Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?

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By Jim Titus

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The Potential Impacts of Climate Change on Transportation

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Introduction

A steady barrage of studies and news reports about global warming has ensured that virtually all transportation planners realize that the transportation sector of the U.S. economy is an important cause of increasing concentrations of greenhouse gases. Less attention has been paid, however, to the effects of global warming on transportation—and virtually no attention has been paid to the ways by which our transportation infrastructure may impair our ability to adapt to the consequences of global warming.

The focus on causes of global warming may be appropriate. The effects on climate of greenhouse gas emissions are not fully evident until roughly 50-100 years after they are released into the atmosphere, so it is generally understood that we have to reduce emissions now to mitigate the problem by 2050-2100.[1] Although the lead-time for roads and airports can be substantial, it is not 50-100 years; so why should a transportation planner worry about the consequences of global warming?

Several plausible answers come to mind: First, because we have been releasing greenhouse gases for over a hundred years, the effects of past emissions are becoming more and more evident. For example, the sea is already rising,[a] so transportation activities that are sensitive to small rises in sea level already have to deal with the consequences. Second, some aspects of our infrastructure have long enough lifetimes to justify a consideration of long-term environmental changes like sea level rise. Finally, and perhaps most important: Transportation routes can channel development patterns for centuries, and thus, the ability of coastal regions to adapt to climate change during the next century and beyond may be helped or hindered by the decisions that transportation officials make today.

The fact that climate change may affect the outcome of today's decisions does not, however, prove that those impacts are important enough to consider today. Ultimately, it's a question of magnitude. The data show that the transportation sector contributes about 27 percent of U.S. greenhouse gas emissions, [2] so DOT clearly needs to think about emissions. But no one has assessed the extent to which today's decisions leave our transportation infrastructure vulnerable to climate change.

This paper is part of a DOT process to motivate adaptation to climate change in the U.S. transportation sector. In this paper, I lay out the implications that seem important enough to think about, both as a first step toward a comprehensive assessment of how the transportation sector can adapt to sea level rise, and hopefully, to motivate some decision makers to recognize those cases where they need not await such an assessment before beginning to take appropriate measures.

[a] Global warming appears to be responsible for about 1 mm/yr of the current rate of sea level rise.

Some Background Facts

Other discussion papers and presentations explain what scientists know about the causes and effects of global warming, and projections of future sea level rise. To recap: Sea level is already rising along the U.S. coast; see Figure 1. IPCC estimates that global sea level will rise 9 to 88 cm during the 21st century.[3] Because of regional subsidence, the rise will be 15-25 cm greater in parts of the mid-Atlantic, and 5-15 cm greater elsewhere along the Atlantic Coast. Considering the effects both subsidence and greenhouse gases, sea level is most likely to rise by about 2 feet along most of the Atlantic Coast. There is a 1- percent chance of a 4-foot rise, and a 95% chance that the sea will rise more rapidly in the next century than in the last century.[4]

Rising sea level inundates low areas, erodes beaches and wetlands, increases flooding from storm surges and rainstorms, and enables saltwater to advance upstream. All of these

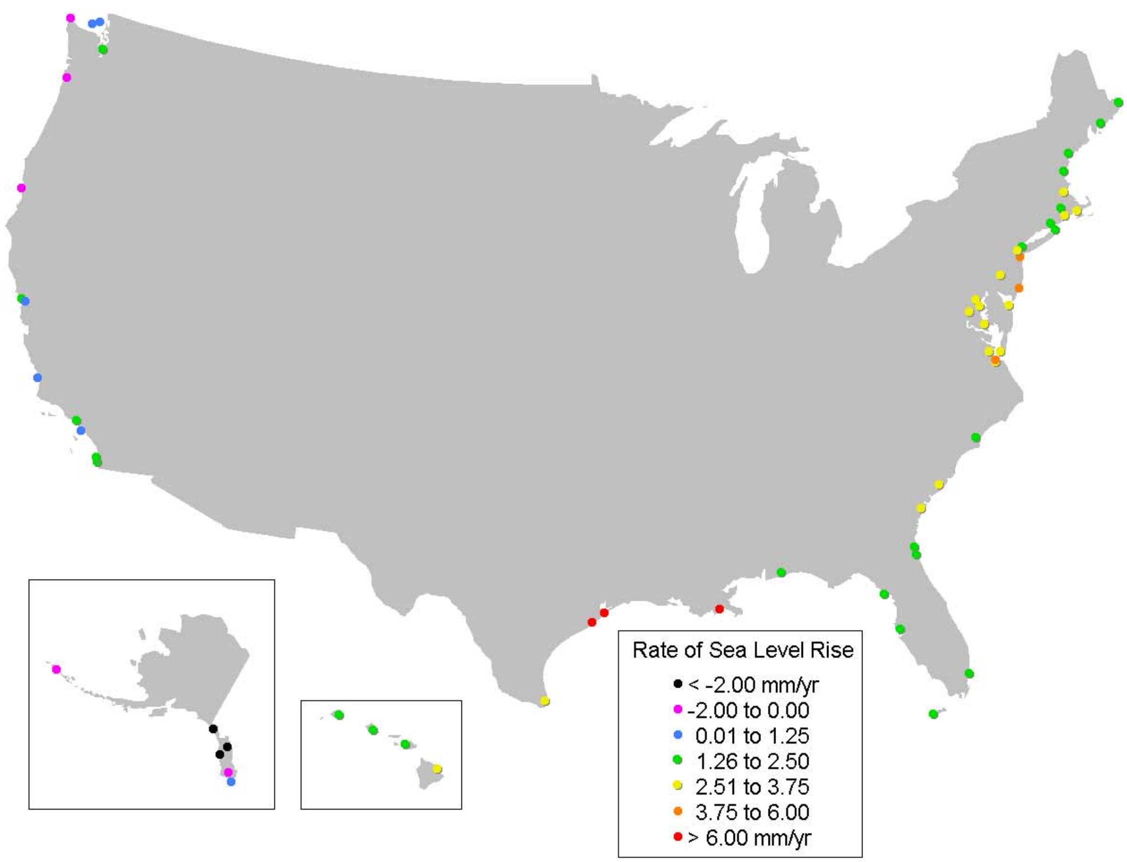

Figure 1. *Sea level trends along the U.S. coast, 1900-2000. This map shows all sites with at least 50 years of data. The greatest sea level rise is shown in Louisiana (at the Mississippi delta), in Texas (near Galveston), and along the mid-Atlantic coast. The estimates are based on a linear regression of sea level on time, using data collected by the National Ocean Service and provided to the Permanent Service for Mean Sea Level in the United Kingdom.*

effects can have impacts on transportation. Figure 2 shows the approximately 60,000 square kilometers of land along the U.S. Atlantic and Gulf Coasts that lies below the 5-ft (NGVD[b]) contour, which is roughly within 2-3 feet above the ebb and flow of the tides.[c] Louisiana, Florida, Texas, and North Carolina account for more than 80 percent of the lowest land. [5] Outside of those four states, the largest vulnerable populated region is the land along the Eastern Shore of Chesapeake Bay stretching from Dorchester County, Maryland to Accomac County, Virginia. Most of the U.S. Pacific Coast is on relatively high ground, although there are some low areas along San Francisco Bay. In addition to these lands, erosion can threaten relatively high ground within a few hundred feet of a tidal shore.

Global warming also increases flooding in the coastal zone. Storm surges from hurricanes and northeasters[d] will build upon a higher base, and hence reach farther inland. Moreover, higher sea level slows the rate at which areas drain, so rainstorms will also tend to cause greater flooding in coastal areas. Furthermore, because a warmer atmosphere can hold more water vapor, rainstorms are getting more intense, which may further increase flooding. In addition to flooding and lands loss, sea level rise enables saltwater to advance farther upstream. [e]

The actual effect of sea level rise depends on what people do in response to the direct physical responses. There are three fundamental response pathways: hold back the sea with dikes and other structures; hold back the sea by elevating the land surfaces and other structures, and allow nature to take its course and accommodate as necessary. As a general proposition, holding back the sea with dikes and other structures results in a large-scale elimination of wetlands, beaches, mudflats, and other coastal habitat; but the environmental consequences may be minor in areas where this habitat has already been destroyed. Elevating land surfaces maintains the status quo and generally preserves the narrow fringing wetlands and beaches; whether there is a large-scale loss of vegetated wetlands depends on whether the effort to elevated land surfaces extends to those areas. Retreat usually has the least environmental impact, because human activities are not squeezing intertidal ecosystems between the rising water and the coastal development;[f] but it can have the greatest impact on communities whose residents have to move. As we discuss below, transportation considerations may often affect which path society takes in its response to rising sea level.

Direct Effects of Sea Level Rise on Transportation

Navigation

Sea level rise makes water deeper, which enables deeper draft vessels to navigate a particular channel. This effect, however, is fairly small compared with the draft of most vessels. Saltwater advancing upstream can alter the point at which flocculation leads to sedimentation and the creation of shoals. Similarly, the clearance under bridges decreases. In a few cases where clearances are extremely tight, this effect could limit the ability of boats to pass underneath a bridge, particularly in the case of very small boats slowly passing underneath very small bridges, where the clearance may be less than a foot. Larger vessels are less likely to be impeded, because most bridges over key shipping lanes are either drawbridges or have very high spans. (A few low bridges have been deliberately located to

[b] The National Geodetic Vertical Datum of 1929 is used as the reference elevation for most topographic maps, although it is gradually being replaced. Along the East Coast, mean ocean sea level is about 8 inches above NGVD, largely because of sea level rise since 1929. Back barrier bays tend to have a mean tide level of about 1 ft. NGVD.

[c] The ocean tide range tends to be about 5-6 feet; in the estuaries along barrier islands the range is much less, while some harbors have much greater tide ranges. The surge from a 100 year storm is close to 20 feet in parts of Florida, but more on the order of 8-10 feet in the Mid-Atlantic and 5 feet in many estuaries.

[d] A number of reports on the EPA Sea Level Rise Reports web page examine the issue of increased flooding and saltwater intrusion. Go to www.epa.gov/globalwarming/sealevelrise .

[e] A number of reports on the EPA Sea Level Rise Reports web page examine the issue of increased flooding and saltwater intrusion. Go to www.epa.gov/globalwarming/sealevelrise .

[f] A number of reports on the EPA Sea Level Rise Reports web page provide estimates of the impact of holding back the sea on wetlands and beaches.

Figure 2. *Map of lands close to sea level along the U.S. Atlantic and Gulf Coasts. Although the results nominally are in meters, the 1.5 meter contour is primarily based on the 5-ft NGVD contour from USGS topographic maps. Source: Titus and Richman (2001).*[6]

prevent large ships from passing farther upstream.[g])

Port facilities are on the water's edge, and therefore potentially vulnerable to sea level rise. Docks, jetties, and other facilities are deliberately set at an optimal elevation relative to the water level and therefore a rise in sea level leaves them at a suboptimal elevation. However, these facilities tend to be rebuilt relatively frequently compared with the time it takes for a substantial rise in sea level.[7]

Sea level rise can also have important indirect effects on navigation, which we discuss below.

Aviation

Sea level rise is not likely to be a serious problem for a mode of transportation that is miles above the sea. Still, coastal cities such as Boston, New York, and Washington tend to have airports built along tidal waters, sometimes on filled areas. Therefore, their runways are

[g] An example of a low bridge that prevents large ships from proceeding farther upstream would be the bridges over the Mississippi River in Baton Rouge.

vulnerable to flooding. A dike already protects New York's LaGuardia airport, but other airports might experience increased flooding as the sea rises, or have to take protective measures.[8] Changes in storms could also affect airports—but no one knows the direction of the likely change.

Rail and Tunnels

Railroads often cut across marsh areas in the coastal zone. In the case of some smaller short-line railroads, tracks are so low that they are often flooded, and the beds may be vulnerable to sinking from compaction of marsh peat. Thus, as the sea rises, some tracks will be more vulnerable to flooding.

Tunnels may also become more vulnerable, both because the risk of their entrances and vents flooding will be greater, and because the hydraulic pressure on the tunnel walls increases as water tables rise.

The New York Metro Area rail and subway system appears to be particularly vulnerable. A number of East Coast railroads have been in their current locations for 150 years, during which time the sea has risen 1.5-2 feet. Many tracks, signals, and stations are low enough to be flooded during severe storms. Many subway entrances are in the 100-year floodplain, and are occasionally flooded by northeasters.[9]

Roads

The most important impact of sea level rise on transportation concerns roads. In many low-lying communities, roads are lower than the surrounding lands, so that land can drain into the streets. As a result, the streets are the first to flood. In some barrier island communities, the lowest bayside streets are already flooded during spring high tides. As the sea rises, this flooding will become more and more frequent. Most roads are not flooded by the tides, and have some type of drainage system to convey water away during rainstorms. As sea level rises, these drainage systems become less effective, causing more flooding—and increased rainfall intensity will further increase the severity and frequency of flooding there.

Whether street flooding is a serious problem or a minor nuisance depends on a variety of factors. In recreational areas during the summer, a flooded street is often a source of entertainment for people who came to that community to be on the water.[10,h] During cold weather or severe storms, however, some of these roads may be critical evacuation routes. Increased flooding increases evacuation times, which either increases the risk to life or requires emergency officials to require evacuation sooner, including for storms where it later becomes evident that evacuation was unnecessary.

Some roads are threatened by erosion. In some cases, the loss of a road parallel to the shore may remove the only road access to a particular area.

Transportation Adaptive Responses to Sea Level Rise

When one attempts to describe the impact of sea level rise on transportation without describing the adaptive response, one is generally implicitly assuming that the community does nothing about sea level rise, that is, that it is simply allowing nature to take its course. But that is only one of many possible options, and in developed areas where most transportation occurs, it is probably the least likely option. That does not mean, however, that sea level rise has no impact on transportation—but it is very different than the impact from passively allowing the situation to deteriorate. Moreover, transportation considerations may often play an

[h] See *Bergen Record, "*Rise in sea level likely to increase N.J. floods," Wednesday, September 04, 2002 (by Alex Nussbaum). "Two days a month… Barnegat Bay creeps over the sea wall at the end of 28th Street in Ship Bottom… Like clockwork, water backs up through storm drains and trickles down the dead-end street that runs between a half-dozen summer homes. Local kids grab their inner tubes and float down the block. Carried by the tide, a few confused crabs wander the pavement. Some days, it's a full-fledged creek. Others, it's merely a puddle around the storm grates…. Laurence Delorme said he has to tie his garbage cans down to keep them from floating off during these tides. 'It gives me beachfront property twice a month,' jokes Delorme, 33. 'The kids splash in it.'"

important role in the actual response to sea level rise. Let us consider the three fundamental pathways, in turn.

Elevate Land and Structures

Roads

Many developed barrier islands and other low lying communities will probably respond to sea level rise by bringing in fill to elevate the land.[i] If the streets are elevated by the amount that the sea rises, flooding will be the same as it is today. In some cases, this may be less expensive than keeping streets at the current elevation. When streets are repaved, it is often necessary to remove the old pavement down to the roadbed, and haul away that material. Simply repaving on top of the existing road saves a step, at least for slow residential streets. On the other hand, high-speed roads may require additional fill and reconstruction of the roadbed.

An important advantage of simply elevating the land is that the location of the roads do not have to be changed. Moreover, many types of drainage systems will continue to work properly, because the head gradient between street level and the sea remains the same. An important exception may be the underground runoff storage systems found in some communities, such as Atlantic City. Those tanks are currently above sea level and hence can gravity drain; if the sea rises and the tanks are below sea level, they would need to be retrofitted with check valves, and perhaps even pumps. Eventually, of course, a higher street would allow for higher tanks; but elevating the streets may be advisable as a near-term measure, whereas reconstruction of the tanks may not be necessary for many decades.

Another advantage of elevating lands is that transportation planners do not have to anticipate long-term sea level rise; they simply need to keep up with the rise as it occurs. When roads become flooded, they can be elevated; but it is probably not necessary to design most roads for future conditions because roads can generally be repaved to a higher elevation as flooding gets worse, as part of the ordinary program of repaving. And there may be problems from making a street too high relative to the surrounding lands.

However, some advance notice may be necessary in those communities that rely on the streets to drain the land. For example, Ocean City, Maryland requires lots to have at least a 2 percent grade so that all property can drain into the street, to prevent standing water and the resulting breeding habitat for mosquitoes. If the town elevated the streets a foot, some streets would drain into people's yards, which would essentially contravene the town's policy. Therefore, as the sea rises, the town tolerates increased flooding in the few streets that are low enough to frequently flood. For all practical purposes, the lowest lot on the block dictates the street elevations for all. Therefore, the town may have to give people some notice that in the future they need to elevate their lots—eventually, low lots can not be a reason to not elevate the street; instead, an elevated street must trigger the requirement to elevate the lot.

The situation in Ship Bottom, Long Beach Island, New Jersey also illustrates the need to look into the future. One of the key thoroughfares is flooded by spring tides as long as there has been at least modest rainfall and hence inflow into the estuaries. The county spent tens of thousands of dollars to retrofit a street drain with a check valve, which prevents the street drain from backing up into the street (unlike numerous side streets to the south). However, during several months of the year, spring tide (about 1.5 feet above mean tide level) overtops the surrounding land and floods the streets anyway (see Figure 3). Confused crabs are often seen walking down the street as the tide recedes. Elevating the street will eventually be necessary—forcing the homeowners to

[i] Eight New Jersey towns on barrier islands have signed agreements with EPA pledging to prepare for the consequences of rising sea level. All of those agreements stated that the particular towns find the dike and retreat options as unacceptable, and hence the communities' only viable option is to gradually elevate land and structures. For an analysis of Long Beach Island, see "Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey", *Coastal Management*, 18:65-90 (1990).

Figure 3. *Photo of flooded street in Ship Bottom, New Jersey. This area tends to be flooded during spring high tides except for drought years, when nearby Barnegat Bay is lower than usual. The author took this photo on Labor Day 2002 during a neap tide with a northeaster whose 25kt winds from the East had elevated the ocean levels by approximately one foot.*

elevate their yards or be flooded by rainwater. Local governments must ask themselves whether retrofitting a drainage system with a checkvalve is a wise use of limited funds if the rising sea will require the street to be elevated anyway; by contrast, the checkvalve is almost certainly a useful first step in an area that must eventually be diked.

Of course, if areas are going to be elevated, then the roads may have to accommodate increased dump truck traffic.

Air, Rail, Shipping, Tunnels

Just as roads can be elevated, so can runways and railroad beds. New bridges and tunnels can be built higher than would otherwise be the case. For example, recognizing the logic of anticipating sea level rise, the designers of the new causeway to Prince Edward Island made it one meter higher than it would otherwise have been. But existing structures will remain at current elevations. Therefore, even communities that are elevated may have increased seepage into tunnels and reduced clearance under bridges.

Navigation in tidal waters will be automatically elevated by the amount of sea level rise, but one has a choice with canals. If water levels are elevated by the amount of sea level rise, canal drainage will remain the same, although bridge clearance will reduce.

Protect with Dikes

If a community will be protected with a dike, the roadways do not need to be elevated, but otherwise, planners have a great deal more to be concerned about, because the response cannot be purely incremental as with elevating the land surface. If a dike will eventually be constructed, it's important to make sure that there is a road parallel to the shore fairly close to the shore, preferably seaward of all construction. Such a road could be the location of the eventual dike system, which may include not only a dike but also a drainage canal and road for dike construction and maintenance. Without such a roadway, the public authority will have to purchase shorefront lands for the dike, and perhaps demolish waterfront homes.

Once land is protected by a dike, the problem of street flooding from tidal and storm surges will be abated. However, rainwater flooding can become worse because the barriers that keep the sea out also keep rainwater in. Even before the dike is built, road engineers need to consider its eventual construction. For example, street drains in some areas are only rebuilt about every 100 years. If a dike is likely to be built in the next 100 years with streets kept at current elevations, the eventuality of check valves, pumping stations, and increased underground storage may imply a different optimal configuration for the drain pipes, especially if a large number of outfalls would be replaced by a smaller number of pumping stations, or if the pumping stations would be located somewhere different from existing outfalls. Because the best way to rebuild a drainage system depends on whether the land will be elevated or protected by dikes, municipal engineering departments need to know whether—and preferably when—the city will elevate the land surfaces or protect with dikes.

Ideally, the leaders of a community will decide with appropriate input whether—and how—to hold back the sea and transportation planners can act accordingly. Because most communities have not yet made those decisions, however, the decisionmaking may flow in the opposite direction: Road planners do what they do, with or without a consideration of sea level rise, and decades later the status quo that the transportation infrastructure created will be a primary determinant of the community's ultimate decision. Even if the retreat option is preferred, the existence of an important road along—and close to—the shore may make holding back the sea the only realistic option. Even if a dike would have been less expensive than elevating the land, the absence of a shore-parallel road may make land acquisition costs too costly or politically impossible. Therefore, if a community does not have a long-term sea level rise plan, anyone planning infrastructure with a long lifetime becomes—by default—the sea level rise planner who must either make an assumption about whether and how the sea will be held back, or ignore the situation and design the system as if the sea was not rising.

Highway reconstruction may also dictate responses to sea level rise if there is no plan. As the sea rises, roads through undeveloped low areas tend to become dikes unless there is an explicit decision to convert it to a causeway. The roadway may have been originally elevated to prevent flooding; but as the sea rises and shores retreat, tidal waters reach the road—and the road blocks the flow of water, acting as a dike. Later, communities may build upon this initial de facto dike and create a complete dike system. Alternatively, the road authority may install culverts under the roadway, or make occasional breaks in the dike with bridges, to allow water to flow around the road, essentially converting the road to a causeway.

Air, Rail, and Tunnels

Dikes can reduce the effective length of a runway. Assuming a typical descent angle of 3 degrees and that the runway stretches all the way to the dike, a one foot rise in sea level effectively shortens the runway by 20 feet. This is not too serious for a typical 10,000-foot runway.

Dikes along with effective pumping systems can largely solve the existing and projected vulnerability of low-lying railroads within the urban areas that are protected. Increased hydraulic head may be a problem for tunnels in areas where the water table continues to rise with the sea; but an effective drainage system would keep the water table from rising.

How Inclusive is the Dike?

Perhaps the most serious problem with the dike option is the fact that because it is not incremental, one must decide which areas are within the dikes and which areas are outside of the dikes, and such decisions may be continually revisited. New highways might logically avoid low areas that are not going to be protected with dikes. But that may be a moving target.

A key question regarding dikes is whether to dike the coast as it is today, or to follow the Dutch approach of shortening the coast. The basic idea behind shortening the coast is that it may be safer and much less expensive to build a large dike across the mouth of a bay, than to build smaller dikes along all the shores of the bay and its tidal rivers and creeks. Because existing ports would now be inside the dike, either ships would have to pass through locks, or new deepwater ports would be built outside the dike. Such an approach seems unlikely in the United States, both because of the environmental consequences and our nation's general preference for small, uncoordinated infrastructure projects over large, coordinated efforts.

Nevertheless, the basic principal of coast shortening will probably be applied in a number of areas. First, in areas with finger canals for recreational boaters, it would be impractical to dike all shores. Dikes around the entire communities with locks at the main stem of the canal would be more feasible, assuming that the communities are not elevated with fill. Second, storm surge barriers such as the Thames River Barrier have the effect of shortening the coastline during storm surges, but they generally stay open and hence need not interfere with navigation. Finally, large-scale water projects have some similarities with coast-shortening dikes. In the Everglades and Dismal Swamps, one must choose between elevating the canal waters by the amount of sea level rise, or keeping canals at current elevations.

The sea will rise for the foreseeable future—perhaps even more rapidly during future centuries than the 21st century. In theory, we might elevate low lands forever as the sea rises. Holding back the sea, however, may become progressively more difficult. At first, tide gates and check valves allow water to drain at low tide; later, communities would need pumps. As the sea continues to rise, a community would have to pump more and more water due to greater infiltration, and the water would have to be pumped to higher locations. The dikes would probably have to be elevated by more than the sea level rise, because the impact of a dike failure would be far greater if the sea was 10 feet above Main Street than if it was only 2 feet above the town. This concern may be an issue for Louisiana, where the eroding shores are bringing the Gulf of Mexico closer every year to New Orleans, which is already below sea level. But for the Atlantic Coast, these are issues for future generations.

Retreat and Accommodation

Just as a dike can avert many impacts of sea level rise on transportation, so a retreat strategy can be very similar to the direct effect of ignoring the issue and addressing the consequences. In some areas that are destined to be abandoned[j], it may not make sense to make additional investments in transportation so as to prevent the consequences of sea level rise. Some of the roads to Delaware Bay in Cumberland County, New Jersey, are very rough, and there is little reason to fix them because much of the coastal zone of that county is being returned to nature. Roads along the

[j] Several communities have used EPA funding to develop maps illustrating which areas will be protected and which will be abandoned.

retreating shores of the undeveloped Outer Banks are washed out during storms and rebuilt inland; roads along developed areas are also washed out in storms, but rebuilt and maintained—and given minimal protection such as a few dump truck loads of sand to act as a sacrificial dune for the next moderate storm.

Although lightly developed areas may retreat without advance planning, a retreat policy requires a substantial degree of planning in more densely developed areas. With no dikes planned and the land surfaces not being elevated, street flooding gets worse and worse; but that flooding can be mitigated by increasing the size of ditches and other maintenance that is probably worthwhile even in an area that will be given up to the sea. Ironically, it may be particularly important to elevate highways as evacuation routes, because such areas will become more and more vulnerable, and will probably remain inhabited until a catastrophic storm destroys most structures.

Just as shore-parallel roads are important for areas that will be diked, areas that will retreat need roads that are not shore-parallel. If someone's only access is a shore-parallel road, then as soon as one part of the road is washed out, she loses access even if her property is a long way from being lost. Put another way, shore-parallel roads tend to thwart a retreat policy, even if it would otherwise be desirable.

Although a retreating ocean shore requires oceanfront roads to be abandoned or relocated inland, the submergence of lands along an estuary does not necessarily mean the road will be abandoned. As an extreme example, consider US-64 and US-264, which connect the Outer Banks to the population centers of North Carolina. As Figure 4 shows, a large portion of the Albemarle-Pamlico Peninsula is low enough to be submerged with a significant rise in sea level. But the Outer Banks will continue to be viable and popular beach resorts, as far as we know, and less vulnerable to complete inundation than the peninsula. Therefore, those coastal planners who have thought about the issue expect that a small number of communities on the peninsula will be protected, the Outer Banks will survive, and people will continue to drive there. Figure 5 illustrates the thinking of these planners, which implies that US-64 and 264 will become a combination of causeway-style bridges, filled causeways, and isthmuses with the highway and some development on either side, connecting the various small towns with the mainland, each other, and the Outer Banks. This map is just one possibility: perhaps one of the highways will instead determine the location of a dike. But currently, retreat is taking place and there is a universal consensus in the state that US 64 and 264 will continue to exist. Many developed barrier islands are connected to the mainland with roads that pass through low-lying marsh that may become open water in the future.

The retreat policy will have only minor impacts on navigation on the East Coast, which fortunately does not have the problems facing Louisiana, where solving land loss will probably require a reconfiguration of shipping lanes. To be sure, retreating barrier islands are difficult to reconcile with inlet stabilization projects, both politically and geologically. Hence Oregon Inlet, along North Carolina's retreating Outer Banks, still has not been stabilized. In most cases, however, the areas where the inlets have a lot of boat traffic have populated barrier islands where retreat is unlikely; while retreating barrier islands are found in areas with relatively little boat traffic.

Figure 6 shows these various options being put into effect in North Carolina. Figures 6a and 6b demonstrates retreat and accommodation in Kitty Hawk and Elizabeth City. Figure 6c shows a dike-protected community, while Figure 6d pictures homes being elevated.

Assessment Options

This cursory examination shows that sea level rise can have important impacts on roads, and that how we plan our roads can have an important impact on how coastal communities deal with sea level rise. The serious impacts of sea level rise on shipping appear to be limited to Louisiana, where a multiagency process is already underway to develop a long-term plan of

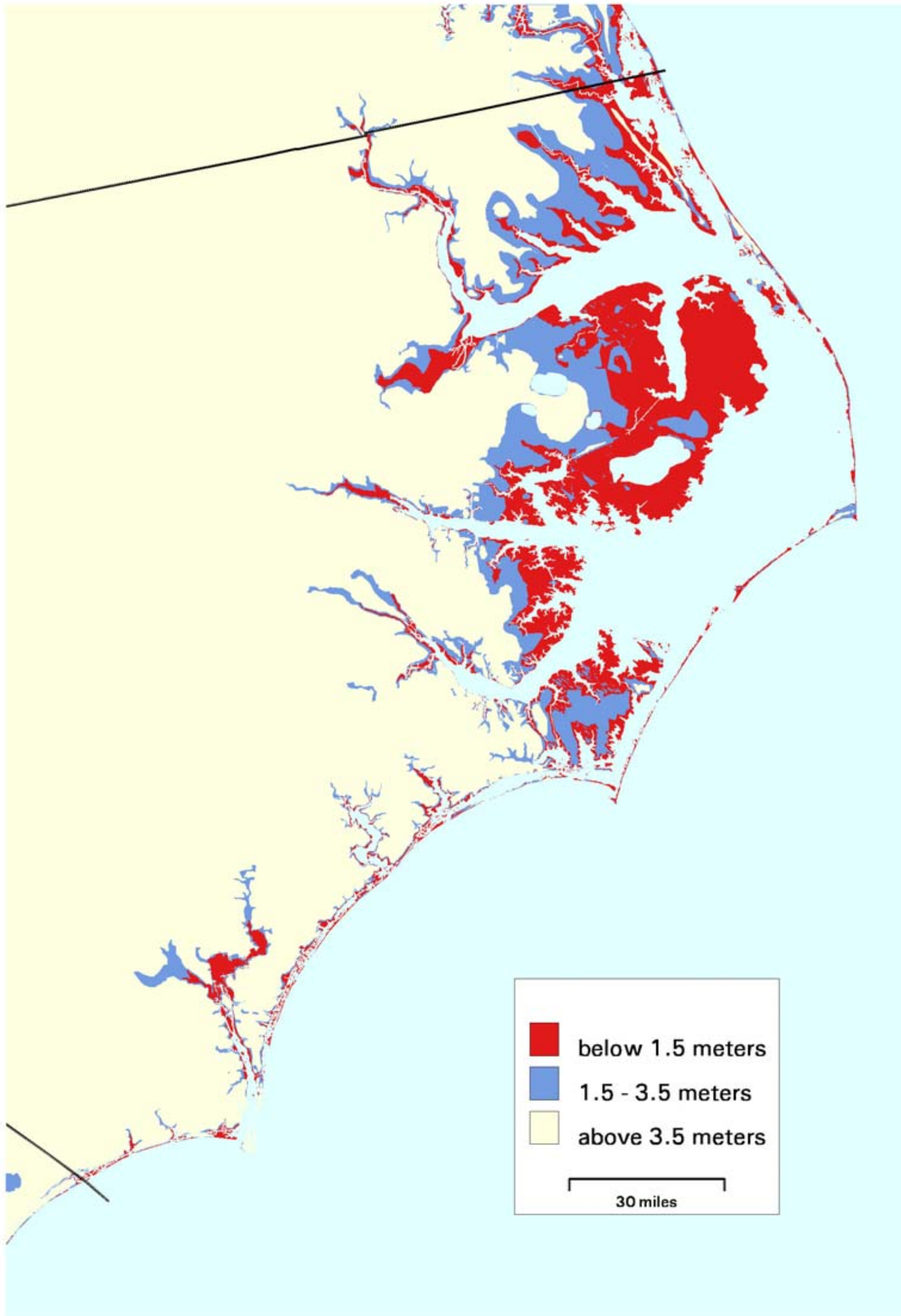

Figure 4. *Map of lands close to sea level in North Carolina. Source: Titus and Richman. (2001).*

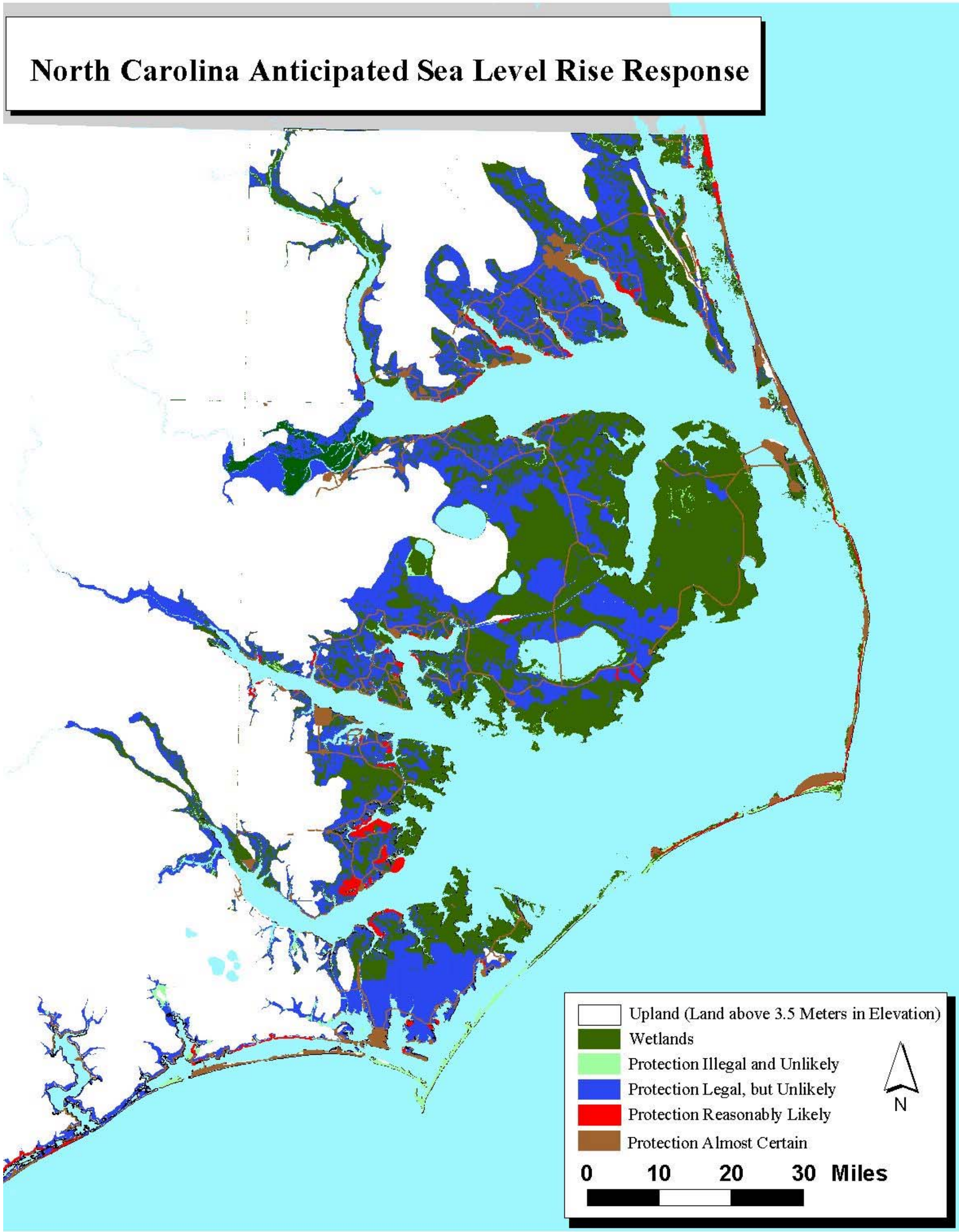

Figure 5. *Draft maps illustrating the areas where North Carolina state coastal planners expect people to hold back the sea. Areas depicted in brown are almost certain to be protected with beach nourishment, fill, or some form of structure. Areas in blue represent privately owned land that the state planners do not expect to be protected. Areas in red represent land that probably will be protected, but where protection is less likely than the areas in brown. For example, along the barrier islands north of Corolla, the Coastal Barrier Resources Act prohibits federal assistance. Although property values may be sufficient to justify beach nourishment to hold back the sea, the absence of federal funding makes such projects less likely than in similar areas that are eligible for federal funding. These maps are being revised to reflect the local expertise of county governments, who generally expect more areas to be protected. Source: Walter Clark, North Carolina Seagrant. See http://plan.risingsea.net/North_Carolina.html*

(a)

(b)

(c)

(d)

Figure 6. *Photos of four ways to respond to sea level rise in North Carolina. (a) Retreat along the Southern portion of Kitty Hawk: houses on stilts being abandoned to the sea; (b) Accommodating the higher water levels in Elizabeth City: a house on stilts is still occupied in this inlet; (c) A dike protects the Gum Neck agricultural community in Tyrrill County; and (d) Every home in sight is being elevated along this road in Carteret County. All photos taken the week of Columbus Day, 2002.*

action. The implications for railroads and airports seem to be more limited, but potentially very amenable to long-term planning for sea level rise because of the relatively small number of decisionmakers, compared with roads.

Unfortunately, the impacts of sea level rise on transportation have not been quantified. Some types of guidance probably do not need quantitative assessments to prove meritorious; but a complete absence of quantitative evidence makes it difficult to be sure that the impacts of sea level rise on transportation are serious at a national scale. Therefore, an obvious next step would be to conduct a few relatively targeted assessments just to quantify the scope of the problem, including:

1. A GIS assessment to quantify roadmiles, miles traveled, railroad miles, and railfreight under various definitions of vulnerable area (e.g., within one meter above the ebb and flow of the tides, within one meter of the 10-year flood, within the area that might either be inundated or eroded as the sea rises).

2. Overlay through areas within 1-meter above the ebb and flow of the tides (or where that form of elevation data does not yet exist, below the 5 and 10-ft contour) and the coastal floodplain.

3. Overlay areas where planners expect people to hold back the sea, and areas that planners expect to be abandoned.

4. Identify the roads in the coastal zone that are currently flooded by tides.

5. Initiate a stakeholder outreach program with coastal highway departments to determine what kind of help they need from DOT to factor sea level rise into their planning.

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[1] Intergovernmental Panel on Climate Change. 2001. "Climate Change 2001: The Scientific Basis". Cambridge and New York: Cambridge University Press.

[2] U.S. Environmental Protection Agency. 2002. *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. Washington, D.C. U.S. Environmental Protection Agency:. EPA 430-R-02-003

[3] Intergovernmental Panel on Climate Change. 2001. "Climate Change 2001: The Scientific Basis". Cambridge and New York: Cambridge University Press.

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