SLR-related problems will not just go away, however. Positive future results will be realized by actions taken immediately. When no action is taken, construction along vulnerable areas of the coastline will continue, as well as additional armoring to fortify private lands against SLR. Additionally, wetland habitats and the services they provide may be destroyed through coastal squeeze caused by development too close to the shoreline. This is an expensive choice as "substantial investments are already at risk and vulnerable."[82]

III. POLICY ISSUES FOR DYNAMIC SYSTEMS

There are many factors to consider when determining which policy should be enacted to protect against SLR. Short- and long-term benefits, ecological and economic impacts, and legal issues including takings are some of the most important considerations. Furthermore, the natural world is a dynamic system; static, rigid laws will not be effective in the long-term unless they recognize the dynamics of a system. Some commentators emphasize the need for adaptive laws that "provide room for changing conditions and lessons learned."[83]

Projected economic and ecologic costs are important when determining which SLR policies are most beneficial and effective. The "values, perceptions, processes and power structures" that exist within a society restrict all policies, and adaptable societies are aware of "diverse values, appreciation, and understanding of specific and variable vulnerabilities to impacts."[84] Communities must also be aware that all SLR adaptations will lead to some loss either in developable land, in wetland habitats and their ecosystem services, or in lost business opportunities if the community retreats. Furthermore, what works in one environment may not be suitable in another one. Factors that must be considered include whether the policy is designed to work in the short- or long-term, the high levels of

[81] Michael Allan Wolf, *Strategies for Making Sea-Level Rise Adaptation Tools 'Takings-Proof'*, 28 J. of Land Use & Envtl. L. 157 (2013), *available at* https://ssrn.com/abstract=2256993.
[82] CAL. DEP'T OF WATER RES. INTEGRATED REG'L WATER MGMT., CLIMATE CHANGE DOCUMENT CLEARINGHOUSE (2010).
[83] Nichols & Bruch, *supra* note 53.
[84] W. Neil Adger et al., *Are There Social Limits to Adaptation to Climate Change?*, 93 CLIMATIC CHANGE 335 (2009).

uncertainty as to what sea level will actually do, what its effects will actually be, and what the community's cultural expectations are.[85]

Policies must be science-based. According to one expert, those that "ignore the dynamics of coastal states and systems" can disrupt both natural and human systems with potentially "catastrophic" results.[86] If the policies disrupt the system and endanger the people living nearby, they clearly have failed, but it would likely be too late for the sensitive system to recover. This emphasizes the need for well considered, scientifically based policies whose impacts have been thoroughly studied.

SLR makes coastal populations more vulnerable to hurricanes since storm waves "attack" the shoreline from higher levels compared to lower sea levels. If no strategies to protect against SLR are enacted, the worst case is billions of dollars' worth of damage and the potential for human casualties particularly from hurricanes. According to one study, approximately 80,000 more people would be at risk of being displaced if Hurricane Ike were to occur in 2100 with 0.74 m of SLR compared to the number actually displaced by Ike in 2008.[87] Additionally, 48 fire stations, hospitals, police stations, and schools in that area are at risk given 0.74 m of SLR by 2100.[88]

Funds to combat huge natural disasters come directly from taxpayer-funded governmental organizations, such as FEMA, which provides billions of dollars in aid. For instance, as of 2015 nearly $20 billion was paid to Louisiana after the 2005 Hurricane Katrina.[89] A reinsurance company found that "by investing 50 billion dollars in cost-effective measures over the next 20 years... [Texas, Mississippi, and Alabama] can avert up to 135 billion dollars in annual losses."[90]

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[85] Kim S. Alexander et al., *Managed Retreat of Coastal Communities: Understanding Responses to Projected Sea Level Rise*, 55 J. OF ENVTL. PLANNING & MGMT. 409 (2012) [hereinafter *Managed Retreat*].
[86] Megan Higgins, *Legal and Policy Impacts of Sea Level Rise to Beaches and Coastal Property*, 1 SEA GRANT L. & POL'Y J. 43 (2008), http://www.nsglc.olemiss.edu/sglpj/Vol1No1/3Higgins.pdf (last visited June 20, 2018).
[87] Subedee et al., *supra* note 29.
[88] *Id.*
[89] FED. EMERGENCY MGMT. AGENCY, LOUISIANA RECOVERY UPDATE: KATRINA AND RITA BY THE NUMBERS (2015), https://www.fema.gov/news-release/2015/08/24/louisiana-recovery-update-katrina-and-rita-numbers (last visited June 20, 2018).
[90] *Shoring up the Energy Coast- Building Climate-Resilient Industries Along America's Gulf Coast*, SWISS RE,

The Army Corps of Engineers' Regulation No. 1100-2-8162 "Incorporating Sea-Level Change in Civil Works Programs" works to integrate "the direct and indirect physical effects of projected sea-level change across the project life cycle in managing, planning, engineering, designing, constructing, operating, and maintaining Corps projects and systems of projects."[91] However, the United States does not currently have a national program to protect its urban areas from SLR. It is up to individual states, cities, and communities to determine how to best combat it. Additionally, politicians do not prioritize SLR planning because, as one article put it, "in political terms," SLR does not need to be "dealt with this week."[92]

Scientific knowledge about SLR and its effects has outpaced legislation and regulations. Consequently, this makes it difficult for any SLR projects to gain traction and to receive the financial support that is necessary for defensive projects, policies, or laws to be successfully executed or implemented. An exception to this is after a disaster such as Hurricane Sandy when funds were made available for research and preparation so that the area was not as vulnerable to a future, similar storm.

Policies designed to combat SLR have strong socio-political aspects; they must attempt to balance economic development and resource protection.[93] For instance, an economically beneficial policy may have such large ecological costs that it is found inferior.[94] The community must determine what it values, what it aims to protect through policies, and how far into the future it is willing to plan. Different policy options will be most suitable for different community values. In general, community members are not only concerned with the "economics and science" of policies but also their "fairness, transparency and morality."[95] For example, communities must consider that in some locations the harm incurred by not armoring is less than the benefits derived by that action. One study in Tybee Island, GA, for example, compared the "estimated recreational benefits" to the costs incurred for armored beaches to those that were 20 m wider with no visible

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http://www.swissre.com/rethinking/Building_a_resilient_Energy_Gulf_Coast.html (last visited June 20, 2018).

[91] U.S. ARMY CORPS OF ENGINEERS, SEA-LEVEL CHANGE CONSIDERATIONS FOR CIVIL WORKS PROGRAMS (2011).

[92] HUNT JANIN & SCOTT A. MANDIA, RISING SEA LEVELS: AN INTRODUCTION TO CAUSE AND IMPACT (2012).

[93] ZOË PFAHL JOHNSON, MD. DEP'T OF NAT. RES., A SEA LEVEL RISE RESPONSE STRATEGY FOR THE STATE OF MARYLAND (2000).

[94] JANIN & MANDIA, *supra* note 92.

[95] *Managed Retreat*, *supra* note 85.

armorings.[96] They found that the wider, unarmored beaches had "very huge" benefits compared to the estimated costs of the higher quality armoring.[97]

Three policy response options to SLR will be considered: armoring, living shorelines, and organized retreat. Living shorelines and retreat are considered sustainable options because they preserve ecosystem services and protect coastal residents. Armoring, conversely, is considered to be unsustainable since it will not be effective once sea level reaches a certain level and either affects the armoring's structural stability directly or overtops it.

A. Armoring

Shoreline armoring is when structures are used to prevent the shoreline from moving. This approach is used by large cities such as New York City and Miami as well as other areas with "highly valued and immovable assets" whose infrastructure is so great that a retreat is not feasible.[98] While it can effectively prevent erosion at a particular section of shoreline, it generally exacerbates erosion down the beach and can cause the net loss of often-critical wetland habitats and the ecosystem services that they provide. Down-beach erosion is caused through the disruption of the longshore currents' erosional and depositional processes that occur naturally on all beaches. In addition, wave refraction erodes sediments around the sides of the armoring, typically causing a concave shape to the shoreline and the erosion of properties downdrift.

Armoring restricts access to sandy beaches and can completely cut off beach access for the public.[99] It can also destroy the beach altogether through coastal squeeze.[100] Vertical erosion is often enhanced in front of seawalls because waves reflect off the seawall and scour below the structure, thereby deepening the water depth.[101] This steepens the slope underwater and causes subsequent waves to strike the seawall harder, thereby accelerating the need to have it reinforced. This is why seawalls and other armorings need to be regularly maintained.[102] Collapse

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[96] Craig E. Landry et al., *An Economic Evaluation of Beach Erosion Management Alternatives*, 18 MARINE RESOURCE ECONOMICS 105 (2003).
[97] *Id.*
[98] *Managed Retreat, supra* note 85.
[99] Gary B. Griggs, *The Effects of Armoring Shorelines—The California Experience*, *in* PUGET SOUND SHORELINES AND THE IMPACTS OF ARMORING—PROCEEDINGS OF A STATE OF THE SCIENCE WORKSHOP 77 (Hugh Shipman, et al., eds., 2010).
[100] Jason D. Toft et al., *Ecological Response and Physical Stability of Habitat Enhancements Along an Urban Armored Shoreline*, 57 ECOLOGICAL ENGINEERING 97 (2013).
[101] Griggs, *supra* note 99.
[102] *Id.*

of the structure can cause the loss of a significant amount of land.[103] Even if they are structurally sound, a rising sea may still overtop static armoring structures that were designed for lower water levels. Issues such as these have led to a tightening of restrictions for armoring projects in some states such as Texas, Maryland, and Rhode Island.

Shoreline armoring has large upfront capital costs. It is estimated that protecting certain vulnerable areas in California through seawalls and levees would cost at minimum $14 billion to construct and $1.5 billion per year in maintenance.[104] Due to the high costs, it is necessary to balance the land saved with the monies spent and ecological damage inflicted. It is also necessary for the community that is considering armoring to consider the length of time that they want to keep the water at bay since "it is a matter of time until shoreline armoring fails… Armoring the coast simply delays the inevitable."[105] Lastly, armoring has large negative environmental costs that are rarely incorporated in cost-benefit analyses due to the loss of ecosystem services that occurs from coastal squeeze and the loss of wetland environments.

The permitting system for armoring is typically well established. Federal agencies are typically willing to grant armoring permits, because they are concerned about takings claims if they do not.[106] It is difficult to phase out of shoreline armoring with methods that are more progressive. Additionally, a problem with both armoring and living shorelines (discussed below) is that both systems can encourage development landward. Therefore, protecting shorelines, if not done in conjunction with good setback, rollback, and/or construction policies and with no commitment to repair and upgrade the project, could increase vulnerability over time, particularly in light of SLR.

B. Living Shorelines

Armoring and other artificial land/water interfaces usually "disrupt highly diverse and productive plant and animal communities" and cause a loss of wetland habitats and their ecosystem services.[107] Living shorelines, the name given to erosion and flooding control projects that utilize natural materials and

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[103] TODD MILLER ET AL., RESTORE AMERICA'S ESTUARIES, LIVING SHORELINES: FROM BARRIERS TO OPPORTUNITIES (2014).
[104] CAL. CLIMATE CHANGE CTR., THE IMPACTS OF SEA LEVEL RISE ON THE CALIFORNIA COAST (2009), http://pacinst.org/app/uploads/2014/04/sea-level-rise.pdf (last visited June 20, 2018).
[105] Celeste B. Pagano, *Where's the Beach? Coastal Access in the Age of Rising Tides*, 42 SW. U. L. REV. 1 (2012), *available at* https://ssrn.com/abstract=2109443 (last visited June 20, 2018).
[106] Titus, *supra* note 78.
[107] Caldwell & Segall, *supra* note 5.

vegetation, are an alternative to shoreline armoring. Living shorelines encourage the preservation or growth of coastal habitats and allow migration when sea level rises. It is an ecologically friendly option which protects coastlines with few negative effects.[108] They can range from using purely natural methods like planting marsh grass to hybrid infrastructure which incorporates both artificial structures and natural elements.[109]

Living shorelines dissipate wave energy, prevent erosion, and enhance the ecological connectivity of the land/water interface by using natural means. They typically are visually appealing, improve water quality, and restore or enhance habitats for wetland organisms including birds, fish, and other aquatic species.[110] They maintain or increase the growth of wetland habitats for a given area, which can increase biodiversity and ecosystem services.[111] While armoring projects aim to prevent erosion through the reflection of wave energy, living shorelines absorb that energy as the vegetation naturally attenuates wave energy through friction.[112] Bagged oyster shells, for example, can be placed in areas where oyster spat can attach to eventually create a reef, which will attenuate wave energy.[113] Living shorelines create more resilient shorelines than armorings do, and downdrift erosion effects are lessened compared to armoring projects. They are also designed to be at least partially self-maintaining once established.[114]

There are several legal issues regarding property rights involved with living shorelines. While the ecologic and protective benefits of living shorelines are widely known, there are concerns regarding how they impact publically

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[108] Carolyn A. Currin et al., *Developing Alternative Shoreline Armoring Strategies: The Living Shoreline Approach in North Carolina United States Geological Survey*, *in* PUGET SOUND SHORELINES AND THE IMPACTS OF ARMORING—PROCEEDINGS OF A STATE OF THE SCIENCE WORKSHOP (Hugh Shipman et al., eds., 2010).
[109] OYSTER RESTORATION WORKGROUP, LIVING SHORELINES AND COASTAL EROSION, http://www.oyster-restoration.org/living-shorelines/.
[110] Currin et al., *supra* note 108.
[111] Carolyn A. Currin, Priscilla C. Delano & Lexia M. Valdes-Weaver, *Utilization of a Citizen Monitoring Protocol to Assess the Structure and Function of Natural and Stabilized Fringing Salt Marshes in North Carolina*, 16 WETLANDS ECOLOGY AND MANAGEMENT 97 (2007).
[112] I. Möller, *Quantifying Saltmarsh Vegetation and its Effect on Wave Height Dissipation: Results from a UK East Coast Saltmarsh*, 69 ESTUARINE, COASTAL AND SHELF SCIENCE 337 (2006).
[113] David L. Meyer et al., *Stabilization and Erosion Control Value of Oyster Cultch for Intertidal Marsh*, 5 RESTORATION ECOLOGY 93 (1997).
[114] Rachel K. Gittman et al., *Marshes With and Without Sills Protect Estuarine Shorelines from Erosion Better than Bulkheads During a Category 1 Hurricane*, 102 OCEAN & COASTAL MANAGEMENT 94 (2014).

owned submerged lands.[115] Materials placed to attenuate wave energy below the MHTL are on publically owned lands. Additionally, living shorelines can cause accretion, which potentially reduces the area of the publicly owned submerged lands. In all states, if accretion occurs and is not due to the intentional actions of the landowner, then it becomes part of their property as was found in the Texas case, *Brainard v. State*.[116] If accretion occurs due to the landowner installing a living shoreline, however, would the property be retained by the state because of the intentional actions or would its ownership transfer to the adjacent owner? This is a question that has yet to be answered.

The U.S. Corps of Engineers Nationwide Permit 54 streamlines the federal permitting process for living shorelines.[117] There was a need for a process that is consistent and predictable as the previous process was confusing and time-consuming. As the loss of some submerged lands is typically preferable to the negative effects caused by shoreline armoring, the government should furthermore offer incentives for property owners to install living shorelines instead of armoring against SLR. At the same time, permitting officials must address the unsettled ownership issue and be open to the notion that landowners are not using living shorelines to increase their private property at the expense of publicly owned submerged lands.

C. Retreat

Because sea level is predicted to rise, the best long-term solution for certain areas may be organized retreat.[118] It is an unpopular option that has potentially large benefits.[119] Since most armoring projects, excepting massive

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[115] TONY WATKINSON & SHEP MOON, REGULATORY PROGRAM OVERVIEW FOR VIRGINIA'S SUBMERGED LANDS AND TIDAL WETLANDS AND OPTIONS FOR PROMOTING LIVING SHORELINES (2006).
[116] Brainard v. State, 12 S.W.3d 6 (Tex.1999).
[117] *Nationwide Permit Information*, U.S. ARMY CORPS OF ENGINEERS, http://www.usace.army.mil/Missions/Civil-Works/Regulatory-Program-and-Permits/Nationwide-Permits/ (last visted June 20, 2018).; *see also* RICHARD MCLAUGHLIN & RACHEL EDWARDS, TEX. A&M UNIV.- CORPUS CHRISTI, HARTE RESEARCH INST., LIVING WITH SEA LEVEL RISE ON THE UPPER TEXAS COAST: PUBLIC POLICY CONCERNS AND COMPARISONS TO FLORIDA (2017) (on file with author).
[118] ANNE SIDERS, COLUM. L. SCH. CTR. FOR CLIMATE CHANGE L., MANAGED COASTAL RETREAT: A LEGAL HANDBOOK ON SHIFTING DEVELOPMENT AWAY FROM VULNERABLE AREAS (2013).
[119] Travis Martay Brennan, *Redefining The American Coastline: Can The Government Withdraw Basic Services From The Coast and Avoid Takings Claims?* 14 OCEAN & COASTAL L. J. 101 (2008), *available at* http://digitalcommons.mainelaw.maine.edu/oclj/vol14/iss1/6/ (last visited June 20, 2018).

levee and dike projects such as those that defend Rotterdam Harbor and New Orleans, protect against a maximum of several meters of SLR. While this may seem large, it is not unusual for a hurricane's storm surge to be greater than several meters in height. Furthermore, it is a matter of when, not if, in the future we reach several meters of SLR. As such, the presence of armoring may only delay inevitable hurricane or flooding damage. Furthermore, any storm that is greater than the anticipated design level will overtop the defenses to cause widespread damage.[120] In comparison, organized retreat, which is the migration of settlements away from the shoreline, gives the rising water a place to go without damaging infrastructure.[121] There are multiple ways for communities to initiate a retreat.

Erosion setbacks enable the government to initiate a slow retreat from rising water levels and eroding coasts. They can be applied in different ways, but a common option is limiting development in hazard-prone areas. This can be done by limiting growth in those locations by issuing a fewer number of building and renovation permits or by requiring the permit-granting institution to consider a future rate of SLR before issuance. Construction of mobile structures which can be picked up and moved away from the sea, such as the Yup'ik Tribe did in Alaska when it voted to move its community inland, is another option.[122] It is also possible to move historic or otherwise important structures inland as demonstrated by North Carolina when the Cape Hatteras lighthouse was moved over 800 m to protect it from erosion.[123] While this option allows for wetland habitat and beach migration, it comes with what are often prohibitively high costs.[124] Another option is for the government, either at the state or federal level, to purchase

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[120] Hsaing Wang, *Water Erosion and Damage to Coastal Structures, in* HURRICANE HUGO, PUERTO RICO, THE VIRGIN ISLANDS, AND CHARLESTON, SOUTH CAROLINA, SEPTEMBER 17-22, 1989 (National Academies Press: OpenBook 1994), https://www.nap.edu/read/1993/chapter/14 (last visited June 20, 2018).

[121] SIDERS, *supra* note 118.

[122] James D. Ford et al., *Climate Change in the Arctic: Current and Future Vulnerability in Two Inuit Communities in Canada*, THE GEOGRAPHICAL JOURNAL (2007), http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4959.2007.00249.x/abstract (last visited June 20, 2018).

[123] *Moving the Cape Hatteras Lighthouse*, NAT'L PARK SERV., https://www.nps.gov/caha/learn/historyculture/movingthelighthouse.htm (last visited June 20, 2018).

[124] ROBERT E. DEYLE, FLORIDA STATE UNIV. DEP'T OF URBAN & REG'L PLANNING, SEA LEVEL RISE ADAPTATION OPTIONS FOR LOCAL GOVERNMENTS, http://www.floridajobs.org/docs/default-source/2015-community-development/community-planning/crdp/sealevelriseadaptationoptionsforlocalgovernments.pdf?sfvrsn=6 (last visited June 20, 2018).

private property in hazardous areas and demolish any buildings located on it.[125] The government can also limit public support including utilities, road maintenance and fire and police services, although the ethics of this are questionable and there may be takings claims.

An organized retreat can be very expensive.[126] However, it preserves ecosystem services by allowing the wetland habitats to migrate inland where topography allows, prevents a catastrophe when artificial structures are overtaken by the sea, and can be economically beneficial in the long run when comparing the loss of whole cities to the expense of slowly retreating.[127] It also may be the most feasible option for communities located in hazard-prone areas that cannot afford to invest in protection. Fairbourne, Wales is such an example. Fairbourne is located on a flood plain, and in 2014 it determined that it would be decommissioned over the next forty years.[128]

Officials must be careful with the wording of the law and how it is implemented to avoid triggering takings claims, but also to protect those living in the coastal area since the potential for social inequality and compensation claims in an organized retreat strategy can be large.[129] For instance, housing prices in Fairbourne "plummeted" after plans were implemented to decommission the village.[130] Additionally, organized retreat strategies can come at a great cost to individual property owners whose property values could drop virtually overnight. While the policy must consider how to compensate those individuals, the overall strategy has the potential to offer great benefits to the community.

As high as the costs to initiate a retreat are, it still may be less than the cost to renourish the beach as found in a Nags Head, NC study. That study found that buying all the buildings expected to be lost to erosion in fifty years would cost

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[125] SIDERS, *supra* note 118.
[126] Carolyn Kousky, *Managing Shoreline Retreat: A US Perspective*, 124 CLIMATIC CHANGE 9 (2014); CHRISTOPHER TURBOTT & ANDREW STEWART, WAIKATO REG'L COUNCIL, MANAGED RETREAT FROM COASTAL HAZARDS: OPTIONS FOR IMPLEMENTATION (2006), https://www.waikatoregion.govt.nz/services/publications/technical-reports/tr/tr200648 (last visited June 20, 2018).
[127] James G. Titus, *Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey*, 18 COASTAL MGMT. 65 (1990); R.K. Turner et al., *A Cost–benefit Appraisal of Coastal Managed Realignment Policy*, 17 GLOB. ENVTL. CHANGE 397 (2007).
[128] *What Is Fairbourne Moving Foward?*, FAIRBOURNE MOVING FORWARD, http://fairbourne.info/ (last visited June 20, 2018).
[129] *Managed Retreat*, *supra* note 85.
[130] Richard Spillett, *Village of the DAMMED*, DAILY MAIL, Feb. 12, 2016, http://www.dailymail.co.uk/news/article-3442264/Welsh-village-decommissioned-warnings-lost-sea.html (last visited June 20, 2018).

$400 million.[131] That was four times less than the costs of a fourteen-mile beach renourishment project that would have to be renourished every three years at a total cost of $1.6 billion.[132] Additionally, the removal of the structures resulted in wider beaches, unobstructed wetland habitats, and ease of access to the beach, yielding higher values of the remaining houses.[133]

Many factors must be considered when determining if green, grey, or hybrid infrastructure is appropriate for a given shoreline. Green infrastructure includes natural design elements such as marsh grasses or oyster reefs, grey infrastructure is purely artificial such as bulkheads or groins, and hybrid infrastructure includes both natural and artificial elements. Because no two shorelines have the same set of parameters, this process must be done for each situation. There is a need for region-specific ecosystem services valuation and the quantification of grey infrastructure's negative costs.[134] For grey infrastructure, this can include downdrift erosion and the loss of the ecosystems and their services that existed prior to the armoring installation. These two metrics allow for a more accurate picture of what exactly is at risk and what the benefits are of the various shoreline protection strategies.

It is also important to determine what time frame is under consideration in a given situation. Living shorelines may not protect against erosion as well as armoring in the short term, but armoring may cause issues that living shorelines mitigate in the longer term. Another consideration is the character of common hazards in a given area and what natural vegetation or habitats are best suited to mitigate them. For instance, marsh grasses are excellent for attenuating wave energy to mitigate erosion on a coastline, but they may not be solely appropriate in more exposed areas where they will erode and not be self-sustaining.

Another consideration is a community's development may dictate different response strategies. Less developed areas may be able to emphasize environmental benefits while more developed areas, particularly those with infrastructure that is necessary to regional or national economic activities, may need to use harder infrastructure strategies for protection purposes. Communities must balance resiliency and vulnerability with economic growth, environmental

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[131] ORRIN H. PILKEY & ROB YOUNG, THE RISING SEA (2d ed. 2011).
[132] *Id.*
[133] Landry et al., *supra* note 96.
[134] EXEC. OFFICE OF THE PRESIDENT, NAT'L SCI. & TECH. COUNCIL COMM. ON ENV'T., NATURAL RES., & SUSTAINABILITY, ECOSYSTEM SERVICE ASSESSMENT: RESEARCH NEEDS FOR COASTAL GREEN INFRASTRUCTURE (2015), https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/cgies_research_agenda_final_082515.pdf (last visited June 20, 2018).

quality, and historical preservation.[135] It is important to gather necessary and relevant data and to explicitly evaluate priorities and desired outcomes to determine the best course of action when installing infrastructure.

IV. CASE STUDIES: WHAT TECHNIQUES ARE MOST APPROPRIATE FOR DIFFERENT COMMUNITIES

The four sites in this study have very different community structures and economic goals. They also have very different built environments. Because of this, different SLR protection strategies are appropriate for each. Below is an outline of actions that may be best suited to each site given their varying regional activities and priorities.

A. Texas City

Texas City, located in Chambers and Galveston Counties, is an industrial city that borders Galveston Bay. It has a port and is a petroleum refining and petrochemical manufacturing center vital to the energy production of both the Gulf region and the United States.[136] The Port of Texas City is the third largest port in Texas and the fifteenth largest in the United States.[137] Its refineries and other infrastructure are necessary to the entire nation, and damages to it from natural disasters such as Hurricane Ike can be catastrophic to the nation. It is affected by subsidence rates between -0.30 and -0.33 mm per year.[138] For these reasons, damages from future storms could be worse because of SLR. Therefore, its protection is a priority.

Accordingly, Texas City does not prioritize coastal ecosystems or their services over the installation and subsequent upkeep of their levee system and dike. The Texas City Dike extends almost to Galveston Island and is designed to protect Texas City from storm surges, and there is also a seventeen-mile long

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[135] *Id.*
[136] T. B. Ryerson et al., *Effect of Petrochemical Industrial Emissions of Reactive Alkenes and NOx on Tropospheric Ozone Formation in Houston, Texas*, 108 J. OF GEOPHYSICAL RES. 8-1 (2003), *available at* https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2002JD003070 (last visited June 20, 2018).
[137] Roy Scranton, *When the Next Hurricane Hits Texas*, N.Y. TIMES, Oct. 7, 2016, https://www.nytimes.com/2016/10/09/opinion/sunday/when-the-hurricane-hits-texas.html (last visited June 20, 2018); *Tonnage of Top 50 U.S. Water Ports, Ranked by Total Tons*, BUREAU OF TRANSP. STATISTICS, DEP'T OF TRANSP., https://www.bts.gov/archive/publications/national_transportation_statistics/table_01_57 (last visited June 20, 2018).
[138] Subedee et al., *supra* note 29.

levee system designed to prevent flooding. Because of these factors, a continuation of hardening its shorelines and installing other grey infrastructure may very well be the best option for Texas City and other highly industrialized coastal cities like it.

B. Galveston

Galveston Island is a barrier island that separates the Gulf of Mexico from Galveston Bay. It is highly developed with an industrial port on the east side, whereas the west side is suburban, including year-round vacation homes. It is about 28 miles by 3 miles in area. Prior to widespread development on the island, sand dunes were up to 4.5 m in height; they have since been destroyed, making the island more vulnerable to large storms. For instance, the Hurricane of 1900 still ranks as the deadliest natural disaster in U.S. history, and it also provided motivation for the city to raise the elevation of the eastern portion of the island and install a massive seawall that is 10 miles long and about 5 m in height above mean sea level. Despite the seawall, Hurricane Ike, which struck in 2008, was the third most costly storm in U.S. history with estimated financial losses of $21.3 billion.[139] Additionally, Ike caused 50 m of erosion from Galveston's seawall to an area 15 km west of the seawall.[140] In another attempt to protect from SLR and storm surge, many structures built and rebuilt after Ike were put on stilts at heights determined by NFIP to protect against the expected surge of a 100-year storm. Even when considering those efforts, erosion and land subsidence have led to projections that parts of Galveston could be underwater in several decades.

Galveston has a long-term Gulf shoreline erosion average of approximately 5 feet per year except for the east end adjacent to the jetties protecting the main entrance to Galveston Bay (Bolivar Roads). Adjacent to the Bolivar Roads jetties, in contrast, the shoreline has advanced at rates up to 88.2 ft. per year.[141] The Bolivar jetties' accretion rate is at the expense of beaches along the west end of Galveston Island, which are sediment starved. Natural bay shorelines of marshes, flats, and beaches dominate the western 18 miles of Galveston and have retreat rates of approximately 3.3 feet per year.[142] The bay

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[139] Mitigation Assessment Team Report, *supra* note 40.
[140] KARA S. DORAN, ET AL., HURRICANE IKE: OBSERVATIONS AND ANALYSIS OF COASTAL CHANGE (2009), https://pubs.usgs.gov/of/2009/1061/pdf/ofr2009-1061.pdf (last visited June 20, 2018).
[141] ROBERT A. MORTON, SHORELINE CHANGES ON GALVESTON ISLAND (BOLIVAR ROADS TO SAN LUIS PASS) – AN ANALYSIS OF HISTORICAL CHANGES OF THE TEXAS GULF SHORELINE (1974).
[142] J.C. GIBEAUT ET AL., CHANGES IN BAY SHORELINE POSITION, WEST BAY SYSTEM, TEXAS (2003), *available at*

shoreline on the eastern 10 miles of the island is mostly armored and heavily developed, and subsidence rates vary between -0.43 and -0.59 mm per year.[143]

Galveston is an example of an area that might benefit most from hybrid infrastructure. It is developed and has an economy driven by tourism, and it is vulnerable to erosion and land subsidence. Galveston's needs protection from erosion in a way that also is not an eyesore for tourists. Hybrid infrastructure, which uses armoring in conjunction with natural materials, may be the best option. The combination of green and grey infrastructure may best balance Galveston's draw to tourists with protection against erosion and storm surges.

C. Anahuac

Anahuac is a small, rural town situated between Lake Anahuac and Trinity Bay at the northeast of Galveston Bay. It is a small, lightly developed town located in Chambers County with a population of approximately 2,000 people as of the 2010 census. Its infrastructure is mostly houses, and Main St. runs north to south through the study site with several roads joining it from the east, northeast and west. Because it has a very small population and very little infrastructure beyond private homes, this is an area that may prioritize the protection of coastal ecosystems. However, its shoreline has been armored in places to protect peoples' private property. Its remaining natural shoreline consists of marshes, beaches, and some bluffs to the south. Subsidence rates are around -3 mm per year.[144]

Because it is a rural area with very little to no infrastructure of national importance, Anahuac may be an excellent choice to install green infrastructure to protect the natural shoreline. Since coastal habitats such as marshes attenuate floodwaters, keeping Anahuac's shorelines natural may give floodwaters somewhere to go besides into more developed lands. Other ecosystem services could be enhanced through the installation of green infrastructure such as seagrass beds as habitat for juvenile fish. This could benefit the region as a whole since fishing is a huge industry in Galveston Bay.

D. Surfside Beach

Surfside Beach is a small, low-lying town in southern Brazoria County. It has a permanent population of less than 1,000 people. Surfside's Gulf shoreline

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http://www.beg.utexas.edu/coastal/presentations_reports/WestBayfinalreport.pdf (last visited June 20, 2018).

[143] Subedee et al., *supra* note 29.

[144] *Id*.

average annual retreat rate is up to 15 feet per year.[145] The region's erosion is caused by both sea level rise and lack of sand, which is due to historical anthropogenic changes to the Brazos River and the dredging of Freeport Harbor Ship Channel.[146] Surfside's subsidence rates are between -3 and -3.2 mm per year.[147] Surfside borders the Gulf, which cannot legally be armored under TOBA. Because of coastal squeeze and erosion, Surfside beaches have very small dune systems, which increase the vulnerability of the area to SLR. Arguably, the best long-term solution is to retreat from the shoreline. However, Surfside's residents prefer beach renourishment and building bulkheads instead.

Surfside Beach's primary industry is tourism; accordingly, preservation of the beach system is paramount. Surfside is in need of immediate and extreme action to mitigate its erosional issues because anthropogenic perturbations have resulted in a nearly complete loss of incoming sediment.[148] Living shorelines cannot be used on beaches. Because of this, Surfside partakes in somewhat regular beach renourishment projects; two renourishment projects were completed between 2011 and 2014, and a third renourishment project in 2017.[149] This is probably the only way the shoreline can be forced to stay more or less in place.

An arguably better and certainly more sustainable long-term solution for Surfside, however, is to retreat from the rising Gulf. Surfside has already relocated structures that were seaward of the vegetation line, but further action appears to be required.[150] By retreating, Surfside would avoid spending millions continually on renourishment projects that quickly erode. A retreat would also increase the safety of the residents by moving them further inland away from the coastline, and insurance claims would certainly decrease due to a fewer number of structures in vulnerable shoreline locations. Although a retreat is typically an extremely unpopular response to SLR, it may be the best option for Surfside as it was for the neighborhood of Brownwood.

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[145] *Surfside Beach*, CONRAD BLUCHER INST., http://cbiweb.tamucc.edu/CHRGIS/Surfside-Beach/ (last visited June 20, 2018).
[146] Matthew Tresaugue, *Surfside Beach Losing Battle Against Erosion*, HOUSTON CHRON., July 18, 2009, http://www.chron.com/news/houston-texas/article/Surfside-Beach-losing-battle-against-erosion-1725314.php (last visited June 20, 2018).
[147] Subedee et al., *supra* note 29.
[148] Robert A. Morton, *Historical Shoreline Changes and Their Causes, Texas Gulf Coast*, 77-6 GEOLOGICAL CIRCULAR 351 (1977).
[149] *GLO Grants: Coastal/Oil Spill Prevention & Response*, TEX. GEN. LAND OFFICE, http://www.glo.texas.gov/coastal-grants/#search (last visited June 20, 2018).
[150] David Baron, *As Beaches Creep In, Ownership Disputes Erupt*, NPR, June 17, 2008, http://www.npr.org/2008/06/17/91586603/as-beaches-creep-in-ownership-disputes-erupt (last visited June 20, 2018).

The severe erosion is partly caused by government actions such as dredging and jetty building, but also by private property owners constructing bulkheads and leaving houses on the beach. Arguably, taxpayers should not be required to continually foot the bill for beach renourishment projects that benefit only those on the coast. In this case, private property owners must be required to move away from the retreating shoreline. This action will improve human safety and will enable public access to the beach. By initiating a retreat, Surfside could be a model for other municipalities in the region with erosional issues, such as Sargent, TX, as well as other communities with similar issues across the United States.

V. CONCLUSION

Sea level is rising, coastal counties are vulnerable, and their fate and the fate of wetland habitats such as marshes and beaches depend on the preparations made today. Due to its history of subsidence from groundwater and petrochemical extractions and its heavily populated coastal areas, Galveston Bay is at particular risk to SLR-induced hazards. As such, it is imperative that considerations are taken now to plan for these hazards and to take steps immediately to mitigate future threats. Reactive strategies ignore problems until a natural disaster strikes, requiring extreme measures to minimize human harm and suffering. A greater recognition of the complexity and far-reaching effects of resiliency strategies will be a first step in providing the necessary research to communities so that they can construct policies that target their individual priorities. Taking proactive actions can minimize human suffering and the associated costs of a reactive strategy. As Benjamin Franklin stated, "An ounce of prevention is worth a pound of cure." The four sites in this study are as examples for similar communities around Galveston Bay.

SLR will affect the world's coasts, but today's actions will directly affect how severe those impacts are. It is much easier socio-politically to be reactive instead of proactive, and even within proactive plans it is easier to focus on the immediate future rather than what may happen in the long-term. Unfortunately, waiting until the effects of SLR are more obvious will set Texas behind; the largest benefits of early action may not be seen for several generations.[151] Actions must occur immediately in order to best protect coastal areas, despite the uncertainty regarding how far and at what rate sea level will actually rise.

[151] Nicholls & Lowe, *supra* note 28.

Actions such as the installation of seawalls or the strengthening of dikes and levees have historically occurred after disasters such as Galveston's Hurricane of 1900 or Hurricane Katrina; taking action before disasters such as these would not only be less expensive but it would also save thousands of human lives. Proactive action has the greatest benefit when it is executed sooner; society can either invest in protective and adaptive measures immediately, or it can wait until natural disasters, such as hurricanes and floods, require a much greater investment in the future.

Community values and priorities will determine which response strategies are most appropriate for each jurisdiction. The future of wetlands is linked intrinsically to socio-economic conditions, policy decisions, perceptions about their value, and their future areal extent are directly affected by today's "complex economic and sociological decisions."[152] A paradigm that protects marshes and allows them the room to migrate upland can increase the resilience of coastal communities, preserve ecosystem services, and can cost less in the long-term.[153] This coupled with the long residence time of greenhouse gas emissions and the negative feedback loop that can occur from marsh degradation and released carbon means that the strategies made in the short-term can have huge consequences on the global climate and built and natural environments far into the future. Thus, it is important to find a sustainable solution that balances current needs with the needs of future generations.

The optimal protection strategy for a given problem is one that best balances social, economic, political, and ecologic factors. Therefore, the optimal solution for SLR protection in communities around Galveston Bay will vary because the priorities and values of the individual communities vary. Armoring may be best for areas such as Texas City, which has preexisting vital infrastructure while areas such as Galveston, which are still economically important, can be protected in some areas with armoring while other areas are left with a natural land/sea interface. Green infrastructure may be best for communities like Anahuac that are not very densely developed while communities such as Surfside Beach may best protect resources by migrating away from the rising seas.

This article explores current laws and legal issues relating to SLR in Texas, and it also offers a discussion of the benefits and drawbacks of each of the policies that could be implemented. It is important to emphasize that policies

[152] Matthew L. Kirwan & J. Patrick Megonigal, *Tidal Wetland Stability in the Face of Human Impacts and Sea-Level Rise*, 504 NATURE 53 (2013).
[153] PILKEY & YOUNG, *supra* note 131.

should focus upon the systems that sustain human activities rather than the human activities themselves, and the policies should be proactive instead of reactive.[154] Short-term actions must be coupled with long-term efforts at all government levels.[155]

Much work remains to be done on this subject. Most obviously, there is too much uncertainty as to how far sea level will actually rise, particularly in regard to the rate of polar ice sheet melt and under different emission and adaptation scenarios in various environments. More study and knowledge is needed on this front as well as on the long-term effects of policy options. The dispersal of this knowledge through outreach efforts and education is of supreme importance in getting the public to realize the dangers associated with SLR. Secondly, with the exception of the Netherlands, no state or country has planned beyond 2100. Since most effects of SLR will occur in the long-term with the potential of 12 m of SLR, studies should begin analyzing impacts over the next one thousand years.[156] Furthermore, different values will lead to the implementation of different strategies to combat SLR, so individual communities need to determine where their priorities in the coastal zone lie. Lastly, in order to identify potentially hazardous and/or threatened areas, it is necessary to predict areas of future population growth and those that are vulnerable to SLR and work to protect them from unwise development.[157]

[154] Higgins, *supra* note 86.
[155] G. Robbert Biesbroek et al., *The Mitigation–Adaptation Dichotomy and the Role of Spatial Planning*, 33 HABITAT INTERNATIONAL 230 (2009).
[156] Nicholls & Lowe, *supra* note 28.
[157] Caldwell & Segall, *supra* note 5.