

Chapter 6

Climate Change and Transportation in the Southeast USA

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Key Findings

All transportation systems in the Southeast (SE) United States are vulnerable to both direct and indirect effects of climate change. Direct impacts of climate change include the following:

- ▶ Sea level rise (SLR) damage to transportation infrastructure, including coastal roads, railways, airports, and ports
- ▶ High-temperature damage to infrastructure and vehicles
- ▶ Extreme storm damage to infrastructure

There are engineering solutions available to adapt to most direct effects of climate change on transportation, but these solutions are often expensive. For example, modifications to roads to prevent damage by SLR are likely to cost \$2 million to \$3 million per lane-mile. This cost exceeds the range of typical road construction costs. Moreover, the engineering responses that might protect transportation infrastructure, may increase vulnerability of adjacent properties to flooding and other climate impacts.

6.1 Evaluation of Southeast Transportation Systems

Transportation networks in the SE USA are vulnerable to direct and indirect effects of severe weather events, which are likely to be affected by climate change, as well as by sea level rise, which is already affecting transportation systems in many coastal areas. The key to economic sustainability is the consistent ability of transportation systems and operations to provide mobility and access that is safe, reliable, and sustainable. The National Research Council (NRC 2009) recommended an evaluation of transportation and other infrastructure performance through five 21st century imperatives, challenges, or goals: (1) economic competitiveness; (2) global climate change; (3) energy supplies; (4) disaster resilience; and (5) environmental sustainability. The environmental sustainability challenge encompasses the full range of natural, built, and sociocultural environments and would, for example, consider ecosystem integrity, community health, environmental justice, and livable communities among other aspects. The United States Environmental Protection Agency (USEPA 2010) noted that there is no single definition of what constitutes a “sustainable” transportation system. However, according to the Transportation Research Board Sustainable Transportation Indicators Subcommittee (TRB 2008) a sustainable transport system does the following:

- “Allows the basic access and development needs of individuals, companies, and society to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations.
- Is affordable, operates fairly and efficiently, offers a choice of transport mode, and supports a competitive economy, as well as balanced regional development; and
- Limits air, water, and noise emissions, waste, and resource use. Limits emissions and waste within the planet’s ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable

resources at or below the rates of development of renewable substitutes, while minimizing the impact on the use of land and the generation of noise.”

Creating a sustainable transportation system will require a change in the current model of cooperative working relationships. The Transportation Research Board (TRB 2008) and NRC (2009) suggest that the institutional arrangements that delivered the 20th century transportation network are inadequate in the face of climate change and other weather-driven events. In part these groups suggest that because of the diversity among the institutions responsible for transportation, there is little incentive to address interconnectivity and vulnerabilities that may lead to failures in policy direction and cooperative infrastructure planning. To create leadership in this regard, the federal government created the Interagency Partnership for Sustainable Communities to reinforce the importance of environmental, economic, and social sustainability. In June 2009, the US Department of Housing and Urban Development (HUD), the US Department of Transportation (USDOT), and USEPA agreed to coordinate housing, transportation, and environmental policies and investments to increase transportation options, improve accessibility to jobs and other destinations, and lower the combined cost of housing and transportation while protecting the environment in communities nationwide (USEPA 2010). But the federal working relationships need to be relevant to local, state, and regional officials in order to address the needs of communities and geographic regions, including those of built and natural environments. It is at the local level where adjustments and adaptation strategies will need to be implemented.

An important component to a sustainable transportation is economic competitiveness. Unfortunately, there are few or no data on the value or value-added of goods shipped into, out of, or through the Southeast. In general, shipping costs range from \$2 per pound for air freight, \$0.1 per pound for truck, \$0.01 per pound for rail, and, \$0.005 per pound for water hauls (Lemp 2008). Norfolk Southern railroad plans to upgrade rail infrastructure between the port of Savannah and Atlanta, suggesting that there is an economic incentive to eliminate some of the more expensive short-haul trucking options (Sneider 2013).

6.2 Climate Change and Transportation Infrastructure

In keeping with the interrelationship between the built environment and its many constituents, Bloetscher (2012) developed a framework to evaluate the impacts of climate change on infrastructure and water resources and economic development. The framework was developed in multiple steps to be readily transferrable to most communities. The first step identified topography, economic drivers, and population, and compared these to likely climate change impacts, especially increased frequency of intense rainfall events, higher temperatures, and sea level rise. Figure 6.1 outlines a simplified flow chart used as a basis for that evaluation.

Topographic and LIDAR data were used for the terrestrial characteristics. The topographic, census, and economic activity data were evaluated to determine how climate changes would impact the population and economy. Economic development requires appropriate management of water, sewer, storm water, and transportation networks,

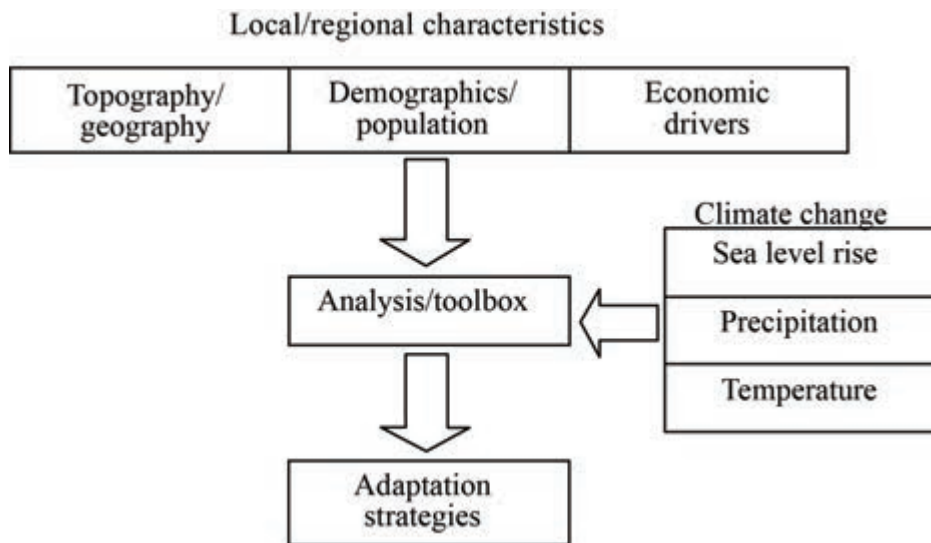


Figure 6.1 Analysis tool (Bloetscher 2012).

which immediately identifies water resource management as a key issue for climate adaptation using the toolbox approach developed by Florida Atlantic University (Heimlich et al 2009). Where water supplies are disrupted or unreliable, it is difficult to sustain long-term economy. Stormwater is the common linkage among all infrastructure.

Local and regional efforts are required to integrate current data sources to develop a methodology for assessing and mitigating the potential impacts of SLR and storm impacts on transportation infrastructure to assist transportation planning. The approach integrates the USDOT information systems with existing state and national topographical and geological data to facilitate (1) the evaluation of current and projected SLR impacts on coastline and low-lying terrain areas, (2) permit downscaling of statewide data bases to local jurisdictions, and (3) the identification of the physical transportation infrastructure most likely to be affected by a range of conditions from frequent flooding to continuous inundation due to SLR. A projection of SLR extent and the timing were outlined using a benchmark approach that brackets time intervals as opposed to specific timing for improvements (Heimlich et al. 2009—see Figure 6.2). Further research is required to evaluate the impact of sea level rise on localized ponding, groundwater levels, and storm surge, which are more difficult areas of investigation than the timing and extent projections (Bloetscher 2012).

6.3 Impacts of Climate Change on Transportation Systems

Transportation in the SE is directly affected by a suite of climate-related risks. Transportation infrastructure along the coastline and low-lying areas is vulnerable to SLR. Coastal bridges may be at risk to moving water from flood waters caused by storms. Access to roads to bridges and railroads also are at risk. In some regions, the geology permits significant migration of saltwater intrusion, thereby increasing the ease by which elevates groundwater levels are raised, causing damage to the transportation

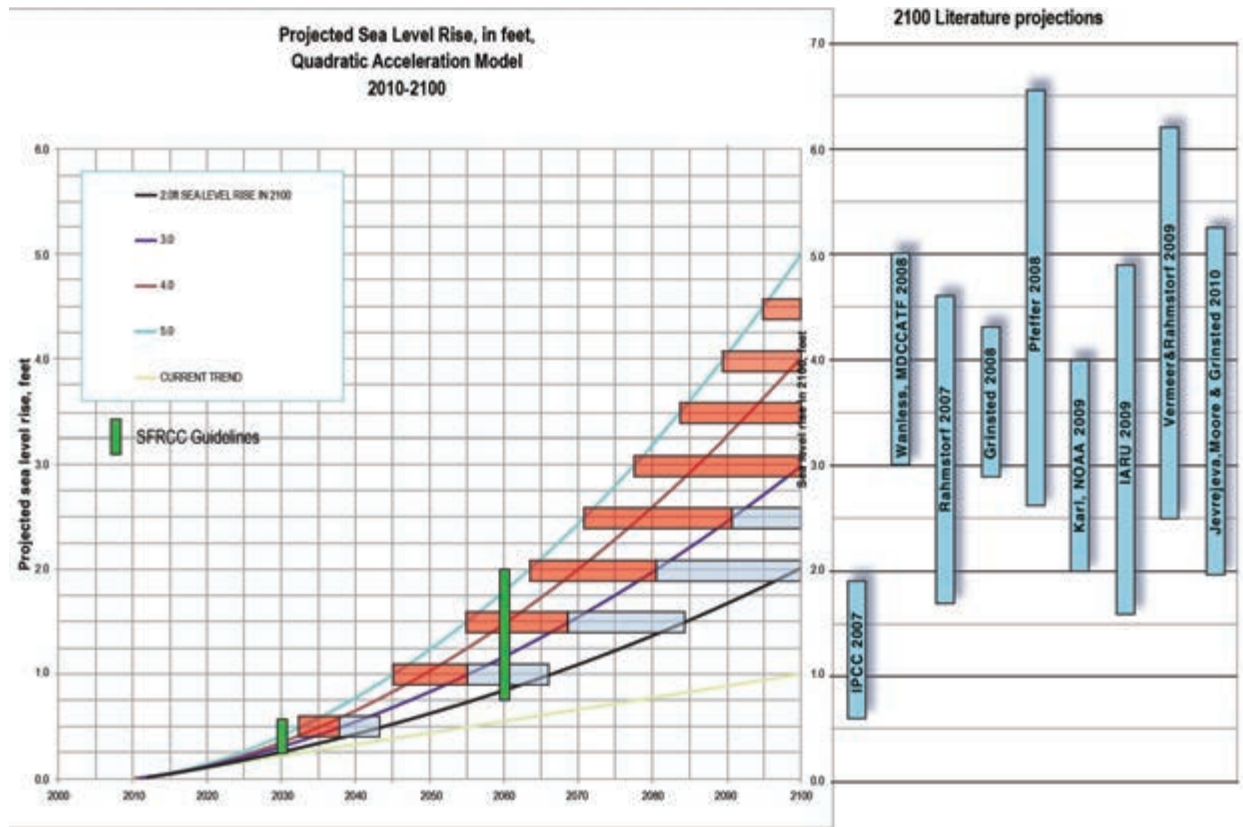


Figure 6.2 Prediction of Sea Level Rise, accounting for time and rise.

system structural base, which will ultimately lead to failure of the system. As sea level rises, groundwater will rise accordingly, which imperils a variety of infrastructure and transportation modes. In such cases, the effect of SLR might indirectly spread through the entire system affecting overall system performance. For example, the flooding of a critical road or facility access will shift traffic flow, in turn causing congestion on other roadways. Since the roadway network would be unable to carry the traffic demand, the system would experience operational failure, resulting in high travel times and delays and perhaps further shifts traffic to other nodes that become stressed. Moreover, the inundation of a critical access could cause transportation connectivity problems by blocking access to other areas.

Other effects of climate change, such as extreme heat events, can soften asphalt, cause concrete to rupture, and warp steel rails, requiring slow-downs and rerouting of certain types of transportation. Changes in hydrology can dramatically increase the consequences of highway runoff on ecosystems. Droughts and floods can directly interfere with inland waterway operations. Drought also can lead to wildfires that may create unsafe driving conditions. Snow and ice events potentially can create landslide and slope failures that create critical transportation bottlenecks. The following paragraphs outline the challenges facing each transportation sector in the Southeast.

Marine and Inland Ports. The SE supports an array of marine and inland shipping ports. Table 6.1 identifies those that rank highest in the USA in terms of tonnage transferred in 2010 and 2011. All are in low-lying coastal areas that are subject to inundation from both storm water and SLR. Three ports—New Orleans, LA, Norfolk, VA, and Mobile, AL—are in the top 10 areas that are most vulnerable to sea level rise, yet all are among the top 25 ports based on total volume of imports and exports.

Importers find economic advantage in marine ports that are physically linked to distribution centers, especially those with spur lines that provide reliable access to regional and national rail and highway transportation networks. Such ports that are linked to rail and highway networks are termed intermodal transportation hubs. Exporters find economic advantage at marine ports that are near production centers with significant intermodal transportation hubs.

While higher water levels are not a problem for ship traffic unless the ships must pass beneath bridges, SLR threatens the rail and highway components of intermodal transportation hubs. Thus, SLR could easily disrupt both import and export operations.

Changes in sea level are expected to have two general effects on ports. Sea level rise increases the depth of port, a positive benefit. However the altered hydrology and sea level are may increase sedimentation rates, which in turn affects operational costs and even the long-term sustainability of some marine ports. In addition, SLR has a cumulative effect on spring high tides and storm surge levels, increasing both. In most of the SE, it is reasonable to assume that countermeasures or hardening will be necessary to protect current infrastructure and maintain levels of service year round, but it may take up to 20 years to develop plans and construct improvements.

A nonclimate factor that will affect shipping routes is the widening of the Panama Canal to allow passage by wide-beamed ships, called “post-Panamax” ships. The Panama Canal is due to open for post-Panamax-sized ships soon, and these ships may have greater access to ports outside of the SE USA. Currently, only Norfolk can accommodate post-Panamax sized ships though several SE marine ports are in the process of expanding or planning to expand channel dimensions to accommodate post-Panamax ships. Expansion of the Panama Canal means wide-beamed ships that currently operate through the Suez Canal may be competitive in areas opened up by the Panama Canal expansion. The Port of Miami for example, is investing more than \$1.2 billion to dredge the port and install raised bumpers to harden the port against the effects of SLR and permit new Panamax Canal shipping, as well as adding 4.4 miles of railroad spur to the Florida East Coast Railroad (Sneider 2013). Port Everglades is gearing up to spend hundreds of millions to dredge and update their facilities as well. Failure to harden the coast and the ports will result in damage to port facilities. Vulnerability without adaptation to climate impacts may force port operations to relocate to more protected environments.

Warmer temperatures or more frequent drought could adversely affect agriculture and related shipments. Ongoing inundation or repetitive storm damage may encourage large growers to move to more protected areas, thereby shifting their use of marine ports to other regions. Shipping routes will also change. With warmer temperatures, Arctic sea ice is melting and the Northwest Passage is expected to be ice-free and open for marine shipping within decades, which may redirect some shipping traffic.

Table 6.1 Waterborne Foreign Trade Volume Rankings for SE Customs Districts in 2011.

Rank	Port	Satellites
1	Port of South Louisiana, LA	New Orleans, Baton Rouge, Plaquemines, Morgan City, Avondale
3	Lake Charles, LA	Beaumont, TX; Port Arthur, TX; Orange, TX
10	Norfolk, VA	Newport News
13	Tampa, FL	St Petersburg, Manatee
17	Mobile, AL	
19	Pascagoula, MS	Biloxi, Gulfport
21	Port Everglades, FL	Miami, Palm Beach, Fort Lauderdale
25	Jacksonville, FL	
28	Memphis, TN	
29	Savannah, GA	
30	Charleston, SC	
34	San Juan, PR	
38	Louisville, KY	
39	Wilmington, DE	
42	Vicksburg, MS	
43	Morehead City, NC	
44	Nashville, TN	
47	Chattanooga, TN	
48	Greenville, MS	
49	Guntersville, AL	
50	Brunswick, GA	
51	Richmond, VA	Hopewell
53	Hopewell, AR	
56	Ponce, PR	

Volume is reported as thousands of metric tons. Source AAPA 2012.

Waterways. Though not well studied, coastal waterways in the SE are vulnerable to hydraulic changes, sedimentation, sea level change, storm surge, and tropical storms. Severe drought could lower water levels to a point where boat traffic is not possible, but this is unlikely to pose a threat in the next 100 years. A more likely threat is that SLR will make it difficult for some ships to pass beneath bridges in tidally affected waterways.

Railroads. Because most railroads were constructed 100 or more years ago, much of the rail system in the USA has a level of built-in protection because early railroad builders

tended to construct railroads on high ground. As a result, railroads may be less subject to climate impacts than roadways and ports. Table 6.2 lists the Class 1 railroads and their locations in the SE USA, and Figure 6.3 shows the USA national network of railroads. Conversely, of great concern is that the railroads built 100-plus years ago did not anticipate the speed or weight of modern rail traffic. When combined with rising sea level or groundwater level, the risk of base saturation and deterioration increases. Figures 6.4 and 6.5 show the current and future railroad base conditions. Base failure and loosening of spikes holding down rails create long-term safety concerns. Although inland railroads are generally on higher ground than roadways, coastal railroads remain vulnerable to storm surge, damage from wind and inundated base conditions.

Table 6.2 Class 1 Freight Railroads in the Southeast USA.

Railroad	Status
Union Pacific	Louisiana; Arkansas
Norfolk Southern	Louisiana; Mississippi; Alabama; Georgia; Florida; Tennessee; Kentucky; South Carolina; North Carolina; Virginia
Kansas City Southern	Louisiana; Arkansas; Mississippi; Alabama
CSX	Louisiana; Mississippi; Alabama; Georgia; Florida; Tennessee; Kentucky; South Carolina; North Carolina; Virginia
Canadian National	Louisiana; Mississippi; Alabama; Tennessee
BSNF	Louisiana; Mississippi; Alabama; Arkansas; Tennessee

Airports. There are hundreds of airports in the SE USA, but only a handful that have significant freight and passenger traffic. Four airports--Atlanta at number one, Miami, Fort Lauderdale, and New Orleans--dominate foreign trade and passenger traffic in the Southeast. However, all airports are vulnerable to extreme weather events that delay or stop inbound and outbound flights. In addition, drought can adversely affect the workforce and certain manufacturing processes that drive airfreight.

Miami International Airport, with 17 million passengers annually, is 8 ft above sea level (Bureau of Transportation Statistics 2012). Fort Lauderdale/Hollywood International Airport, with 10 million passengers annually (projected to 32 million by 2030) is 5 ft above sea level and located in the coastal hazard zone. The Louis Armstrong Airport in New Orleans, with 4.07 million passengers in 2010, is 4 ft above sea level (Bureau of



Figure 6.3 Source: wikipedia.com, 2012.

Transportation Statistics). These three airports, as well as many other coastal airports, are in the process of expansion or are undergoing various stages of upgrades. Fort Lauderdale, for example, is actively constructing a runway project that will be 65 ft above sea level, (North American Vertical Datum 1988[NAVD88]). Like railroads, the runways are on higher ground than surrounding areas, but long-term base failure due to rising groundwater is a potential failure point (Figures 6.6 and 6.7). Ongoing expansions have kept the runways high and dry, but the access roads to get to the airports may be compromised (Figure 6.8), which may lead to airports becoming isolated from intermodal transportation links. Most smaller airports in the SE are owned by local governments, which may limit resources for maintenance and adaptation to climate change effects, including sea level rise.

Roadways. By far the greatest transportation infrastructure system in the USA is roadways. The network of highways and roads in the SE USA is owned by state and local transportation agencies. Five times more freight is driven over roads than railroads.

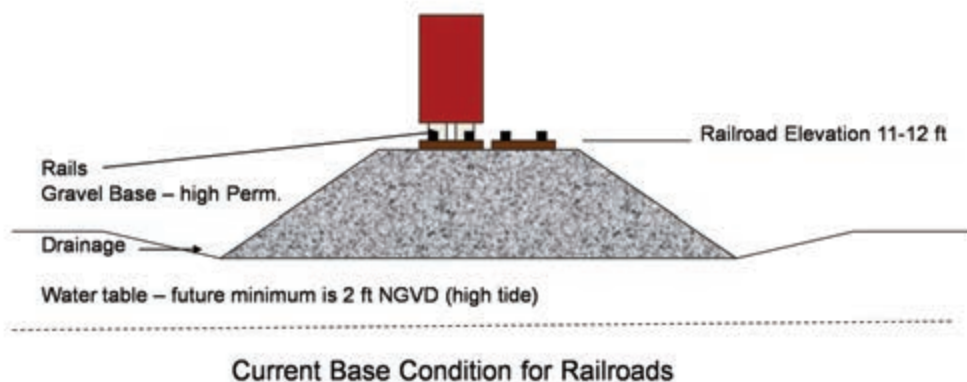


Figure 6.4 Cross sectional diagram showing the current base condition for railroads relative to the water table.

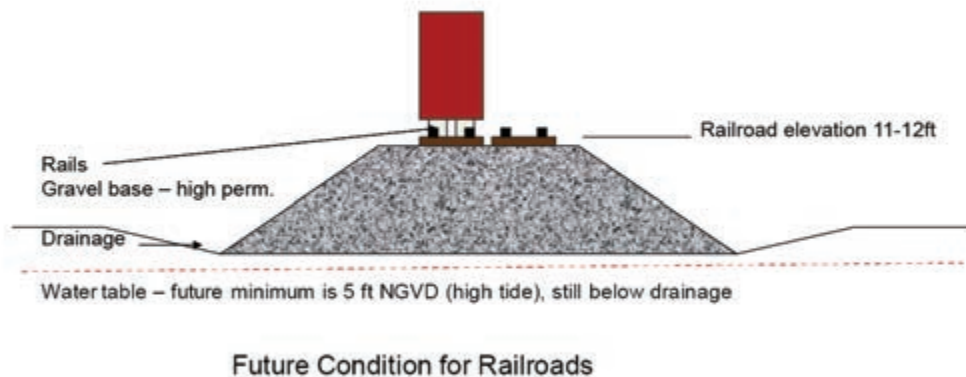
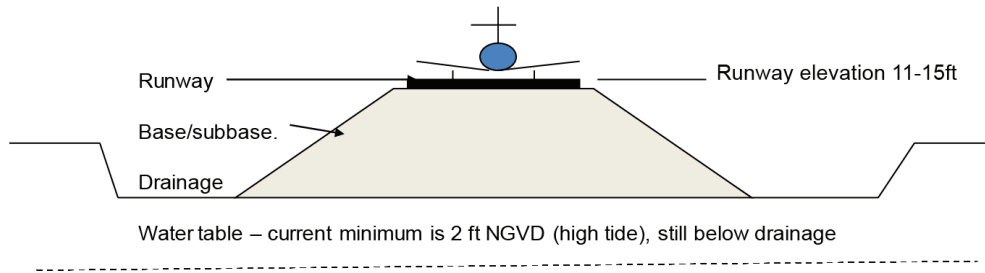


Figure 6.5 Future railroad condition showing that rising ground water level (dotted line) nearly reaches the gravel base, which can result in base deterioration and failure.

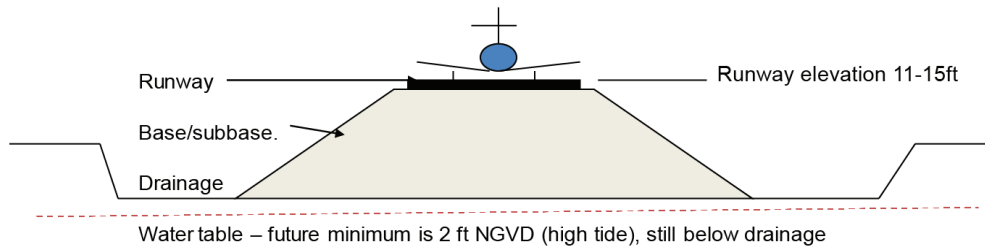
Related to the transportation infrastructure is the related effectiveness of flood control and storm-water drainage systems for the transportation corridors. The increased risk of severe flooding in low-lying terrain can adversely affect transportation infrastructures along the coastline; roads can be inundated and roadway beds can be damaged. Sea level rise will raise coastal water tables, which will compound the risk of flooding in low-lying areas because soil storage capacity would be reduced. Road bases below 5 ft NAVD88), would become saturated under this scenario, causing premature base failure. In addition, because soil storage capacity is diminished, the potential for frequent flooding of roadways would likely damage pavements. Many local roads that do not meet the standards necessary to withstand frequent flooding and would be more vulnerable to failure (see Figure 6.9).

Because it is critical to protect the roadway base, all efforts should begin with providing the base with adequate drainage systems to meet future conditions. At present most base courses are installed above the water table. As long as the base stays dry, a



Current Runways

Figure 6.6 Airport runways are generally elevated. Note that water table is below drainage requirements (dotted line).



Future Runways

Figure 6.7 Sea level rise will threaten runways, but because runways are designed with more elevation than roadways, runways will not be affected by inundation as early as are roadways or railroads. Note that water table is still below drainage requirements (dotted line).

roadway surface will remain stable. As soon as the base is saturated, the roadway can deteriorate. Additional storm-water systems will be useful in the short term to counter sea level rise as long as adequate means for discharging increased storm water are provided. As sea level rises, wellpoint systems may be needed for more permanent drainage. Wellpoint systems are a series of small diameter wells spaced regularly along excavations of a project into the water table, which continuously pump water from roadways (see Figure 6.10). Wellpoints are most commonly used in dewatering projects on construction sites. Wellpoint water is usually turbid, containing sand, other particles, and contaminants from runoff. This form of dewatering requires treatment areas for removal of particulates and sand, which means additional area for discharge purposes will be required. Wellpoint pump stations need to be regularly spaced along a roadway at risk for flooding. As a result a series of pump stations might be needed for every mile of roadway since typical dewatering systems are generally confined to areas less than 500 ft in length. Because wellpoints do not function under flood conditions, additional drainage measures must be provided to address wellpoint failure during heavy rainfall events.

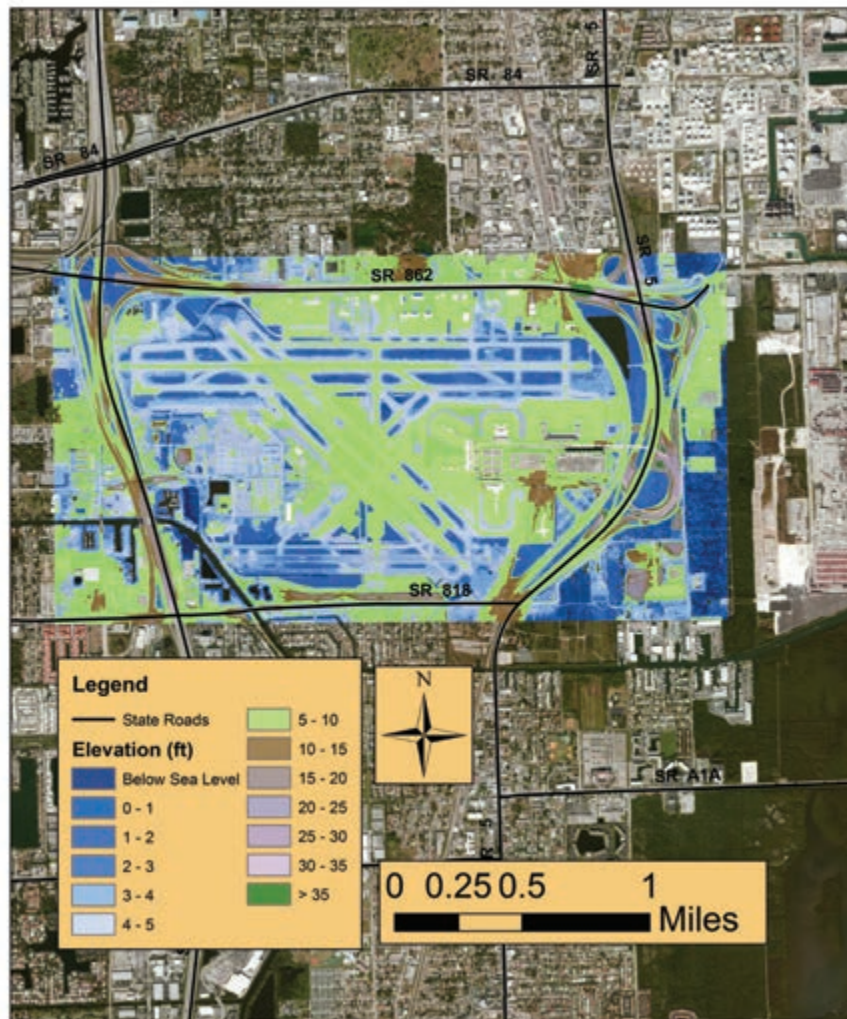


Figure 6.8 Illustration of Fort Lauderdale Hollywood International Airport. LiDAR map shows runways are currently above SLR projections; however drainage areas are not above SLR projections. Dark blue areas are would be inundated with 1 ft of sea level rise (SLR) and medium blue areas would be inundated with 3 ft of SLR.

State transportation departments and most municipalities rely heavily on exfiltration trenches or French drains. These systems work because the perforated piping is located above the water table. They cease to function if they are located below the water table. Exfiltration systems in low-lying areas will cease to work as they become submerged. However this existing infrastructure could be repurposed and extended as infiltration galleries (see Figure 6.11) along roadways, where perforated piping would be used in a similar manner as wellpoints, whereby the water will drain into the perforated pipe, and be directed to a pump station. In these situations, the pump stations might be 2000 feet apart. Storm-water systems should be designed like sanitary sewers with tight

Topographic map of potential transportation infrastructure vulnerability -Dania Beach-

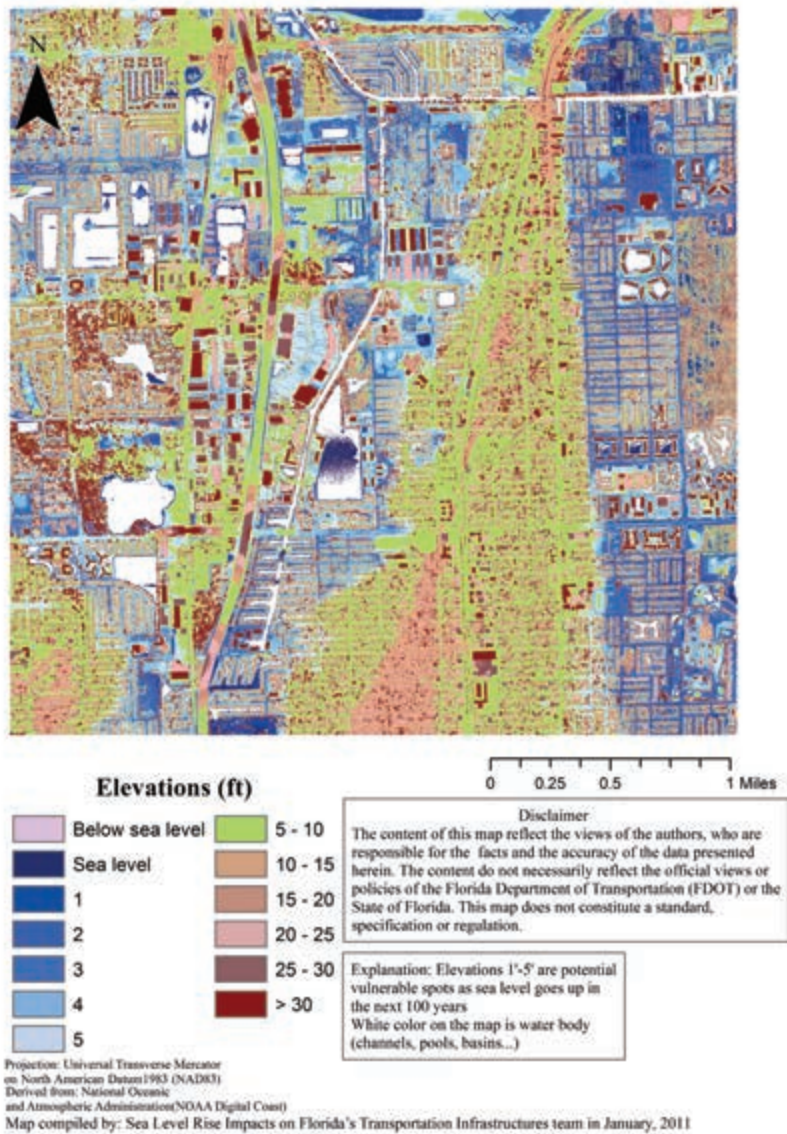


Figure 6.9 Dania Beach Overlay Map Using High Resolution LiDAR Data (7" in vertical accuracy).

pipng, minimal allowances for infiltration, and adequately sized pumping stations with permitted discharge points and means for associated treatment. The costs for such systems could exceed \$1 million per lane-mile (Bloetscher et al. 2012). A much farther range issue will be the volume and contaminant content may make this water unsuitable for discharge to surface waters, but it may be treatable as a potable water supply.

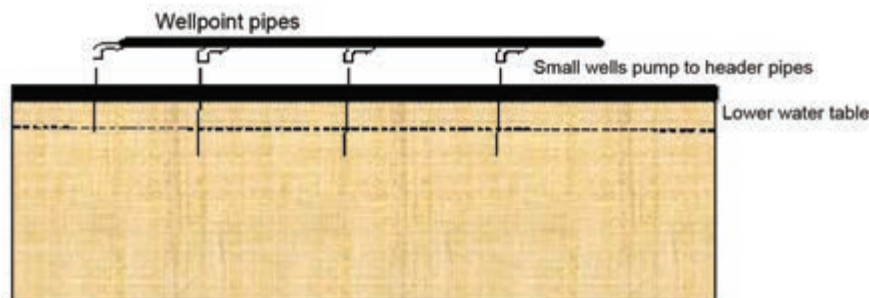


Figure 6.10 Wellpoints.

Exfiltration trenches could also be replaced by storm-water gravity wells or Class V injection wells (see Figure 6.12). Storm-water gravity wells are a useful option where saltwater underlies the surface. Drainage wells along the southeast Florida coast can drain 1 million gallons per day under certain conditions. However as sea level rises, the potential differential may be altered since the saltwater wedge may migrate inland as a result of surficial drainage efforts. Also, increased head due to water table rise will alter pump characteristics. Depending on local conditions, these wells may or may not be appropriate. Wells of this type generally cost about \$150,000 each for a 24-inch diameter well. They also require splitter boxes and filters to remove solids. Regular inspections are required to insure they are not plugged or back flowing saltwater to the surface.

Gravity wells require regular maintenance increasing transportation system budgets. Obtaining permits remain a challenge, and it is likely that wells will have to be deeper than current gravity wells (Bloetscher et al. 2012). Permitting Class V injection wells requires consideration of the Underground Injection Control program under the Safe Drinking Water Act, something that is not currently considered in most transportation jurisdictions. Permitting and consistent monitoring of Class V wells is required. In addition, these 24-inch Class V injection well may have to be hundreds of feet deep in some locations. As a result, the transportation entity will have to include ongoing

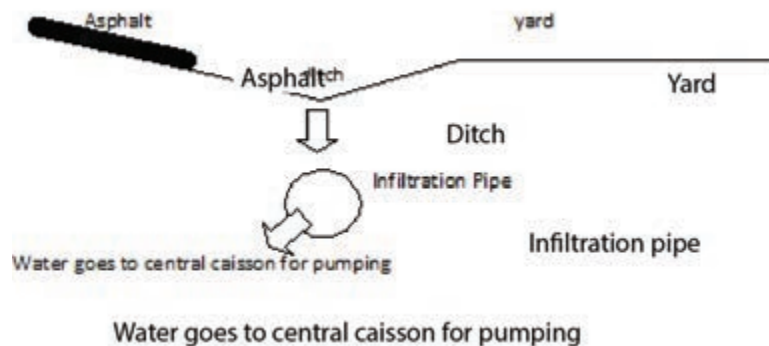


Figure 6.11 Infiltration Gallery Concept..

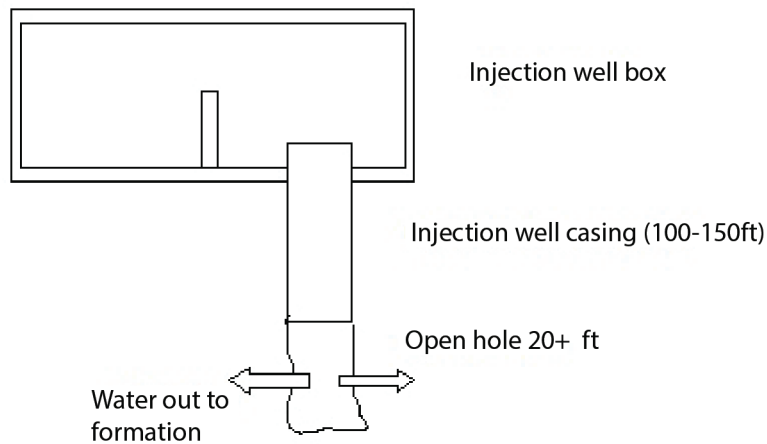


Figure 6.12 Injection Well Concept.

storm water efforts for Class V well compliance (Bloetscher et al. 2012). Elevating roads may be an option for some low-lying areas. However, this option comes with two significant issues: deciding the proper roadway elevations and impacts on adjacent properties. Roadways are designed for a 50- to 100-year service life. As a result, transportation agencies should design roadway bases to be above the mean high water table of 5 ft NGVD. Such roads would likely have surface elevations at or above 10 ft NGVD, above many existing roads in low-lying areas. Such elevated roadways will be well above adjacent properties so people living or working next to these roadways would view the sides of the road from their properties. Moreover, such elevated roads would act as dams that flood adjacent properties unless provisions, such as culverts or pumps, are made for horizontal movement of water.

Local roadway elevations are limited by the adjacent buildings. For example, in Dania Beach, FL, the typical elevation of the floors of houses east of US Highway 1 is between 6 ft and 8 ft NGVD. It makes little sense to raise roadway elevations beyond the typical lowest elevation of dwellings. Elevated roads, in situations such as this, would create bowls that have no outlet, thereby leading to prolonged flooding. Runoff would increase and runoff from private property to the right-of-way would be precluded. As a result, local neighborhoods would need extensive pumping to remove storm water that cannot flow to the right-of-way nor escape the area on its own. In addition, sanitary sewers, water mains, and other utilities underlie these pavements. Elevating the roads would require manholes to be reconstructed, water lines replaced, and most other underground utilities replaced, which would add significant costs to adaptation.

Raising roadways is expected to exceed the cost of new roads. This cost is estimated to be \$1 million per lane-mile, according to one of the authors. With the added improvements, additional right-of-way, and extensive fill, the cost more likely will be much higher. Adjacent properties would need pumps to remove storm water and prevent runoff from entering properties. These costs might exceed \$500,000 per property,

one of the authors estimated. In addition, if property is required for retention or run-off, the costs could exceed \$1 million per acre as adjacent areas are built-out. Such improvements would cause a displacement of some current residents. Where these displaced residents go is uncertain although migration and displacement of residents could result in a domino effect. In addition, residents remaining near the sites of these improvements would experience noise, dust, and inconvenience from the ongoing construction.

Moving people away from vulnerable or inundated roadways would create congestion elsewhere and cost commuters an estimated \$850 to \$1600 per year (FHWA 2013). Congestion means longer travel times, increased costs, and less reliable pick-up and delivery times for truck operators. To compensate, motor carriers typically add vehicles and drivers and extend their hours of operation. Over time, most of these costs are passed along to shippers and consumers. The Federal Highway Administration (FHWA) estimates that increases in travel time would cost shippers and carriers an additional \$25 to \$200 per hour depending on the product carried. The cost of unexpected truck delays can add another 50 percent to 250 percent (Strocko 2008).

6.4 Conclusions

All transportation networks in the Southeast USA are vulnerable to severe weather events and climate change. Ongoing efforts to identify vulnerable infrastructure and to measure the risk and disruption posed by climate change from an economic and societal perspective are generally in their infancy. From a transportation planning perspective, there is great need to understand how climate and weather effects on the economy should be incorporated into larger policy frameworks.

Warmer temperatures along with more intense rainfall events will require re-engineering of transportation surfaces and storm water collection and disposal. Permitting for disposal of storm water may pose a significant challenge to an area where nutrients create significant eutrophication problems in slow moving and coastal waterways. Outside-the-box thinking will be required to deal with the problem of too much water. However, with respect to weather phenomena, while potentially catastrophic, storm damage is temporal in nature as opposed to the permanent threat of sea level rise.

Coastal transportation infrastructure in SE USA is increasingly vulnerable to sea level rise. Given the high population density near the coasts, the potential exposure of transportation infrastructure to flooding is immense (NOAA 2010). The SE transportation system is extremely weather dependent for the two National Research Council (NRC 2009) imperatives—economic competitiveness and disaster resilience. Transportation is strongly interconnected with other infrastructure systems and is highly susceptible to natural hazards. The highest priority needs are associated development of incentives to encourage various levels of government to collaborate with each other (National Research Council 2010). The physical elements of the SE USA transportation infrastructure are vulnerable to climate impacts just as water, storm water, and power are interrelated. Approaching infrastructure renewal by continuing to use the same processes, practices, technologies, and materials that were developed in the 20th century may yield the same results: increasing instances of service disruptions, higher operating and repair costs, and the possibility of catastrophic, cascading failures. If the

nation is to meet some of the challenges of the 21st century, a new paradigm for the renewal of critical infrastructure systems is needed. As the renewal of infrastructure is undertaken over the next 20 to 50 years, NRC (2009) challenges local officials to re-think the infrastructure paradigm. Solutions must be local as there are no universally applicable solutions (Bloetscher 2012). The new paradigm must recognize transportation systems are interconnected; they are not independent. Moreover, the intermodal elements of this overall transportation system are particularly vulnerable to climate-related risks. For ports and marine shipping, climate factors such as sea level change, storm surge, and sediment dynamics need to be considered.

Engineering options are already available for strengthening and protecting transportation facilities such as bridges, ports, and railroads from coastal storms and flooding, but inundation from sea level rise is a different issue. The development and implementation of technologies that monitor major transportation facilities and infrastructure, and the development, update and re-evaluation of current design standards, are required for adapting to SLR in coastal areas. Many issues require policy decisions, such as the elevation of roadway surfaces, the installation of wellpoints and infiltration galleries, new drainage systems, and roadway diversion or abandonment. However, little attention has been given to evaluation approaches for where and when such options should be pursued or to the potential co-benefits or unintended consequences (NRC 2010).

Planning for SLR adaptation in transportation infrastructure will require new approaches to engineering analysis, including the development and use of risk analysis based on uncertain SLR and the development of new engineering standards to reflect future climate conditions (NRC 2010). The US Climate Change Science Program has recommended the following approaches to incorporate climate information into transportation decision making (USDOT 2002):

- Planning time frames
- Risk assessment approach
- Integrated climate data and projections
- Risk analysis tools
- Region-based analysis
- Interdisciplinary research
- Identification of vulnerable assets and locations
- Identification of opportunities for adaptation of specific facilities
- Understanding changes in the life span of facilities caused by SLR
- Understanding the modes and consequences of failure
- Assessing the risks, costs, and benefits of adaptation

As sea level rises, populations at low elevations areas along Southeast coastline may move inland, causing changes in travel patterns. As a result, re-routing of current transit, roadway, and non-motorized systems may be necessary, along with the relocation of pipelines, freight, seaports, and airport facilities. Travel pattern changes could potentially exacerbate climate change vulnerabilities, thereby affecting the operational

efficiency, capacity, and level of service of transportation systems. A significant increase of facility users, on roadways for example, could exceed the operational capacity of facilities, increasing user delays. Similarly, traffic delays will affect the reliability, efficiency, and capacity of the transit systems. Transit passengers may experience longer travel times affecting the quality of service of the transit systems. These transportation issues may significantly affect traffic safety and quality of life of the communities served by these transportation systems. Transit and other modes of transportation that are not single-occupant vehicle mode may become more prudent to reduce congestion. Traffic safety plans that address the changes in environment conditions will need to be developed and implemented, including a detailed route signing system and emergency response plans that provide new evacuation routes, accessibility, and mobility plans.

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