Selmon Expressway Western Extension -
Gandy Boulevard Assessment

Adaptation Strategies

prepared for

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Executive Summary

Hillsborough County is extremely vulnerable to hurricanes and heavy precipitation. Recognizing this, the Hillsborough Metropolitan Planning Organization (MPO) leveraged a Federal Highway Administration (FHWA) grant to perform a Vulnerability Assessment and Adaptation Pilot Project in 2014. The objective was to identify cost-effective strategies to mitigate and manage the risks of coastal and inland inundation for incorporation into the Hillsborough MPO’s 2040 Long Range Transportation Plan (LRTP) and into transportation planning and decision-making processes more generally. The study looked at several critical assets and evaluated mobility and economic impacts if any of these facilities were to be out of service.

Gandy Boulevard, part of an important link between Hillsborough and Pinellas Counties, was one of the assets evaluated. The segment commences as Gandy Boulevard makes landfall, continuing east to the site of the planned western extension of the Selmon Expressway elevated connector. A map that details the surrounding area can be seen in Figure 1. The section of road analyzed is highlighted in green.

The 2014 study provided planning level information about strategies and costs to mitigate the impacts of storm surge and flooding inundation for each facility analyzed. The next question and task is how to turn the information into actionable projects to protect against potential risks. The Tampa-Hillsborough Expressway Authority (THEA) coordinated with the Hillsborough MPO and asked for assistance in refining the strategies for consideration in the design-build of the Selmon Expressway Western Extension. This report documents the results of:

- additional risk evaluations specific to the Gandy Boulevard segment,
- further refinement of strategies appropriate for the area,
- conceptual designs for consideration by THEA and other purposes,
- more specific pre-engineering cost estimates for the strategies evaluated, and,
- most importantly, recommends low risk, high benefit solutions for implementation.

Storm surge and sea level rise impacts in the Gandy Boulevard area were revisited as part of this project, and included the Tampa Bay Climate Science Advisory Panel’s (CSAP) recommendations for a unified projection of sea level rise in the Tampa Bay area. The project evaluated impacts for 2040 and 2060 and storm surge from Category 1, 2, and 3 level storms. A scenario approach is useful in developing project recommendations based on the local context. In this case, Tampa Bay provides some protection from storm surge for Gandy Boulevard; however, given the elevation of the area, some overtopping from storm surge, particularly with high tides, or flooding inundation is possible. This project evaluated strategies to prevent and...
inundation is possible. This project evaluated strategies to prevent and mitigate inundation and overtopping, and emphasizes strategies to protect the facilities from damage due to erosion, washout, or scour.

A broad list of strategies with the intent of providing general information for future implementation were considered. These strategies were evaluated in the context of incorporating, or mainstreaming, the strategy as part of the design-build project. As such, cost estimates are provided as marginal costs. For example, the costs to upgrade the road to full-depth concrete as part of the proposed project primarily relate to a change in construction materials and techniques. If building Gandy Boulevard from the bridge to the elevated section with full-depth concrete was tackled as an independent project, the costs are estimated to be nearly five times more ($3.4 million) to cover items such as final design, road removal, construction inspections, and traffic mobilization. The components are already part of the expressway project. The strategies evaluated are listed below and more descriptions about the strategy are in later sections of the report.

- Do Nothing
- Erosion Control
  - Wave Attenuation Devices and Living Shorelines
  - Revetments and Sea Walls (Riprap)
  - Vegetation (binding grasses and shrubs)
- Drainage
  - Permeable Pavement
  - Enhanced Drainage Structures
- Strengthen and Raise Profile
  - Raise Profile
  - Hardened Road Surface / Full Depth Concrete
- Pier Protection
  - Vegetation to Prevent Scour

The final implementation options for the THEA design-build project are shown in Table 1. These options are low risk, low marginal cost, and provide benefits to mitigate storm or flooding impacts and support quick restoration of service (if needed) after an event.

**Table 1: Implementation Options**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cost Differential</th>
<th>Level of Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do nothing</td>
<td>None initially. Reconstruction cost is $3,312,000</td>
<td>Highest Risk. Required if roadway is destroyed.</td>
</tr>
<tr>
<td>Upgrade to full-depth concrete pavement</td>
<td>$676,000</td>
<td>Medium Risk. Road damage possible if inundation occurs.</td>
</tr>
<tr>
<td>Raise Profile</td>
<td>$1,119,000</td>
<td>Low Risk. Inundation from storm surge, rain or tide related flooding.</td>
</tr>
<tr>
<td>Erosion control via vegetation</td>
<td>$104,544</td>
<td>Low Risk. Embankment damage or washout if inundation occurs.</td>
</tr>
<tr>
<td>Pier protection via vegetation</td>
<td>$30 per pier (total depends on design)</td>
<td>Low Risk. Pier scour or damage possible if surge occurs.</td>
</tr>
</tbody>
</table>
1.0 Background

The purpose of this project is to refine strategies, concepts, and costs for strategies to address vulnerabilities associated with Gandy Boulevard identified in the Hillsborough MPO’s Vulnerability Assessment and Adaptation Pilot Project (2014).

1.1 Gandy Boulevard

This segment of Gandy Boulevard makes landfall, continuing east to the site of the planned Selmon Expressway elevated connector. The area is partially armored with riprap and a shallow bulkhead (proximate to a commercial/industrial facility on the northern face of the peninsula). Piles (remains of a former pier structure) ring the northwestern tip of the peninsula, providing some wave attenuation benefits (but not systematically so). The eastbound (EB) lane reaches the peninsula at grade, while the westbound (WB) lane rises from grade to an elevated, armored bridge approach. The WB approach is drained on the north side, using a shallow surface channel and grated inlets (flush with channel). The EB lane has no obvious drainage until the median begins (3 inlets near turn lanes). Figures 2 and 3 provide aerials of the west and east portions of the segment.

This segment lies within a peninsula that extends into Old Tampa Bay and is surrounded by water on the north, west, and south sides. A US Marine Corps Reserve facility is located on the north side of the roadway. A frontage road provides access to this site as well as to Pinellas Park and the now-closed Friendship Trail Bridge. The Florida Fish and Wildlife Commission building is on the south side of the roadway. To its east lies the Coast Guard Auxiliary facility and the Gandy boat ramp. A short frontage road provides access to these facilities and Gandy Park South to the west. Access to both frontage roads is currently provided at the same location, where full traffic movements are allowed at a median opening. The 2010 conceptual plans for this Selmon Expressway connector indicate that left turns will no longer be provided at this location, and that a new full movement intersection will be constructed approximately 550 feet west of the current intersection.

Most of the land on this peninsula is owned by the Florida Department of Transportation (FDOT). The site on which the Coast Guard Auxiliary is located, including the Gandy boat ramp, is owned by Hillsborough County. Several parcels of land east of the boat ramps, and adjacent to Bridge Street, are privately owned. Any widening of the footprint of Gandy Boulevard that is required in order to reduce the vulnerability to inundation or storm surge is not expected to create a need for additional right-of-way. The primary constraint is the wetlands, especially on the south side.

The Gandy Boulevard Bridge is approximately 14 feet above sea level and this segment of Gandy Boulevard is approximately 9 to 10 feet above sea level. The Selmon Expressway Western Extension will come down to grade level on Gandy Boulevard to connect to the bridge.
Figure 2: Gandy Boulevard - West End of Segment
Figure 3: Gandy Boulevard - East End of Segment
1.2 Potential for Storm Surge and Inundation

The Hillsborough County Local Mitigation Strategy (LMS)\(^1\) indicates the probability of a hurricane or tropical storm in the Tampa Bay region as high. The frequency identified for tropical storms and minor hurricanes (Category 1 and 2 storms) is every three to five years; and, the frequency for major storms (Category 3 through 5) hurricanes is every five to 10 years. Coastal and riverine erosion also are identified with frequencies of five to 10 years. A graphic of historic hurricane tracks by intensity within 65 nautical miles of Tampa is shown in Figure 4. More information from the LMS, and about historic storms, and potential property impacts is provided in Appendix A.

Figure 4: Historic Hurricane Storm Track\(^2\)

The Vulnerability Assessment provides an overview of storm and inundation risks. These were revisited as part of this project. Storm surge and sea level rise (SLR) were analyzed in combination. SLR was simply added to the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model rather than remodeling surge under SLR scenarios. This technique provides illustrative results, but is valuable for planning. Table 2 shows the inundation depth for all combinations analyzed.


\(^2\) See: [https://coast.noaa.gov/hurricanes/](https://coast.noaa.gov/hurricanes/) for Tampa, Fl. And 65 nautical miles. Hurricanes only.
Table 2: Inundation Depth from Sea Level Rise and Storm Surge Scenarios

<table>
<thead>
<tr>
<th>Inundation Depth (ft)</th>
<th>Storm Surge Scenario</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cat. 1-Mean</td>
<td>Cat. 1-High</td>
</tr>
<tr>
<td>Present Day-Low</td>
<td>4.70</td>
<td>5.60</td>
</tr>
<tr>
<td>2040-Low</td>
<td>6.37</td>
<td>7.27</td>
</tr>
<tr>
<td>2040-High</td>
<td>7.20</td>
<td>8.10</td>
</tr>
<tr>
<td>2060-Low</td>
<td>6.53</td>
<td>7.43</td>
</tr>
<tr>
<td>2060-High</td>
<td>8.20</td>
<td>9.10</td>
</tr>
</tbody>
</table>

Note that these values may differ slightly when comparing to the pilot report. For this analysis, the SLOSH values were selected from the exact grid where Gandy Boulevard is located.

Flooding from intense precipitation can also affect inland transportation assets, in conjunction with or separately from coastal phenomena. The approach to assessing future vulnerabilities to inland flooding leveraged official 100-year (one percent annual chance) floodplain maps. Based on the analysis of FEMA’s official Digital Flood Insurance Rate Map (DRIRM), the Vulnerability Assessment report defines a FEMA 1% chance flood height of 9 feet.

Comparing road elevation to categories of storm surge is helpful to understand the level to which the roadway is protected against varying levels of storms. However it is also important to understand how often storm surges will happen. For this we can compare the road elevation to the design peak storm surge heights. Table #3 shows the peak design storm surge heights recommended by the Florida Department of Transportation for Tampa Bay. For nearly all sea level and design storm combinations a roadway at 10 feet above sea level would sustain a period of permanent inundation. As noted previously, the segment of Gandy Boulevard evaluated is approximately 9-10 feet above sea level.

Table 3: Peak Design Storm Surge Height

<table>
<thead>
<tr>
<th>Peak Storm Surge Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-Year</td>
</tr>
<tr>
<td>100-Year</td>
</tr>
<tr>
<td>500-Year</td>
</tr>
</tbody>
</table>

The various sources of information provide a range of potential impacts due to storm surge and inundation. This project did not select a specific surge height or frequency. Instead, these figures factored into options for erosion control and surface hardening. The study team also considered this information when elevating the strategy to raise the road profile. Based on Table 2 and Table 3, raising the road elevation to 13 to 15 feet would provide potential protection against storm surge due to a 100-year storm event or a Category 2 and possibly Category 3 hurricane. Raising the profile higher would provide protection from the potential risks of more intense storms. In this situation, the Gandy Boulevard bridge elevation of 14 feet was also a consideration. It is possible to raise the roadway higher than the bridge, yet impractical. Should a storm event with surge higher than 14 feet occur, passage via the bridge will be blocked. Raising the road higher

blocked. Raising the road higher than 14 feet should be considered with any plans to reconstruct and raise the elevation of the adjoining bridge. Raising the elevation of the section of Gandy Boulevard connecting to the elevated expressway project was considered and is explained in Section 2. It was not recommended for inclusion in the expressway project due to additional design and site constraints related to the increased slope of the road. Increasing the road elevation to 14 feet means access to adjacent sites and intersections would be steeper, which would require design and construction considerations. It also could require coordination with property owners and the City of Tampa, which is complicated by the timeline of the project.

More details about the information on storm surge and sea level rise considerations is provided in Appendix B.
2.0 Adaptation Options

A general rule is that the design life of bridges and roadways are 50 and 20 years, respectively. The Hillsborough MPO has started the process of identifying infrastructure potentially at risk of coastal and inland flooding by conducting the Vulnerability Assessment. In the case of a storm, evacuation procedures will work to reduce the potential for loss of life or injury by asking people to leave harm’s way. It is during and after a storm where the usefulness of the strategies described here become known. Keeping a road passable for emergency personnel and post-event support is critical.

The Vulnerability Assessment focused on three general types of strategies: wave attenuation, drainage improvements, and raise the profile. This study evaluated these strategies and added some additional strategies based on the Gandy Boulevard context. This section provides a description of each strategy, advantages of each, and approximate costs where appropriate.

Incorporating strategies to reduce potential vulnerabilities in existing infrastructure-related projects provides a tremendous opportunity to reduce risks for lower marginal costs in areas prone to storms, flooding, or sea level rise. Context is key to identification, conceptual design, and cost estimation.

2.1 Do Nothing

With this “no build” strategy, no adaptation strategies would be mainstreamed with the implementation of the Selmon Expressway Western Extension. This approach avoids costs at this time; however it overlooks opportunities to incorporate low risk, low cost strategies that can help avoid the costs of future repair. The estimated cost of rebuilding the segment of Gandy Boulevard is $3,312,000.

2.2 Erosion Control

Wave action and storm surge are potential threats to roadways at low lying elevations and to roadways where increased wave height and energies can cause erosion and scour on road embankments. When sea level rise is coupled with storm surge there will be even greater erosive effects and a greater possibility of overtopping. In order to combat the erosive forces adaptation strategies can be put into place to improve the

Impact Narratives

Category 1 Storm Surge
Gandy Boulevard suffers negligible structural damage, with the exception of minor erosion and slope destabilization, particularly near the elevated connector approach. The roadway is free of standing water within 24 hours, permitting debris removal, inspections, and repairs. Roadway regains full functionality in approximately one week.

Category 3 Storm Surge
Gandy Boulevard suffers washouts and erosion from coastal surge. At low-lying sections, inundation persists as upland areas drain, yielding extended periods of base/sub-base saturation in lower elevations, requiring repair. Repair and debris removal activities are delayed due to standing water and recovery resources are strained. Roadway regains full functionality in approximately four weeks. Note that segments crossing the Bay are not considered in this analysis—severe damage to the Gandy Bridge could prolong disruption considerably.

Source: MPO Vulnerability Assessment

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4 The MPO Vulnerability Assessment identified replacement costs as $613,000 based on conceptual engineering plans. The revised costs used here assume full reconstruction (similar to new construction) and are based on FDOT's Long Range Estimating System.
resiliency of Gandy Boulevard. The following sections provide overviews of strategies evaluated further and Appendix B provides details.

### 2.2.1 Wave Attenuation / Living Shorelines

Wave attenuation devices (WADs) can be used to protect on shore infrastructure from increasing forces of erosion. WADs reduce the force of waves striking the coast by dissipating energy when waves encounter them. Floating devices and structures attached to the floor of the water body are both available. The effectiveness of the WADs is strongly influenced by the design and configuration of the structures.

Living shorelines provide a more natural approach for erosion control, while allowing access for coastal and estuarine organisms. This approach provides shoreline stabilization using living plant material (emergent and submerged aquatic vegetation), oyster shells, earthen material or a combination of natural structures with rip rap or offshore breakwaters to protect the shoreline against erosion. Appendix D provides a presentation with options and unit costs.

For Gandy Boulevard and the larger Hillsborough County coastal region, providing a WAD, living shoreline, or a hybrid approach remains a long term strategy to providing storm surge and wave protection along the bay. As more communities use these mechanisms, more information will be available on applicability and costs. For example, living shorelines appear to do best in low energy environments. Monitoring information about other approaches that support higher energy surges will be beneficial to address storm risks.

![Figure 5: Living Shoreline Concepts](image)

### 2.2.2 Revetments and Sea Walls

Coastal roads can be extremely susceptible to erosion on the seaward side due to increased wave erosion and higher tides. The concept of hardening the seaward side is to provide protection against this increased hydrologic action and specifically to protect the roadbed from direct exposure to the elements. To accomplish this protection, the seaward side of the road embankment can be hardened using a revetment or seawall.
The distinction between revetments and seawalls is one of functional purpose and in the United States the terms may be used interchangeably. Revetments are layers of protection on the top of a sloped surface to protect the underlying soil. Seawalls are walls designed to protect against large wave forces. Seawalls are rigid structures or rubble mound structures specifically designed to withstand large wave forces. Some types of larger seawalls are not common in the U.S. because they require extensive marine structural design. Rubble mound seawalls are much more common and look like revetments, but contain larger stones to withstand larger waves. Figure 6 shows a typical revetment design cross-section.

Sea level rise and its impact on sustaining taller waves could present challenges for maintaining the functionality of the roadway or coastal embankments. Therefore, the increase in sea level and wave height should be taken into consideration when designing seawalls and revetments. The current sections of the coast surrounding Gandy Boulevard that are already armored with rip rap should be assessed to see if they are appropriately sized for increasing sea level rise and storm velocities. During a storm surge event, road embankments that are not ordinarily exposed to wave action wave erosion could be due to higher water levels. In order to prevent erosion during these extreme events, this embankment should be armored according to a revetment design.

The cost of hardening the seaward side of a road is primarily comprised of the cost associated with placing riprap along the seaward side. However, to arrive at an appropriate cost, the recommended design guidelines for the placement are taken into account. For Gandy Boulevard, the total cost of hardening per 0.25 mile is approximately $306,695. Appendix B provides details on the design assumptions and costs of rock and riprap.

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2.2.3 Vegetation

Another approach to reducing erosion on the seaward side of a road in scenarios where there is only minor to moderate wave or overtopping actions is to use vegetation as binder on the seaward slopes. Specifically, grassy vegetation and shrubs can be used to combat erosion in slight to moderate conditions. Florida has had success with a wide variety of trees and shrubs for erosion control ranging from Live Oak and Buttonwoods to shrubs such as Holly. However, the most common approach to direct erosion control is seeding with grasses. Grass is effective at covering and protecting soil from wind and water erosion. When seeding grasses it is ideal to use a mixture of creeping and clumping types. Creeping grasses form a continuous root system, or mat. Clumping grasses leave gaps between plants that can be vulnerable to erosion, but grow very deep roots.

The total cost of vegetation is based on a similar approach to that taken for strengthening the seaward side with riprap. Specifically, the total area of coverage is calculated from the recommended design guidelines for a slope and then the cost of the vegetation is calculated for that area of coverage. For Gandy Boulevard, the total cost of vegetation per 0.25 mile is approximately $11,871. Appendix B provides details on the design assumptions and costs of plants.

The variable in this calculation is the specific cost of the vegetation. In the case of Gandy Boulevard, several options exist based on experience in Florida including grasses, shrubs, and even trees in some areas. Recent studies have placed installed costs for these different options at $3 per gallon planting for grasses to $5 per gallon for trees. The total cost will then be dependent on amount of coverage required. However, the benefit of vegetation is that it is intended to be self-sustaining in that once it is planted, there should be minimal maintenance cost in the future.

Undertaking this strategy as a stand alone project is financially feasible given the lower relative costs for vegetation versus road infrastructure. However, this assumes the design of the elevated structure is such that there is room for vegetation or other strengthening techniques. As a standalone projects, there are costs to remove existing vegetation, design the landscape, and construct the site. These costs are primarily borne by the expressway project if erosion control is integrated, or mainstreamed, as part of the project early in the process.

Wave attenuation, living shorelines, or revetments are recommended to be implemented in the long term. Sea level rise is a slow process and will not have dramatic effects on coastal erosion for quite some time. In general, Gandy Boulevard is not very vulnerable to coastal erosion at present day sea levels because it lies 120-300 feet from the coast. As sea levels begin to rise the coast will move closer to the roadway and WADs and revetments may have to be implemented. Erosion of the roadway embankment is still a concern during a storm event. Vegetation as erosion control of the roadway embankment is an easy and cost-effective method...
effective adaptation that can be implemented in the near term. The bridge abutment is vulnerable to storm surge and this vulnerability will increase with rising sea levels. It is recommended that the area be monitored and re-analyzed using future sea level and wave projection scenarios.

2.3 Drainage

According to the National Oceanic and Atmospheric Administration, the frequency and duration of extreme flood events is increasing in the Gulf. Furthermore, climate models are predicting an increase in precipitation events in the Tampa Bay area. This makes enhancing drainage systems, in general, a top priority.

Storm surge and sea level rise typically effect drainage efficiency in many ways. Lower hydraulic head and higher water tables would reduce natural drainage and storm surges will be higher and may permanently inundate the area. Permanent inundation will render gravity systems useless and will require modifications, such as backwater prevention, to keep seawater from entering the system. Increased precipitation may also lead to increases in flood frequencies and therefore will effect drainage systems. Drainage system adaptation strategies should be put into place to expedite flood recovery, and to properly drain larger runoff flows from increased precipitation. Appendix B provides more detailed descriptions, including some engineering considerations.

In this portion of Gandy Boulevard, any significant rise in the water level during a storm event will cover the miscellaneous drainage culverts in the area during the time of inundation. This results in a probable need for maintenance crews to clean out the structures of vegetation following an event of any magnitude. No damage is expected to occur as a result of heavy local rainfalls, as the storm water will percolate into the sandy soil and any excess will simply sheet flow off the peninsula into the bay.

2.3.1 Permeable Pavement

Permeable pavements, also referred to as porous pavements, are load-bearing, durable highway surfaces that have an underlying layered structure that temporarily stores water prior to infiltration into soil or drainage to a controlled outlet. The advantage of such a pavement system is that it can help to reduce runoff volume during periods of peak flow and minimize flooding. Permeable pavements are appropriate only for gentle slopes and only for roadways with low traffic volumes and travel speeds (less than 30 mph).

Gandy Boulevard does not fall within the limitation of speed, however permeable pavements could be an option for the local roads to either side. Limiting the runoff of these surfaces will help to reduce flows into the overall drainage system. In the Gandy Boulevard situation where swales predominate, permeable pavements would reduce surface flows.

![Figure 8: Typical Cross Section of Permeable Pavement](http://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf)
Permeable pavements are up to 25% cheaper (or at least no more expensive than the traditional forms of pavement construction), when all construction and drainage costs are taken into account\(^7\).

### 2.3.2 Enhanced Drainage Structures

Gravity drainage typically can be enhanced by increasing the size of drainage pipes and inlets. Increasing the size of the pipes or drainage canals will allow the system to drain a greater capacity of water. The number of inlets can also be increased. Inlets should always be located at the low points in the profile. In addition flanking inlets on each side of the low point inlet should be installed to act in relief of the low point inlet when the low point drain gets clogged (common during intense storms) or if the design spread is exceeded\(^8\).

Another major problem associated with storm water runoff is the stability and durability of the slopes, ditches, and embankments. One identified method for preventing erosion of these earthen structures is to reinforce them with concrete surface treatments. Additionally, during the reinforcement process, the ditch capacity can be increased. Such treatment decreases floodwater concentration and promotes flow to designated reservoirs.

Drainage in the area surrounding Gandy Boulevard, east of Bridge Street, is collected in roadside ditches and storm sewers, then directed to a canal known as the Gandy Canal. The Gandy Canal lies north of the commercial businesses that line the north side of Gandy Boulevard. It flows to the west, passing under Culbreath Key Way through a box culvert before discharging into Old Tampa Bay. The peninsula on which this segment of Gandy Boulevard is located is west of the outlet, meaning this area is seaward of the nearest outfall and drainage canal.

Any potential rise in the water level from a storm event will cover the miscellaneous drainage culverts in the area during the time of inundation. Additional storm water or rainfall will simply sheet flow off the peninsula into the bay. Because of the closeness to the bay and the current drainage configuration, the choice of drainage improvements in the Gandy Boulevard area is limited to possible swale/ditch improvements. The City of Tampa is preparing to undertake a watershed study for the area of South Tampa known as the Lower Peninsula. Gandy Boulevard is within the limits of the study area. The resulting stormwater study will allow the City to identify and prioritize if any improvements to the drainage system needed for Gandy Boulevard. As such, drainage enhancements were not emphasized in this study.

### 2.4 Strengthen and Raise Profile

These strategies relate to road surfaces themselves. Raising the profile, or elevation of the road, is designed to reduce the likelihood a road becomes inundated as a result of storm surge or rain- or tide-related flooding. Increasing the height of a roadway provides increased mobility during events and offers the possibility to restore operations more quickly afterward. Maintaining access to adjacent properties and ensuring appropriate drainage are considerations.

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\(^8\) FHWA, 2009. Hydraulic Engineering Circular 22
Roads that become submerged due to storm surge or flooding stand the chance of being compromised, chiefly the longer they are inundated. When the water recedes, or as the result of wave action, portions of the road may wash away or buckle, making the road impassable. Constructing a road with concrete or hardening the base layer, instead of using rock or aggregate, are strategies to help avoid this possibility. For the Gandy Boulevard implementation, full depth concrete was investigated.

2.4.1 Raise Profile

When considering raising the profile of a roadway, access to adjacent uses and turning movement considerations are critical. This study assumed it is necessary to maintain the proposed access points\(^9\) under any modification recommended. Another major factor is the elevations of the connecting sections. The Selmon Expressway West Extension is an elevated structure and the east end of the project will rise to meet the elevated corridor. The west end of this segment connects to the Gandy Bridge to Pinellas County. The westbound Gandy Bridge is at elevation 24, and the older eastbound bridge is at elevation 14. The grade of the road from the ends of these bridges drops to an elevation of 9 feet until the profile rises to meet the new elevated structure. Approximately 3100 feet of the alignment will be at an elevation at or below that of the eastbound bridge.

Two options were evaluated for raising this segment: 1) raise both the eastbound and westbound directions of the roadway or 2) raise only one direction.

The option to raise one side of the roadway (north side is more practical technically) to 14 feet would prohibit left turn movements at the intersection. In order for eastbound traffic to access the Marine Corps Reserve facility, drivers would have to make a U-turn just east of the beginning of the Gandy Connector bridge and proceed westerly along the at-grade westbound lanes to the main entrance to the facility. In a similar fashion, there is no feasible method for westbound traffic to access the facilities on the south side. The most likely location for westbound drivers to access the south side would be to allow left turns at Bridge Street, then construct a new frontage road from Bridge Street west to a point where it could tie to the existing frontage road, east of the Fish & Wildlife Conservation Commission building. Such a road would require a modification to operations at both the Fish and Wildlife site and the Coast Guard Auxiliary, and would require the acquisition of right-of-way from private property on the southwest quadrant of Gandy Boulevard and Bridge Street. Furthermore, the Contraflow plan, as described in the PD&E Study, would no longer be feasible, since traffic was designed to cross the median in this area. For these reasons, the option of raising only one side of the alignment was dropped from further evaluation.

Therefore, the best option for raising the profile of this segment would be to raise all lanes from the Gandy Bridge to a point east of the east access to the Marine Corps facility. This is the location where the primary (at-grade) lanes of Gandy Boulevard will begin to diverge to make room in the median for the center lanes to rise as they approach the connector bridge. The outside lanes can stay at-grade because they provide access to the at-grade segment of Gandy Boulevard.

The proposed, new, full intersection (at Sta. 611+70) that will provide access to the local facilities would be raised along with the alignment of Gandy Boulevard. In order to keep the access roads leading up to the intersection from within reasonable grades, each of the four legs of the access roads would have to be lengthened approximately 150 feet more than what was shown in the 2010 concept plans. It is likely that a

---

\(^9\) The preliminary plans for the Selmon Expressway West Extension project provide minor adjustments to access points for adjacent uses. This study relied on these plans when investigating the raise profile strategy.
short retaining wall not exceeding 5 feet in height would be required on the outside of the frontage road on the south side to avoid impacts to the wetlands. In order to reduce the size of the roadway footprint, 2:1 side slopes are assumed. Guardrail would be required on both sides. Appendix C provides more details on the design assumptions and constraints.

The cost to raise the alignment in the segment, with no other changes to the pavement structure, is approximately $1,119,000. This cost was determined based primarily on the marginal cost of additional earthwork needed to raise the alignment, new guardrail and retaining wall. The costs to raise this same portion of Gandy Boulevard as an independent project is triple the cost and is estimated at $3,762,000. The additional costs include final design, construction engineering and inspection (CEI), and other costs, such as mobilization (maintaining traffic flow during construction), which are already part of the THEA project. Site preparation, such as removal of the existing roadway, would also be required, along with any utility and agency coordination.

Raising the elevation of small section of Gandy Boulevard connecting to the elevated expressway project is not recommended for inclusion in the expressway project due to additional design and site constraints. The current road elevation is 9-10 feet and increasing to 14 feet means access to adjacent sites and intersections would be steeper. This change in slope would require design and construction considerations, particularly because of the many boat trailers that travel through this area and access the bay nearby. It also could require coordination with property owners (including federal and state agencies) and the City of Tampa.

A conceptual plan. Identified as the "MPO Profile" in Figure 9, shows an elevation view of how Gandy Boulevard would be raised to match the bridge elevation on the west and then link to the elevated expressway corridor in the east.

2.4.2 Hardened Road Surface

A significant period of inundation of the roadway could cause pavement failures along this segment. In order to reduce the possibility of such failures, concrete pavement could be considered. The risk associated with pavement buckling from prolonged inundation is much less with a rigid pavement (Portland Cement Concrete) than it is with asphalt pavement.
Figure 9: Conceptual Plan to Raise the Road Profile
While concrete would provide an increased level of risk against failure, it does not provide assurance that the entire roadway will not be washed away as a result of constant and sustained wave action during a surge. For this segment of Gandy Boulevard, the marginal cost of construction using full depth concrete as part of the currently planned expressway project is estimated to be $676,000. If this strategy was pursued as an independent project the costs are estimated at $3,402,800. The additional costs include final design, construction engineering and inspection (CEI), and other costs, such as mobilization (maintaining traffic flow during construction), which are already part of the THEA project. Site preparation, such as removal of the existing roadway, would also be required, along with any utility or agency coordination.

2.5 Pier Protection

During storm events, the piers for bridges and potentially overhead structures can be subject to scour from the rush of water and waves before, during, and after the storm. This is similar to everyday wave action on the coast but more extreme given the wind and wave energy during a storm. As such, using vegetation or more hardened protection for piers are appropriate strategies. This investigation focused on the on-land pier structures associated with supporting the elevated expressway corridor. Additional research for bridge piers is recommended. Given the inland nature of these piers, the focus was on vegetation for protection; although more hardened approaches can be considered. The use of vegetation here is similar to the use of vegetation as erosion control. It is designed to dissipate wave and water action around the piers to reduce potential scour.

2.5.1 Vegetation to Prevent Scour

The protection of piers from erosion due to storm surge can be assisted through the use of hard surfaces or vegetation to provide stability to the surrounding soil. The key component of this protection is the ability to stabilize the top soil around the piers. The most damaging scour will occur during the flood surge and later when the surge ebbs. To minimize the scour risk to a bridge pier or other structure, protection must be put into place. Protection such as vegetation, rip rap and bulkheads, or even additional concrete, will help to prevent erosion of soil and undermining of a bridge or elevated structure.
For this study, because the piers are inland for overhead structures, the use of vegetation (grasses) appears to have a large potential benefit. The grasses may be augmented by larger vegetation if wave action is of concern. Providing vegetation roughly twice the diameter of the pier is needed to encompass the soil surrounding the piers and the potential footings. Given that a gallon planting of grass should be done every two feet approximately, and using an 18” diameter pier, then a conservative estimate would be 8 – 10 gallon containers per pier. This would result in a minimal material cost of approximately $30 per pier with these sizes. However, this number could double if specialty grasses are used. Additional costs for larger shrubs should be considered if additional protection around the boundary is required. Adding vegetation around piers as a stand alone project is more feasible than raising the road’s profile or hardening the surface, assuming the elevated structure design has room for vegetation or other options. There are additional costs to remove existing vegetation, design the landscape, and construct the site. These costs are primarily borne by the expressway project if erosion control is integrated, or mainstreamed, as part of the project.

2.6 Summary of Strategies

The table below provides a complete list of the strategies considered, with potential risks, and costs. These strategies where considered in the context of Gandy Boulevard and the Selmon Expressway West Extension, and apply only for the segment of Gandy Boulevard connecting the Gandy Bridge to the elevated corridor. The information is beneficial for other situations and should be customized as necessary.

The cost information provided are the marginal costs (cost differential) to implement the strategy as part of the Selmon Expressway West Extension project. Costs would be higher to implement the strategy as a stand-alone-solution, and are identified in the “Full Costs” column of the table. Cost components are identified when exact costs are not provided.

The level of risk provides an indication of the likelihood of mobility or infrastructure impacts as the result of a storm or flooding event should the strategy be implemented.

The phasing information indicates the relative time frame when the strategies should be considered for implementation. Based on climate stressor trends and planned construction projects a recommended time for implementation was chosen for each strategy. Near term represents an investment before 2020 which is warranted based on near-term sea level rise predictions together with precipitation projections. Long term represents an investment after 2040 where the climate indicators show that it is appropriate to delay actions. Finally, the congruent actions are adaptations that may make the most sense to implement while constructing a project.
## Table 4: Adaptation Strategies as Considered for Gandy Boulevard

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>MARGINAL COSTS</th>
<th>FULL COSTS</th>
<th>LEVEL OF RISK</th>
<th>PHASING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NO BUILD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Strategies Included</td>
<td>None.</td>
<td>Reconstruction cost is $3,312,000.</td>
<td>Highest Risk. Required if roadway destroyed.</td>
<td></td>
</tr>
<tr>
<td><strong>EROSION CONTROL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Attenuation Device</td>
<td>See Appendix D. $180-$250 per liner foot.</td>
<td>Same as marginal costs.</td>
<td>Medium Risk.</td>
<td>Long term.</td>
</tr>
<tr>
<td>Living Shoreline</td>
<td>See Appendix D. Dependent on design and materials.</td>
<td>Low Risk.</td>
<td>Long term.</td>
<td></td>
</tr>
<tr>
<td>Revetments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riprap ($306,700 @1/4 mile)</td>
<td>$2,698,960</td>
<td>Additional costs for design, engineering, site preparation, CEI, mobilization.</td>
<td>Medium Risk.</td>
<td>Near to long term.</td>
</tr>
<tr>
<td>Vegetation ($11,880 @1/4 mile)</td>
<td>$104,544</td>
<td></td>
<td>Low Risk.</td>
<td>Concurrent with project or near term.</td>
</tr>
<tr>
<td><strong>DRAINAGE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeable Pavement</td>
<td>Similar to conventional pavement when construction and drainage costs considered.</td>
<td>Additional costs for design, engineering, road removal, CEI, mobilization.</td>
<td>Not Applicable. Medium Risk.</td>
<td>Applicable for low speed and low volume roads, such as local roads accessing Gandy Boulevard.</td>
</tr>
<tr>
<td><strong>RAISE PROFILE/HARDEN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-depth concrete pavement</td>
<td>$676,000</td>
<td>$3,402,800</td>
<td>Medium Risk. (Lowest risk if combined with below.)</td>
<td>Concurrent with project.</td>
</tr>
<tr>
<td>Raise roadway profile to elevation 14 feet</td>
<td>$1,119,000</td>
<td>$3,762,000</td>
<td>Low Risk</td>
<td>Concurrent with project, if feasible.</td>
</tr>
</tbody>
</table>
### 3.0 Selmon Extension Adaptation Options

THEA’s consideration of adaptation strategies as part of the Selmon Expressway Western Extension project decrease risk of flooding and inundating and result in long term cost savings. By mainstreaming these strategies into the construction process, smaller marginal costs are needed to provide benefits from potential future risks.

A broad range of adaptation strategies were considered for implementation, and in coordination with THEA staff and consultants. The strategies are shown in Table 5 along with potential risks and costs. The total proposed costs are estimated to be $2,019,000 and may vary depending on the vegetation used for the pier protection, which is anticipated to be less than the embankment erosion control costs.

**Table 5: Selmon Expressway Adaptation Options - Strategies, Costs, & Risks**

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>COST DIFFERENTIAL</th>
<th>LEVEL OF RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation ($11,880 @1/4 mile)</td>
<td>$104,544</td>
<td>Low Risk.</td>
</tr>
<tr>
<td>Pier Protection Vegetation (Twice diameter of pier. Gallion plants @$3 each)</td>
<td>$30 per 18-foot diameter pier (More if specialty grasses or shrubs are included)</td>
<td>Low Risk.</td>
</tr>
<tr>
<td>Full-depth concrete pavement</td>
<td>$676,000</td>
<td>Medium Risk. (Lowest risk if combined with below.)</td>
</tr>
<tr>
<td>Raise roadway profile to elevation 14 ft</td>
<td>$1,119,000</td>
<td>Low Risk.</td>
</tr>
<tr>
<td>TOTAL (Maximum)</td>
<td>$2,019,000 (depends on pier protection)</td>
<td></td>
</tr>
</tbody>
</table>

It may be possible to undertake vegetation-based solutions as stand alone projects; however, because landscaping is part of the expressway project, identifying appropriate vegetation and specifying beneficial locations and types of plants (namely around piers and embankments) can be addressed early in the project. Hardening the road surface would be impractical to tackle as a stand-alone project and nearly always should be incorporated in a major upgrade or rehabilitation project, like the Selmon Expressway Western Extension. Emergency repairs would be another time to consider hardening the roadway.

In this performance-based age of planning and providing infrastructure, it is important to monitor the implementation effectiveness of the three strategies. Routine maintenance and operational activities should assess how the vegetation and hardened surface are faring over time. This is important to determine if adjustments should be made concerning the materials used in future projects.

Given the long design life of bridges and roadways, it is critical to incorporate vulnerability screening in future projects, starting with planning and continuing through engineering, design, and construction.
Appendix A – Storm Vulnerability

The Hillsborough County Local Mitigation Strategy\textsuperscript{10} was recently revised in 2015 [http://www.hillsboroughcounty.org/index.aspx?NID=3859](http://www.hillsboroughcounty.org/index.aspx?NID=3859). The LMS provides a profile of multiple risks, including storms and hurricanes. It assesses the vulnerability, identifies mitigation strategies, and outlines mitigation implementation. It is not possible to know with certainty when a storm will strike an area or the damage it may cause. However, the LMS provides a good reference for hazard and emergency management professionals. From the LMS:

The three major hazards produced by hurricanes and tropical storms are the storm surge, high winds and large rainfall.

Storm surge is the rise in water level in coastal areas caused by the wind and pressure forces of a hurricane. The more intense the hurricane the higher the surge will be. The output of the National Oceanic and Atmospheric Administration (NOAA) storm surge prediction model SLOSH shows that storm surge height of 28 feet or more above sea level could impact certain coastal and river areas under a “worst case” Category 5 hurricane.

Rainfall varies with hurricane size, forward speed, and other meteorological factors. Residents must be aware of flooding that may result from a hurricane especially along rivers that are major drainage systems and low-lying areas. Heavy rainfall may continue after the hurricane loses strength. The rainfall associated with a hurricane is from 6 to 12 inches on average with higher amounts common.

Historically, hurricanes and tropical storms are the natural disasters that pose the greatest threat to Florida including Hillsborough County. They have caused the greatest amount of property damage and as more people move to Hillsborough County and more development takes place the potential for hurricane-related deaths and damages, increases each year.

The National Oceanic and Atmospheric Administration (NOAA) also provides storm related information and has tracks of storms as far back as the 1850s. The past is not a predictor of the future but it offers perspective on the potential for a storm to strike.

Another important variable is to evaluate the economic impacts of potential storms. Recently, property information firm CoreLogic published a report stating that 454,746 homes, with a reconstruction cost of $80.6 billion, are vulnerable to hurricane flooding. Of those, 92,103 could be affected by a relatively modest Category 1 hurricane with storm surge in the 4- to 5-foot range.

Historical Hurricane Tracks

National Oceanic and Atmospheric Administration

Summary of Search

Location: 27.950575,-82.4571776
Buffer: 120380 Meters (65 Nautical Miles)

Search Refined By

Categories: H5,H4,H3,H2,H1

https://coast.noaa.gov/hurricanes/report.htm
<table>
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<th>Storm Name</th>
<th>Date</th>
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<tr>
<td>UNNAMED</td>
<td>1852Sep 03, 1852 to 1852</td>
</tr>
<tr>
<td>UNNAMED</td>
<td>1852Sep 09, 1852 to 1852</td>
</tr>
<tr>
<td>UNNAMED</td>
<td>1859Oct 23, 1859 to 1859</td>
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</tr>
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<td>UNNAMED</td>
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<td>UNNAMED</td>
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<td>UNNAMED</td>
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<td>UNNAMED</td>
<td>1880Aug 24, 1880 to 1880</td>
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<td>UNNAMED</td>
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<tr>
<td>UNNAMED</td>
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<td>UNNAMED</td>
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<td>UNNAMED</td>
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<td>UNNAMED</td>
<td>1921Oct 20, 1921 to 1921</td>
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<td>UNNAMED</td>
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<td>UNNAMED</td>
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<td>UNNAMED</td>
<td>1939Aug 07, 1939 to 1939</td>
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<tr>
<td>UNNAMED</td>
<td>1944Oct 12, 1944 to 1944</td>
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<tr>
<td>UNNAMED</td>
<td>1945Jun 20, 1945 to 1945</td>
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<tr>
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<td>1945Sep 12, 1945 to 1945</td>
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<tr>
<td>UNNAMED</td>
<td>1946Oct 05, 1946 to 1946</td>
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<td>UNNAMED</td>
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<td>EASY</td>
<td>1950 Sep 01, 1950 to 1950</td>
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<tr>
<td>DONNA</td>
<td>1960 Aug 29, 1960 to 1960</td>
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<td>GLADYS</td>
<td>1968 Oct 13, 1968 to 1968</td>
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<tr>
<td>ERIN</td>
<td>1995 Jul 31, 1995 to 1995</td>
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<tr>
<td>CHARLEY</td>
<td>2004 Aug 09, 2004 to 2004</td>
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<tr>
<td>FRANCES</td>
<td>2004 Aug 25, 2004 to 2004</td>
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<tr>
<td>JEANNE</td>
<td>2004 Sep 13, 2004 to 2004</td>
</tr>
</tbody>
</table>
Storm surge imperils 455,000 Tampa Bay homes, report says

By Susan Taylor Martin and Richard Danielson, Times Staff Writers

Wednesday, June 1, 2016 11:41am

Nearly 455,000 Tampa Bay homes could be damaged by hurricane storm surges, the most in any major metro area except Miami and New York City. And rebuilding all those homes could cost $80.6 billion.

That's according to a report released Wednesday by CoreLogic, a global property information firm, as the 2016 Atlantic hurricane season officially kicks off with two named storms already on the record books.

CoreLogic said 454,746 Tampa Bay homes are vulnerable to hurricane flooding, a number that represents about a third of all the area's homes. Of those, 92,103 are in what CoreLogic calls the "extreme" risk zone. That means they could be affected by even a relatively modest Category 1 with winds from 74 to 95 mph and a surge in the 4- to 5-foot range.

A color map accompanying the report shows the extreme risk zone in bright red, outlining almost the entire coastlines of Pinellas, Pasco and Hernando counties and most of the coastal areas in Hillsborough.

The gravity of the threat does not mean greater public awareness, however.

"I think any time we go this long without anything happening, people stop paying attention," Sally Bishop, Pinellas County's emergency management director, said Wednesday. "And you've got to remember that we're getting 50,000 new people (in the bay area) a year, probably a lot from parts of the country that don't even know what a hurricane is."

Tampa Bay has not received a direct hit from a major hurricane since 1921, though it dodged a potential catastrophe in 2004 when Hurricane Charley made an unexpected turn and slammed into the gulf coast farther south around Punta Gorda.

The federal Climate Prediction Center says the 2016 Atlantic season could have 10 to 16 named storms, of which as many as eight could become major hurricanes with winds of 111 mph or higher. Two tropical systems already have formed this year — Hurricane Alex, an extremely rare January storm,
and Tropical Storm Bonnie, which drenched parts of the Carolinas over the Memorial Day weekend.

The CoreLogic report is not quite as dire as one released last fall by a Boston-based firm, Karen Clark & Co. (KCC), which said Tampa Bay is the nation’s most vulnerable metro area to storm surge flooding caused by a once-in-century hurricane. It estimated potential losses at $175 billion, more than in New Orleans or New York City.

KCC said Tampa Bay acts as a "large funnel" for surges, forcing water into narrow channels and bayous with nowhere else to go.

"A severe storm with the right track orientation will cause an enormous buildup of water that will become trapped in the bay and inundate large areas of Tampa and St. Petersburg," the KCC study said. "Fifty percent of the population lies on ground elevations of less than 10 feet."

At a Tampa City Hall media conference Wednesday, city and National Weather Service officials said storm surge is the No. 1 threat from hurricanes or a tropical storm.

With a Category 3 hurricane or stronger, "you could very well see 25 feet of water where we are right now in downtown Tampa," said Brian LaMarre, meteorologist-in-charge of the National Weather Service for the Tampa Bay area.

June is a time when storm surge risk rises for the bay area, and LaMarre said forecasters already are watching "a developing system that may come close to Florida by mid to late next week."

"If we got a Cat 3 coming across Hillsborough Bay, my house is gone," said Mayor Bob Buckhorn, who lives on Davis Islands. "There will come a day when we will be hit. That is going to happen, I can promise you. ... When you hear me say it's time to evacuate, I am not kidding."

Thanks to a $30,000 federal grant it received a few years ago, Hillsborough County bought and posted 15 signs throughout the county to show how high the water could get.

"Most are no less than 13 feet, they're very dramatic," said Preston Cook, the county's emergency management director. "It's to remind people how serious this is."

Both Hillsborough and Pinellas offer a new system that sends weather alerts and other emergency information via cellphones, landlines, voice mail and text. (Sign up at pinellascounty.org/emergency or hillsboroughcounty.org/hcflalert or tampagov.net/police/programs/alert-tampa.)

According to CoreLogic, Florida has the highest number of homes at risk from hurricane flooding with a total of 2.7 million. In addition to Tampa Bay, the Fort Myers, Sarasota, Naples and Jacksonville areas ranked among the top 15 metro areas most vulnerable to storm surges.

Nationwide, more than 6.8 million homes along the Atlantic and gulf coasts are vulnerable to hurricane-related flooding, CoreLogic said.

Like other emergency management offices, "We (in Pinellas) do our best to educate residents," Bishop said, "but most people don't like to think about bad things happening to them specifically."

Contact Susan Taylor Martin at smartin@tampabay.com or (727) 893-8642. Follow @susanskate.
## Storm surge risk for top 10 metro areas

<table>
<thead>
<tr>
<th>METRO AREA</th>
<th>TOTAL PROPERTIES AFFECTED*</th>
<th>TOTAL RECONSTRUCTION COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miami</td>
<td>780,482</td>
<td>$144 billion</td>
</tr>
<tr>
<td>New York, N.Y.</td>
<td>779,373</td>
<td>$260.2 billion</td>
</tr>
<tr>
<td>Tampa Bay</td>
<td>454,746</td>
<td>$80.6 billion</td>
</tr>
<tr>
<td>New Orleans</td>
<td>390,806</td>
<td>$9.4 billion</td>
</tr>
<tr>
<td>Virginia Beach</td>
<td>385,084</td>
<td>$83.5 billion</td>
</tr>
<tr>
<td>Fort Myers/Cape Coral</td>
<td>306,953</td>
<td>$62 billion</td>
</tr>
<tr>
<td>Houston</td>
<td>280,112</td>
<td>$51.9 billion</td>
</tr>
<tr>
<td>Sarasota/Bradenton</td>
<td>250,615</td>
<td>$47.3 billion</td>
</tr>
<tr>
<td>Naples</td>
<td>180,919</td>
<td>$43.2 billion</td>
</tr>
<tr>
<td>Jacksonville</td>
<td>166,709</td>
<td>$35.8 billion</td>
</tr>
</tbody>
</table>

*Affected by all hurricane categories. Source: CoreLogic

---

Storm surge imperils 455,000 Tampa Bay homes, report says 06/01/16
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Appendix B – Adaptation Strategy Analysis for Gandy Boulevard

Submitted by Resilient Analytics
FINAL

Technical Memorandum

Adaptation Strategy Analysis for Gandy Blvd.

Prepared by:
Resilient Analytics, Inc.
Louisville, CO

June 2016
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1.0 Executive Summary

The Tampa Hillsborough Expressway Authority (THEA) is in the process of developing the request for proposal to design/construct the elevated connector and is interested in including adaptation strategies in the scope of work. The Pilot provided high level estimates of adaptation costs with little detail on physical design and construction. The purpose of this analysis was to analyze the vulnerabilities of the elevated section of the expressway extension at Gandy Boulevard and provide potential adaptation strategies for the three categories of vulnerability. Based on this overall objective, Resilient Analytics utilized both existing information from the Pilot study as well as climate models and analysis from the Infrastructure Planning Support System (IPSS) to determine additional vulnerability and adaptation strategies.

The result of the study indicates that the proposed Gandy Blvd. project is vulnerable in multiple areas including the three overall categories of concern; bridge piers and abutments, road surface and base, and adjoining coastal structures. Of particular concern in the study is the effect of storm surge and sea level rise. The additional height of inundation due to these variables requires the engineering solutions for Gandy Blvd. to consider additional stresses on the project from changing environmental conditions.

For bridge piers, the threat of scour from the increased wave and surge action may require additional strengthening or diversionary design considerations for the elevated section of the roadway. Similarly, the raised profile of the road will create embankments that are vulnerable to increased wave activity and erosion. Additional hardening of the embankments will be essential to minimize damage to the roadway base layers.

The surface of the roadway will not only undergo stress from the storm surge, but climate models indicate additional precipitation may weaken the roadway surface. Although permeable pavement does not appear to be an appropriate option, a cost-benefit analysis for options such as a concrete surface may be appropriate.

In summary, the storm surge and climate models indicate that the greatest threat to the Gandy Blvd. extension is the increased inundation depth that the project will likely experience. Given this vulnerability, a consideration for increasing the profile of the project a minimum of four additional feet will provide a significant benefit in terms of resiliency. When combined with pier strengthening, embankment hardening, and surface strengthening, the resiliency of the Gandy Blvd. project will be significantly enhanced.
2.0 Description of Site

The assessed segment commences as Gandy Boulevard makes landfall, continuing east to the site of the planned elevated connector. This segment is a critical link between Hillsborough and Pinellas counties. A map that details the surrounding area can be seen in figure #. The section of road analyzed is highlighted in green.

The area is partially armored with rip rap and a shallow bulkhead (proximate to a commercial/industrial facility on the northern face of the peninsula). Piles (remains of a former pier structure) ring the northwestern tip of the peninsula, providing some wave attenuation benefits (but not systematically so). The eastbound (EB) lane reaches the peninsula at grade, while the westbound (WB) lane rises from grade to an elevated, armored bridge approach. The WB approach is drained on the north side, using a shallow surface channel and grated inlets (flush with channel). The EB lane has no obvious drainage until the median begins (3 inlets near turn lanes).
3.0 Climate Data

Three type of inundation were analyzed for the assessment of Gandy Blvd:

- Sea level rise
- Storm Surge (combined with sea level rise), and
- Inland flooding

Sea level rise refers to the gradual increase in ocean elevations relative to land (as measured by tide gages) due to a variety of global and regional factors, such as melting artic ice sheets and glaciers, increasing water temperatures (thermal expansion), increasing salinity, and land subsidence.

For each analysis year and high and low projection was selected (intermediate scenarios were not used), following the methodology adopted by GeoPlan. Mean Higher High Water (MHHW), corresponding to the average highest high water height of each tidal day was selected as the tidal datum for all scenarios. The resulting sea level rise values can be seen in table #1.

<table>
<thead>
<tr>
<th>Scenario Depth (in)</th>
<th>2040 Sea Level Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (MHHW) 30</td>
<td></td>
</tr>
<tr>
<td>Inter (MHHW) 22</td>
<td></td>
</tr>
<tr>
<td>Low (MHHW) 20</td>
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<table>
<thead>
<tr>
<th>Scenario Depth (in)</th>
<th>2060 Sea Level Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (MHHW) 42</td>
<td></td>
</tr>
<tr>
<td>Inter (MHHW) 27</td>
<td></td>
</tr>
<tr>
<td>Low (MHHW) 22</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 1: SEA LEVEL RISE SCENARIOS

These scenarios were selected collaboratively and reflect the expert judgment and risk tolerance of key partners in the Tampa Bay region (such as the Regional Planning Council).

Storm surge is a coastal phenomenon that occurs when water is forced into the shore by powerful winds—most commonly due to a hurricane, tropical storm, or tropical depression—causing the temporary, sometimes dramatic elevation of sea levels. NOAA models surge using the Sea, Lakes, and Overland Surges from Hurricanes model (SLOSH). The height of the surge is determined based on historical, hypothetical, or predicted hurricanes, accounting for the atmospheric pressure, size, forward speed, tidal phase, and track of the storm event, as well as a set of physics equations that integrate shoreline characteristics, unique bay and river configurations, water depths, bridges, roads, levees and other physical features.

SLOSH simulates thousands of storms within a specific ocean basin, producing a record of the maximum recorded result for hundreds of shoreline grid cells, referred to as the Maximum Envelope of Water, or MEOW. By assembling the MEOW for each cell, the Maximum of the MEOWs, or MOM, is produced. There is one MOM for each hurricane velocity tier in the well-known Saffir-Simpson scale (hurricane Categories 1 through 5).

The MOMs, which were used for this study (Category 1 and Category 3), provide a valuable estimate of the greatest depth and extent of coastal flooding associated with the selected hurricane category at

---

1 http://sls.geoplan.ufl.edu/
3 http://www.nhc.noaa.gov/surge/slosh.php
specific locations. However, because the MOMs are the product of a multitude of simulated storms, it is important to note that the surge extents and depths they depict drastically overstate the potential inundation impacts of any single hurricane event within that Saffir-Simpson category\(^4\).

Sea level rise and storm surge were analyzed in combination. SLR was simply added to SLOSH, rather than remodeling surge under SLR scenarios. This technique provides illustrative results, but is valuable for planning. Table #2 shows the inundation depth for all combinations analyzed.

<table>
<thead>
<tr>
<th>Inundation Depth (ft)</th>
<th>Storm Surge Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cat. 1-Mean</td>
</tr>
<tr>
<td>Present Day-Low</td>
<td>4.70</td>
</tr>
<tr>
<td>2040-Low</td>
<td>6.37</td>
</tr>
<tr>
<td>2040-High</td>
<td>7.20</td>
</tr>
<tr>
<td>2060-Low</td>
<td>6.53</td>
</tr>
<tr>
<td>2060-High</td>
<td>8.20</td>
</tr>
</tbody>
</table>

**TABLE 2: INUNDATION DEPTH FROM SEA LEVEL RISE AND STORM SURGE SCENARIOS**

Note that these values may differ slightly when comparing to the pilot report. For this analysis, the SLOSH values were selected from the exact grid where Gandy Blvd is located.

Flooding from intense precipitation can also affect inland transportation assets, in conjunction with or separately from coastal phenomena. The approach to assessing future vulnerabilities to inland flooding leveraged official 100-year (one percent annual chance) floodplain maps. Based on the analysis of FEMA’s official Digital Flood Insurance Rate Map (DRIRM), the pilot report defines a FEMA 1% chance flood height of 9 feet.

4.0 Adaptation Strategies
The focus of this effort is to provide adaptation options for three distinct threats to Gandy Blvd; 1) bridge piers and abutments, 2) general road and adjoining area vulnerability, and 3) erosion issues to coastal roads. These three areas combine within a broader group of adaptation strategies that cross the different vulnerability categories. These adaptation categories include; 1) erosion control, 2) drainage, and 3) strengthening and profile adjustment. The following sections delineate options within each of these adaptation categories.

4.1 Erosion Control
Sea level rise is a potential threat to roadways at low lying elevations and to roadways where increased wave height and energies can cause erosion and scour on road embankments. Increases wave heights from sea level rise will require an increase of protection of the coast and roadway embankment. When sea level rise is coupled with storm surge we will see an even greater erosive effects and a greater possibility of overtopping. In order to combat the erosive forces associated with the potential increase in sea level rise and storm surge, adaptation strategies can be put into place to improve the resiliency of Gandy Blvd. This section will discuss a variety of possible strategies.

4.1.1 Wave Attenuation Devices
Wave attenuation devices (WADs) can be used to protect on shore infrastructure from increasing forces of erosion. WADs reduce the force of waves striking the coast by dissipating energy when waves encounter them. A field experiment was conducted at the Greenshores Coastal Restoration Inc. (CRI)\(^5\) wave-attenuation-device site in Pensacola Florida in order to quantify the wave-height and wave-energy reduction achieved by a wave attenuation devices. Wave height and wave energy measurements were taken from and offshore area and from various locations in the protected near shore area. The field measurements show that WADs are capable of reducing the wave height and wave energy by over 80%. It is important to note that the effectiveness of the WADs is strongly influenced by the design and configuration of the structures. Results of each site reduction in wave height and wave energy can be seen in figure #2.

For this study one of the 4 sites performed poorly in comparison due to a substantial gap and reflected waves from a seawall. Wave characteristics may also have a significant influence on wave reduction.

There are two main commercial types of WADs. The first type, which was used in the field study, is usually made with concrete and is submerged to the ocean floor and can be seen in figure #3.

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http://www.livingshorelinesolutions.com/uploads/Wave_Attenuation_Study_2007.pdf, Figure 12

http://www.tbo.com/news/business/pyramid-key-to-saving-egmont-key-20140526/
This type of WAD has minimal impact on the live bottom due to its small footprint. They act as an artificial reef and facilitate local fish populations. The second type is a floating WAD. Floating WADs are completely portable and do not require major construction to move.

![Floating Wave Attenuation Device](https://www.whisprwave.com/products/wave-attenuators/medium-floating-wave-attenuator/)

The flexibility provides usefulness for sites that are subject to change. In one case study, a floating Wave Dispersion Technologies, Inc. (WDT) WAD was able to dissipate waves within a marina in Lake Ontario NY by 90%.

The effective use of wave attenuation devices for the Gandy Blvd. project is dependent on the potential increase in wave activity in the more protected, inland area where the project is proposed to be built. As previous studies on wave action in the Tampa Bay region have found, the difference between the outer areas of Tampa Bay and the inner regions is significant in terms of wave impacts. However, sea level rise and the accompanying storm surge could change this dynamic in the future.

4.1.2 Revetments and Sea Walls
Coastal roads can be extremely susceptible to erosion on the seaward side due to increased wave erosion and higher tides. The concept of hardening the seaward side is to provide protection against this increased hydrologic action and specifically to protect the roadbed from direct exposure to the elements. To accomplish this protection, the seaward side of the road embankment will be hardened using a revetment or seawall that is placed along the slope where exposure to water may occur.

The distinction between revetments and seawalls is one of functional purpose. Revetments are layers of protection on the top of a sloped surface to protect the underlying soil. Seawalls are walls designed to protect against large wave forces. Seawalls are rigid structures or rubble mound structures specifically designed to withstand large wave forces. Some types of larger seawalls such as the Galveston Seawall

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also protect against overtopping. These larger structures are not common in the US because they require extensive marine structural design. Rubble mound seawalls are much more common in the US. Rubble mound seawalls look like revetments, but contain larger stones to withstand larger waves. Thus, the Federal Highway Administration (FHWA) uses the two terms seawall and revetment interchangeably.

For revetments the FHWA recommends a design approach based on determining a design wave and using Hudson’s equation to estimate stone size for embankments subject to wave action. The fundamental philosophy is that the revetment will be efficient at absorbing wave energy in that damage is not often catastrophic. Figure #5 shows a typical revetment design cross-section.

![Revetment Design:](image)

**FIGURE 5: TYPICAL REVETMENT DESIGN CROSS SECTION**


Sea level rise and its impact on sustaining taller waves could present challenges for maintaining the functionality of the roadway or coastal embankments. Therefore, the increase in sea level and wave height should be taken into consideration when designing seawalls and revetments. The current sections of the coast surrounding Gandy Blvd that are already armored with rip rap should be assessed to see if they are appropriately sized for increasing sea level rise and storm velocities.

During a storm surge event, road embankments that are not ordinarily exposed to wave action wave erosion could be due to higher water levels. In order to prevent erosion during these extreme events, this embankment should also be armored according to a revetment design.
FIGURE 6: WESTBOUND LANE EMBANKMENT OF GANDY BLVD.

Figure #6 shows an embankment of the westbound lane of Gandy Blvd. Although the base of this embankment is approximately 7 feet above sea level, under sea level rise and storm surge conditions this slope may be exposed to wave attack. Although the trees will provide some erosion protection, armoring this slope with rip rap or other natural vegetation will help improve the resiliency of the roadway.

4.1.3 Vegetation as Erosion Control

Another approach to reducing erosion on the seaward side of a road in scenarios where there is only minor to moderate wave or overtopping actions is to use vegetation as binder on the seaward slopes. Specifically, grassy vegetation and shrubs can be used to combat erosion in slight to moderate conditions. Dune grass and marsh grass have proven to be effective to reduce erosion as well as shrubs appropriate to local conditions\(^1\).\(^2\). Florida has had success with a wide variety of trees and shrubs for erosion control ranging from Live Oak and Buttonwoods to shrubs such as Holly.

However, the most common approach to direct erosion control is seeding with grasses\(^3\). Grass is effective at covering and protecting soil from wind and water erosion. When seeding grasses it is ideal to use a mixture of creeping and clumping types. Creeping grasses form a continuous root system, or mat. Clumping grasses leave gaps between plants that can be vulnerable to erosion, but grow very deep roots. Seed mixes normally include grasses that germinate quickly, and the optimum seed mic will depend on the soil, site and climatic conditions. To ensure the highest success rate, the surface soil should be scarified and loosened. Grasses can be established by hand seeding, hydro seeding, or with sod.

Another category of grasses that have been used to stabilize structures are deep rooted grasses such as vetiver. Vetiver is a perennial grass that grows in large clumps with a branched and spongy root system. Vetiver has been shown to decrease soil loss by more than 80% compared to stone barriers, other


\(^3\) http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_430.pdf
vegetation and bare ground. Vetiver’s massive root system generally holds the upper 3-4 meters of soil in place. Vetiver roots have an average tensile strength of 75 MPa, which increase the average strength of the surrounding spoil by 30 to 40%16. Furthermore, vetiver grass has not been observed as an invasive species. Vetiver is widely adaptable to adverse growing conditions. It has no major pests or diseases, it is extremely salt tolerant and can grow in many different soil types.

### 4.2 Cost Approach for Coastal Erosion Strategies

#### 4.2.1 Revetments

When determining the appropriate design for the seaward hardening of a road structure, several design guidelines are appropriate. First, the recommended slope of the riprap is important as a slope which is too steep will experience damage from wave action which will result in rocks being removed from the hardening layer. Second, appropriate size armor stones must be used to ensure that the stones are large enough to resist the wave action. And finally, the placement of the riprap must be guided by individuals rather than just dumped by the side of the road to ensure proper interlocking and placement. These guidelines are used to develop the cost approach.

Specifically, the cost of hardening the seaward side of a road is primarily comprised of the cost associated with placing riprap along the seaward side. However, to arrive at an appropriate cost, the recommended design guidelines for the placement are taken into account.

The total cost of riprap is based on the tons of riprap required for a project. Determining this quantity is based on the recommendation that the riprap slope be not more than a 3:1 slope and that the median size of the individual stones in the riprap be 770 pounds17. A variable in this analysis is the height of the road above the sea level. Since this will be specific to each case, the DOT recommendation of having at least a 7.5’ horizontal run for the slope is used as a baseline. Using this guideline, the actual cost is calculated as follows:

- Design height = 7.5’ / 3 = 2.5’
- Rock weight: 770 pounds
- Cost per ton of riprap (RS Means 2008): $40
- Weight of rock per cu. Ft.: 150 pounds
- Size of design triangle (1 ft wide) = 7.5’ * 2.5’ * 1’ = 18.75 cu. Ft.
- Pounds of rock per cu. Ft.: 150 pounds * 18.75 cu. Ft. = 2,812.5 lbs.
- Tons of rock per .25 mile: 7,420 tons
- Cost of rip rap per .25 mile: $296,775
- Cost of geotextile slope protection per .25 mile: $9,920
- Total Cost of hardening per .25 mile: $306,695

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4.2.2 Vegetation as Erosion Control

The total cost of vegetation is based on a similar approach to that taken for strengthening the seaward side with riprap. Specifically, the total area of coverage is calculated from the recommended design guidelines for a slope and then the cost of the vegetation is calculated for that area of coverage. Once again, determining this quantity is based on the recommendation that the design slope of the roadside not be more than a 3:1 slope\textsuperscript{18}. Since the height of the road is specific to each case, the DOT recommendation of having at least a 7.5’ horizontal run for the slope is used as a baseline. Using this guideline, the actual cost can be calculated as follows:

Design height = \( \frac{7.5'}{3} = 2.5' \)
Length of slope to cover = 8 Ft. (top to bottom)
Number of rows of vegetation required at 1’ intervals: 3
Cost of 3 plants: $3.00 * 3 = $9.00
Total Cost of vegetation per .25 mile installed: $11,871

The variable in this calculation is the specific cost of the vegetation. In the case of Gandy Blvd, several options exist based on experience in Florida including grasses, shrubs, and even trees in some areas. Recent studies have placed installed costs for these different options at $3 per gallon planting for grasses to $5 per gallon for trees\textsuperscript{19}. The total cost will then be dependent on amount of coverage required. However, the benefit of vegetation is that it is intended to be self-sustaining in that once it is planted, there should be minimal maintenance cost in the future.


\textsuperscript{19} South Florida Coastal Program
4.3  Drainage

Sea level rise will effect drainage efficiency in many ways. Lower hydraulic head and higher water tables would reduce natural drainage and storm surges will be higher and may permanently inundate the area. Permanent inundation will render gravity systems useless and will require modifications to prevent seawater from backing up into the system\textsuperscript{20}. Increased precipitation may also lead to increases in flood frequencies and therefore will effect drainage systems. Drainage system adaptation strategies should be put into place to expedite flood recovery, and to properly drain larger runoff flows from increased precipitation.

4.3.1  Permeable Pavement

Permeable pavements, also referred to as porous pavements, are load-bearing, durable highway surfaces that have an underlying layered structure that temporarily stores water prior to infiltration into soil or drainage to a controlled outlet. The advantage of such a pavement system is that it can help to reduce runoff volume during periods of peak flow and minimize flooding. According to the California Storm Water Quality Association\textsuperscript{21}, permeable pavements have the following limitations:

- Appropriate only for gentle slopes;
- Can become clogged if improperly installed or maintained; and
- Appropriate only for highways with low traffic volumes, axle loads, and travel speeds (< 30 mph)

Gandy Blvd. does not fall within the limitation of speed limit, however permeable pavements could be an option for the local roads to either side. Limiting the runoff of these surfaces will help to reduce flows into the drainage system for Gandy Blvd. Permeable pavements are up to 25 % cheaper (or at least no more expensive than the traditional forms of pavement construction), when all construction and drainage costs are taken into account\textsuperscript{22}.

The design elements associated with the construction and maintenance of porous pavements include initial grading, paving, and excavation of up to four feet of soil. Once excavated, a sight well, stone fill, and filter fabric are installed. Finally, the area is seeded and landscaped appropriately. A schematic representation of a porous pavement design, including the major construction elements, is provided below.

![FIGURE 7: TYPICAL CROSS SECTION OF PERMEABLE PAVEMENT](image)

The benefit of this form of solution is that permeable pavement will reduce the runoff associated with traditional pavement by allowing greater drainage into the soil. The design lifespan remains the same

\textsuperscript{20} Journal of Water Resources Planning and Management, Vol. 113, No. 2., March 1987
\textsuperscript{21} https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Section_4.pdf
\textsuperscript{22} Niemczynowicz J, Hogland W, 1987.
and typical maintenance remains the same according to existing studies\textsuperscript{23}. However, as stated previously, the load capacity of permeable pavements is less than traditional pavements thus making it usable more for side roads than main thoroughfares.

### 4.3.2 Enhance Drainage Structures

Gravity drainage can be enhanced by increasing the size of drainage pipes and inlets. Increasing the size of the pipes or drainage canals will allow the system to drain a greater capacity of water. The number of inlets can also be increased. Inlets should always be located at the low points in the profile. In addition flanking inlets on each side of the low point inlet should be installed to act in relief of the low point inlet when the low point drain gets clogged (common during intense storms) or if the design spread is exceeded\textsuperscript{24}. A flanking inlet system can be seen in figure #8.

![FIGURE 8: EXAMPLE OF FLANKING INLETS\textsuperscript{25}](image)

This type of system will benefit the roadway under two separate scenarios, increased precipitation and inundation from storm surge. When designing inlets to high volume culvert numerous cross-sectional shapes are available. The most commonly used shapes are circular, pipe-arch and elliptical, box (rectangular), modified box, and arch. Other general drainage design considerations are detailed by the FWHA\textsuperscript{26}.

Drainage on bridge decks is often less efficient than roadway drainage because slopes are flatter and are easily clogged by debris. Runoff from bridge decks should be collected directly after it flows to the underlying road system. In order to account for this excess water, larger grates and inlet structures should be constructed where the bridge meets the roadway\textsuperscript{27}.

Another major problem associated with storm water runoff is the stability and durability of the slopes, ditches, and embankments. One identified method for preventing erosion of these earthen structures is to reinforce them with concrete surface treatments. Additionally, during the reinforcement process, the

\textsuperscript{23} Virginia DCR Stormwater Design Specification No 7 http://vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec7PERMEABLEPAVEMENT.html
\textsuperscript{24} FHWA, 2009. Hydraulic Engineering Circular 22
\textsuperscript{25} FHWA, 2009. Hydraulic Engineering Circular 22, Figure 4-22.
\textsuperscript{26} FHWA, 2009. Hydraulic Engineering Circular 22
\textsuperscript{27} Journal of Water Resources Planning and Management, Vol. 113, No. 2., March 1987
ditch capacity can be increased. Such treatment decreases floodwater concentration and promotes flow
to designated reservoirs. One should note that ditches are used on many standard highway construction
projects as a means to control runoff from the highway surface\textsuperscript{28}.

Sea level rise is likely to create a higher water table below the road structure. Under this condition the
saturation of the sub-base can reach levels that decrease the strength of the aggregate. Impermeable
gotextile can be placed between the subbase and the subgrade to avoid such saturation. This should be
coupled with a draining layer to let water flow from the subgrade to the lateral drain\textsuperscript{29}.

\textsuperscript{29} Climate Change, Energy, Sustainability and Pavements, 2014.
4.4 Strengthen and Raise Profile

Sea level rise and storm surges will cause more frequent inundation of Gandy Blvd. This section will detail two of the more direct ways to combat inundation damages. The first is raising the profile of the roadway and the second is strengthening the road to withstand increased flooding forces.

4.4.1 Raise Profile

According to the THEA conceptual plans, the elevated connector will run over top of the existing Gandy Blvd. from the Selmon Expressway and begin to decline back to grade approximately .38 miles from the Gandy Blvd Bridge. This will leave approximately .35 miles of Gandy Blvd at grade before the Gandy Blvd Bridge. The proposed roadway profiles for the eastbound and westbound lane can be seen in figure #9.

Once at grade the westbound lane continues until it eventually rises from grade to an elevated, armored bridge approach, while the eastbound lane reaches the peninsula at grade. According to the plans, the lowest point of the eastbound and westbound lanes are approximately 10 feet above sea level. This section is clearly the most vulnerable to permanent inundation. Raising the profile of these roads using an elevated embankment is one option to alleviate possible inundation. However, the eastbound and westbound lanes have two different limiting elevation assuming that the bridge connectors must be kept at the same elevation. The westbound lane connects with the Gandy Blvd Bridge approximately 24

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30 FTE, 2015
feet above sea level, while the eastbound lane makes landfall at only 14 feet above sea level. Therefore the maximum elevation of the westbound and eastbound lanes are 14 and 4 feet respectively.

In order to analyze the benefits of elevating the roadway, we first have to address the possible storm surge and sea level rise scenarios. All of the possible scenarios analyzed can be seen in table #3.

<table>
<thead>
<tr>
<th>Inundation Depth (ft)</th>
<th>Storm Surge Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cat. 1-Mean</td>
</tr>
<tr>
<td>Present Day-Low</td>
<td>4.70</td>
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<tr>
<td>2040-Low</td>
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<td>6.53</td>
</tr>
<tr>
<td>2060-High</td>
<td>8.20</td>
</tr>
</tbody>
</table>

**TABLE 3: INUNDATION DEPTH FROM SEA LEVEL RISE AND STORM SURGE SCENARIOS**

Based on table #3 and the FEMA 1% chance flood depth of 9 feet we can begin to see what event the roadway will be vulnerable based on inundation levels and the lowest elevation of the roadway. We can see that if the lowest roadway elevation is 10 feet above sea level, permanent inundation would not occur for any sea level and category 1 storm surge combination. However, we may see overtopping from wave attack if waves are just a few feet in height. For category 2 and 3 storm surges we would see permanent inundation in all but one sea level and storm surge combination if the roadway is 10 feet above sea level.

Based on the limiting elevation of 14 feet for the eastbound lane, both roads could potentially be elevated by 4 feet. This would involve constructing a 4 foot embankment for both lanes to sit on. Furthermore the embankment must be armored with a revetment described in previous sections in order to protect from erosion during storm events. If the roadway is built at 14 feet above sea level it is protected against permanent inundation all category one sea level storm surge and sea level combinations. Furthermore, the roadway would be protected against most category 2 storm surge combinations. Although a 4 foot elevation of the road profile would not protect against a category 3, 4 or 5 storm surge scenario, it would still provide benefits in recovery. When the water levels begin to subside, the elevated road will allow for a quicker recovery effort and allow emergency vehicles to use the roadway again.

Comparing road elevation to categories of storm surge is helpful to understand the level to which the roadway is protected against varying levels of storms. However it is also important to understand how often storm surges will happen. For this we can compare the road elevation to the design peak storm surge heights. Table #4 shows the peak design storm surge heights recommended by the Florida Department of Transportation for Tampa Bay.

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TABLE 4: PEAK DESIGN STORM SURGE HEIGHT

For all sea level and design storm combinations a roadway at 10 feet above sea level would sustain a period of permanent inundation. However, when raising the profile to 14 feet above sea level we avoid permanent inundation for varying design storm and sea level rise combinations. These results are summarized in table # 5.

<table>
<thead>
<tr>
<th>Permanent Inundation (14 ft)</th>
<th>50-Year</th>
<th>100-Year</th>
<th>500-Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level Rise Scenario</td>
<td>Present Day 2040-Low</td>
<td>2040-High</td>
<td>2060-Low</td>
</tr>
<tr>
<td>50-Year</td>
<td>No</td>
<td>No</td>
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</tr>
</tbody>
</table>

TABLE 5: PERMANENT INUNDATION PROFILE

Avoiding permanent inundation is extremely valuable for multiple reasons. If the roadway is clear of water, this will allow for emergency vehicles to continue to use the roadway as needed. Furthermore, overtopping can cause significant stresses on the roadway due to weir flow. Furthermore the recovery process is expedited when the road is elevated. Figure #10 shows a time series of surge height for each design storm under present day sea level conditions.

FIGURE 10: TIME SERIES HYDROGRAPH FOR TAMPA BAY DESIGN STORM SURGE

Figure #10 shows the time of permanent inundation for each of the road profiles. A 500 year surge height leaves the 10 foot road and 14 foot road permanently inundated for 9 hours and 2 hours respectively. A 100 year surge height leaves the 10 foot road and 14 foot road permanently inundated for 4 hours and 0 hours respectively. A 50 year surge height leaves the 10 foot road and 14 foot road permanently inundated for 2 hours and 0 hours respectively. This illustrates that the raised road profile will decrease the time of inundation significantly, which will allow emergency vehicles to use the roadway once again.

Another option in raising the profile of the road is to only raise the westbound lane to a higher elevation. Only raising the westbound lane would provide economic benefits and still allow the roadway to be utilized in emergency situations. Evacuation traffic or emergency vehicles could still use the raised lane in a storm event in one or both directions, while the lower eastbound lane would remain closed due to inundation. As previously discussed, the westbound lane has a higher limiting elevation and can therefore be raised to a higher elevation. By raising the elevation of the westbound lane to an elevation of 15 feet, 20 feet or 24 feet, inundation could be avoided for a much larger storm surge event. Furthermore, emergency vehicles could use both lanes of the westbound lane to travel east or west. Raising the profile of the road to a higher elevation also provides some additional challenges in embankment construction and protection. The higher elevation would also provide a challenge when connecting Gandy Blvd to the local road on the north side of Gandy Blvd.

It is also important to note that the elevation profile of the route that emergency vehicles will take should be analyzed so that we can verify a limiting elevation. If any elevation under 14 feet exists on the route then some benefits of raising the profile on this section are lost until these elevation are also raised.

4.4.2 Bridge Pier and Abutment Protection

The combination of sea level rise and potentially more intense storm surges enhance the threat of potentially damaging coastal bridges. These forces can caused three different modes of failure: (1) the superstructure is uplifted by waves and washes away, (2) the substructure gets uprooted from vertical forces acting on the superstructure, or waves create lateral forces that cause failure, and (3) the substructure fails due to excessive scour. The first two modes of failure generally act on the bridge span, which is not included in the scope of this work, so no further details are provided.

Scour is one of the main failure mechanisms of a bridge pier or abutment. The raising of the Gandy Blvd. profile includes a component of bridge design that introduces the potential of scour for the project. The peak velocities of the storm surge that will cause the most damaging scour will occur during the flood surge and later during the ebb surge. In order to protect the bridge pier or abutment from scour, protection must be put into place. Protection component such as rip rap, bulkheads, and willow mattresses will help to prevent erosion of soil and undermining of the bridge structure.

Determining the appropriate protection for the bridge piers is dependent on the velocity of the water that is determined for the ebb and flow during the storm surge events. The velocities identified to move sand and non-sand particles provide the basis for determining when bridges need to be strengthened. Specifically, if the velocity of the water is fast enough to move particles, then the potential exists for scour.

---

to occur around the foundation. Therefore, given the establishment of a minimum velocity where strengthening needs to be considered, the next step in the process is to determine what levels of velocity could be absorbed by specific types of strengthening procedures. Once again, the FHWA provides guidance in this matter by establishing the use of riprap as the preferred initial countermeasure against scour (FHWA 2001). In this process, large rocks are placed at the base of bridge piers to protect the foundation footings and piers from the direct impact of water flow (Garcia 2006). The rocks create a diversion around the foundation and protect the bridge from critical scour forces. This recommendation and process are incorporated by the team as the initial countermeasure recommended for increased water flows.

Although riprap provides a strong countermeasure to scour, it is limited in terms of the maximum velocity it can withstand. When flow velocities become too high, there is concern that the riprap will fail and the bridge will once again be subject to scour. When velocities are determined to be above the maximum for the use of riprap, bridge piers need to be strengthened through the use of additional concrete strengthening around the footings.

Once again, the use of additional concrete follows established design guidelines set forth by governing agencies. This process requires the bridge footings to be partially excavated and a new application of concrete to be applied around the footing based on the load that the footing must absorb. This countermeasure will then be sufficient to absorb the increase in flows from climate change.

The east side of the Gandy Blvd. Bridge is already armored with rip rap and a shallow bulkhead. In order to prevent future failure due to scour, the current site should be re-analyzed using future sea level and wave projection scenarios.

### 4.4.3 Road Surface

A simple adaptation strategy that can be implemented is the use of rigid pavement over flexible pavements. Rigid pavements are more capable of withstanding erosive flows of water and are not structurally dependent on the sub-grade. Increased flooding and precipitation could cause more deformations in the subgrade which are transferred to the upper layer of flexible pavements and cause surfaces distresses. For rigid pavements, the deformation is not transferred to the subsequent layers and will therefore be more resilient to increase saturation. Overall the strength of the rigid pavements is less dependent on the strength of the subgrade, which limits failures under increased saturated conditions.

---

Although rigid pavements have a higher cost up front, the maintenance frequency and cost is lower. For this particular site, which is less than a half mile, the disadvantage of higher upfront cost would be limited. It also important to note that the use of reinforced concrete in the marine environment typically requires additional engineering considerations.36

4.4.4 Armored Shoulders
There are several ways in which overtopping damages pavements. One is direct wave attack on the seaward side of the road. A second is parallel flow of water to lower spots in the road as a storm surge recedes. The final mechanism is weir flow. Under weir flow conditions the road embankment acts like a broad crested weir to the incoming storm surge. As the surge exceeds the elevation water flows across the road and down the landward side at super critical flows. The super critical flows scour the shoulder material and can create devastating damages. Damages can occur with and without tail water. Figure #11 illustrates weir flow damage.

![Figure 12: Weir Flow Leading to Failure of Embankment](image)

Roads that experience overtopping can be armored to withstand high velocity flows. The armoring include sheet piling and gabions. The sheet piling should be located on the shoulder where supercritical flows are most likely to occur. Buried gabions are used when overtopping flow may be lower but parallel to the road during a storm event. A concrete revetment system is another option to reduce erosion from overtopping. The system should be comprised of heavy blocks, vertical and horizontal interlocking cables and anchors to resist hydraulic forces from overtopping. Capabilities of interlocking blocks have been confirmed in laboratory tests.39

---

36 Sosa et al, 2011.
37 FHWA, 2008.
38 FHWA, 2008. Figure 8.4
5.0 Time Series Analysis

A major decision for adaptation strategies is when they should be implemented. Looking at the general trends of climate stressors can help identify when certain strategies will be needed. This particular study focuses on flooding so the trends for precipitation and sea level rise were analyzed. Storm surge data is adjusted with sea level rise so it will show a similar trend. Figures #12 and #13 summarize the climate stressor trends. Precipitation data was compiled using the Infrastructure Planning Support System (IPSS). IPSS uses 42 IPCC approved CMIP5 climate models for the climate projections and historic Princeton climate data for the historic scenario. Low, intermediate and high scenarios were chosen based on the 5%, median and 95% model respectively from the 42 initial models.

![FIGURE 13: SEA LEVEL RISE TREND](image13)

![FIGURE 14: MAXIMUM MONTHLY PRECIPITATION](image14)
The sea level rise trends are very clear. Levels will increase 1.5-2.5 feet by 2040 and 2-3.5 feet by 2060. The precipitation trends are not as clear. The intermediate and high scenario predict that there will be an increase is maximum monthly precipitation compared to historic data. However, the low scenario predicts a decrease. Overall based on the models we can predict that maximum monthly precipitation will increase. The result of this increase is that pavement surfaces and drainage adaptations should be considered as a priority together with the protection from sea level rise and storm surge. Additionally, this increase has an impact on the timing of the adaptation consideration.

Adaptation strategies can be implemented in congruence with planned construction in order to save time and money. The planned elevated connector for this project has a huge influence on the recommended times for implementing many of the adaptation strategies.

Based on climate stressor trends and planned construction projects a recommended time for implementation was chosen for each strategy. A summary of this and each adaptation strategy can be seen in table #6. Near term represents an investment before 2020 which is warranted based on near-term sea level rise predictions together with precipitation projections. Long term represents an investment after 2040 where the climate indicators show that it is appropriate to delay actions. Finally, the congruent actions are adaptations that may make the most sense to implement while constructing the new Gandy Blvd. connector.

<table>
<thead>
<tr>
<th>Adaptation Option</th>
<th>Mitigation Effect</th>
<th>Recommended Time of Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Attenuation Device</td>
<td>Protects against increasing forces of erosion by reducing wave height and energy</td>
<td>Long Term</td>
</tr>
<tr>
<td>Coastal Revetment</td>
<td>Harden coast and embankment to protect from increasing forces of erosion</td>
<td>Near Term/ Long Term</td>
</tr>
<tr>
<td>Vegetation as Erosion Control</td>
<td>Reduce erosion of road to minor to moderate wave actions</td>
<td>Near Term</td>
</tr>
<tr>
<td>Permeable Pavement</td>
<td>Reduce flows into drainage system by limiting runoff of local roads</td>
<td>Congruent with Elevated Connector</td>
</tr>
<tr>
<td>Enhance Drainage System</td>
<td>Increase capacity and resilience of system to limit damage and increase flood recovery time</td>
<td>Near Term</td>
</tr>
<tr>
<td>Raise Profile</td>
<td>Prevent or lessen overtopping and permanent inundation</td>
<td>Congruent with Elevated Connector</td>
</tr>
<tr>
<td>Rigid Pavement</td>
<td>Increases resilience of road surface to erosive flows and subgrade failure</td>
<td>Congruent with Elevated Connector</td>
</tr>
<tr>
<td>Armored Shoulders</td>
<td>Protects against overtopping damages</td>
<td>Congruent with Elevated Connector</td>
</tr>
</tbody>
</table>

**TABLE 6: ADAPTATION STRATEGY SUMMARY**
WADs and Coastal Revetments are recommended to be implemented in the long term. Sea level rise is a slow process and will not have dramatic effects on coastal erosion for quite some time. In general the roadway is not very vulnerable to coastal erosion at present day sea levels. The specific stretch of Gandy Blvd. lies 120-300 feet from the coast. As sea levels begin to rise the coast will move closer to the roadway and WADs and revetments may have to be implemented. Erosion of the roadway embankment is still a concern during a storm event. Vegetation as erosion control of the roadway embankment is an easy and cost effective adaptation that can be implemented in the near term. The bridge abutment is vulnerable to storm surge and this vulnerability will increase with rising sea levels. It is recommended that the current site should be re-analyzed using future sea level and wave projection scenarios.

According to the National Oceanic and Atmospheric Administration\(^{40}\), the frequency and duration of extreme flood events is increasing in the Gulf. Furthermore climate models are predicting an increase in precipitation events in the Tampa Bay area. This makes enhancing the drainage system a top priority and a near term investment. Depending on the construction time of the elevated connector plans, the drainage system could be congruent.

The four remaining adaptation strategies are recommended to be implemented in congruence with the planned elevated connector. The local roads may have to be relocated due to the elevated connector, therefore adapting the local roads to be permeable pavement should wait until the connector construction. Raising the profile of the road will have an effect on the elevated connector, therefore this too should be implemented before for during the elevated connector construction. Raising the profile of the road is recommended to lessen the frequency of permanent inundation and increase recovery time. We recommend the road profile for both lanes be raised to 14 feet above sea level. If raising the profile of both lanes proves to be too costly then we recommend that only the west bound lane be raised. Furthermore the revetment protecting the raised embankment must be designed to withstand storm surge flow forces in order to limit failure. Armored shoulders and embankments are extremely important in protecting the roadway from flood flows. If the road profile is raised, then this strategy should be implemented during construction. If the profile is raised, rigid pavement should also be implemented during the construction process in order to save time and money. However, if the road profile is not raised, then it is recommended that rigid pavement be a long term investment or an investment at the end of the roads life.

Appendix C – Technical Memorandum Gandy Boulevard Adaptation

Submitted by Florida Transportation Engineering
FINAL

Technical Memorandum

Gandy Boulevard Adaptation

Hillsborough MPO
Metropolitan Planning for Transportation

Prepared by:
Florida Transportation Engineering, Inc.
Tampa, Florida

June 2016
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1.0 Purpose

The Hillsborough MPO is currently analyzing future impacts of high water due to sea level rise, storm surge, and wave action on several roadways in Hillsborough County.

The MPO is aware of plans by the Tampa Hillsborough Expressway Authority (THEA) to construct a two-lane elevated structure over Gandy Blvd., referred to by THEA as the Selmon Extension. It would allow drivers to bypass the business district along West Gandy Blvd. from Bridge Street to the current terminus of the Selmon Expressway near South Dale Mabry Highway via an elevated two lane bridge over the median. The final design and construction of the Selmon Extension is expected to be awarded as a design-build project by THEA in 2017.

A Project Development and Environmental Study (PD&E) for the proposed elevated structure (referred to then as the Gandy Connector) was completed in 2010. As part of that study, conceptual plans were developed for the entire 2.2-mile segment from the east end of the bridge over Old Tampa Bay (Gandy Bridge) to South Dale Mabry Highway. The plan is to reconstruct the roadway at its current elevation from the Gandy Bridge to Bridge Street. The two eastbound and two westbound lanes will be shifted outward to allow development of the embankment necessary to construct the ramps that will meet the new elevated structure. The eastbound and westbound lanes will continue to provide access at ground level to and from the business district. The elevated structure will begin approximately 3470 feet east of the Gandy Bridge and extend all the way to S. Dale Mabry Highway. It will provide a vertical clearance of 30 feet above Gandy Blvd.

The westbound Gandy Bridge is at elevation 24, and the older eastbound bridge is at elevation 14. The grade from the ends of these bridges drops to an elevation of 9 feet until the profile rises to meet the new elevated structure. Approximately 3100 feet of the alignment will be at an elevation at or below that of the eastbound bridge.

The MPO has identified that 3100-foot segment of Gandy Blvd. as being vulnerable to inundation during significant hurricane events, and wants to determine the costs associated with reducing the vulnerability of that segment.

This report summarizes the costs of various strategies, including hardening of the roadway surface through the use of concrete pavement, raising this segment from 9 to 14 feet above sea level, and reconstructing this segment. These strategies were analyzed in two ways: 1) implementation as part of the proposed construction of the Selmon Extension, and 2) implementation independent of the Selmon Extension.

2.0 Data Collection

The PD&E documents provided by THEA were reviewed, including the 2010 conceptual plans for the preferred alternative. An onsite review of the project site was conducted. References to stationing herein are based on the stationing used in the 2010 conceptual plans.
3.0 Existing Conditions

This segment lies within a peninsula that extends into Old Tampa Bay and is surrounded by water on the north, west, and south sides. A US Marine Corps Reserve facility is located on the north side of the roadway. A frontage road provides access to this site as well as to Al Palonis Park and the now-closed Friendship Trail bridge.

The Florida Fish and Wildlife Commission building is on the south side of the roadway. To its east lies the Coast Guard Auxiliary facility and the Gandy boat ramp. A short frontage road provides access to these facilities and Gandy Park South to the west.

Access to both frontage roads is currently provided at the same location, where full traffic movements are allowed at a median opening. The 2010 conceptual plans indicate that left turns will no longer be provided at this location, and that a new full movement intersection will be constructed approximately 550 feet west of the current intersection, at Sta. 611+70.

It is assumed that it will be necessary to maintain the proposed access points under any modification recommended by this study.

Most of the land on this peninsula is owned by the Florida Department of Transportation (FDOT). The site on which the Coast Guard Auxiliary is located, including the Gandy boat ramp, is owned by Hillsborough County. Several parcels of land east of the boat ramps, and adjacent to Bridge Street, are privately owned. Any widening of the footprint of Gandy Blvd. that is required in order to reduce the vulnerability to inundation is not expected to create a need for additional right-of-way.

The primary constraint is the wetlands, especially on the south side.

4.0 Analysis

4.1 Drainage

The City of Tampa is preparing to undertake a watershed study for the area of South Tampa known as the Lower Peninsula. Gandy Blvd. is within the limits of the study area. The resulting stormwater model will allow the City to prioritize improvements to the drainage system. Drainage in the area surrounding Gandy Blvd, east of Bridge Street, is collected in roadside ditches and storm sewers, then directed to a canal known as the Gandy Canal. The Gandy Canal lies north of the commercial businesses that line the north side of Gandy Blvd. It flows to the west, passing under Culbreath Key Way through a box culvert before discharging into Old Tampa Bay. The peninsula on which this segment of Gandy Blvd. is located is west of the outlet, so any stormwater that falls in this study area will not affect the drainage area served by the canal. Thus, the canal will not be affected by any work on the subject segment of Gandy Blvd.

Any significant rise in the water level during a hurricane event will cover the miscellaneous drainage culverts in the area during the time of inundation, resulting in a probable need for FDOT maintenance crews to clean out the structures of vegetation following an event of any magnitude. No damage is expected to occur as a result of heavy local rainfalls, as the storm water will percolate into the sandy soil and any excess will simply sheet flow off the peninsula into the bay.
4.2 **Harden the Roadway Pavement**

A significant period of inundation of the roadway could cause pavement failures along this segment. In order to reduce the possibility of such failures, concrete pavement could be considered. The risk associated with pavement buckling from prolonged inundation is much less with a rigid pavement (Portland Cement Concrete) than it is with asphalt pavement.

4.3 **Raise the Roadway Profile**

Two options were evaluated for raising this segment: 1) raise both the eastbound and westbound directions of the roadway or 2) raise only one direction.

The option to raise one side of the roadway to elev. 14 would prohibit left turn movements at the intersection. In order for eastbound traffic to access the Marine Corps Reserve facility, drivers would have to make a U-turn just east of the beginning of the Gandy Connector bridge and proceed westerly along the at-grade westbound lanes to the main entrance to the facility.

In a similar fashion, there is no feasible method for westbound traffic to access the facilities on the south side. The most likely location for westbound drivers to access the south side would be to allow left turns at Bridge Street, then construct a new frontage road from Bridge Street west to a point where it could tie to the existing frontage road, east of the Fish & Wildlife Conservation Commission building. Such a road would require a modification to operations at both the Fish and Wildlife site and the Coast Guard Auxiliary, and would require the acquisition of right-of-way from private property on the southwest quadrant of Gandy Blvd. and Bridge St. Furthermore, the Contraflow plan, as described in the PD&E Study, would no longer be feasible, since traffic was designed to cross the median in this area. For these reasons, the option of raising only one side of the alignment was dropped from further evaluation.

Therefore, the best option for raising the profile of this segment would be to raise all lanes from the Gandy bridge to a point east of the east access to the marine corps facility. This is the location where the primary (at-grade) lanes of Gandy Blvd. will begin to diverge to make room in the median for the center lanes to rise as they approach the connector bridge. The outside lanes can stay at-grade because they provide access to the at-grade segment of Gandy Blvd. Hence, there is no advantage in keeping those lanes elevated.

The full intersection at Sta. 611+70 that will provide access to the local facilities would be raised along with the alignment of Gandy Blvd. In order to keep the access roads leading up to the intersection from within reasonable grades, each of the four legs of the access roads would have to be lengthened approximately 150 feet more than what was shown in the 2010 concept plans. It is likely that a short retaining wall not exceeding 5 feet in height would be required on the outside of the frontage road on the south side to avoid impacts to the wetlands. In order to reduce the size of the roadway footprint, 2:1 side slopes are assumed. Guardrail would be required on both sides.

4.4 **Reconstruct the Roadway**

The roadway can tolerate minor inundation on the order of a few inches for a short period of time, more so if the pavement is Portland Cement Concrete. However, in the event of a major inundation of the
roadway, including significant wave action, the likelihood of the roadway being washed out is significantly higher if the above strategies are not implemented.

The cost of total reconstruction of the roadway was estimated (excluding the outer segments that will provide access to Gandy Blvd.), as reconstruction is more likely to be required if the roadway remains at elevation 9.

5.0 Costs

This report does not include a recalculation of the cost estimate for the proposed work as shown in the 2010 concept plans. Rather, the intent is to identify items of work that would be required to upgrade the 2010 concept plans to include the additional features identified and discussed in this report.

Conceptual costs for this analysis are based on historical unit costs tabulated by the Florida Department of Transportation (FDOT).

The costs required to harden the pavement and the costs required to raise the alignment were developed for two different cases: 1) If the work can be accomplished in conjunction with the upcoming Selmon Extension project, the marginal cost to upgrade the pavement or to raise the alignment are significantly lower, since the Final Design, Construction Engineering & Inspection (CEI), and other costs, such as mobilization, are already incorporated into the previously-established cost estimates. 2) If the work is accomplished at a date after the Selmon Extension is constructed, then the costs will be higher, because the work will involve an entirely new project, independent of previous work on the alignment.

While concrete would provide an increased level of risk against failure, it does not provide assurance that the entire roadway won’t be washed away as a result of constant and sustained wave action during a surge.

Table 1 provides a summary of costs associated with various upgrades.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cost to implement as part of Selmon Extension project</th>
<th>Cost to implement independently</th>
<th>Level of Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do nothing</td>
<td>N/A</td>
<td>N/A</td>
<td>Highest Risk</td>
</tr>
<tr>
<td>Upgrade to full-depth concrete pavement</td>
<td>$676,000 (^1)</td>
<td>$3,402,800</td>
<td>Medium Risk</td>
</tr>
<tr>
<td>Raise roadway profile to Elev. 14</td>
<td>$1,119,000</td>
<td>$3,762,000 (^2)</td>
<td>Low Risk</td>
</tr>
<tr>
<td>Raise profile to Elev. 14 and upgrade to full-depth concrete pavement</td>
<td>$1,795,000</td>
<td>$4,438,000 (^1) + (^2)</td>
<td>Lowest Risk</td>
</tr>
<tr>
<td>Reconstruct this segment with asphalt pavement</td>
<td>N/A</td>
<td>$3,312,000</td>
<td>Required if roadway is destroyed</td>
</tr>
</tbody>
</table>
6.0 Adaptation Cost Calculations

Determine cost to upgrade thru lanes from asphalt to PC concrete (as part of Selmon Extension)

Assumptions:

For asphalt pavement, use 5’ AC over OBG 10
For concrete, use 10” PCC

Pavement area:

From Sta. 600+60 to Sta. 606+00, 48’ (add 20% to allow for shoulders)
From Sta. 606+00 to Sta. 623+00, 84’ (add 20% to allow for shoulders)
From Sta. 623+00 to Sta. 635+50, 52’ (includes shoulders)

Area = ((540’ x 48’ x 1.2) + (1700’ x 84’ x 1.2) + (1250’ x 52’)) ÷ 9 = 29,718 SY

Asphalt pavement cost:

AC: 29718 SY x 5” x 110 ÷ 2000 = 8172 Ton \[ \rightarrow \] 8172 T @ $110 = $899,000

OBG: 29718 SY @ $17 = $505,000

$1,404,000

Concrete pavement cost:

10” PCC 29718 SY @ 70 = $2,080,000

Cost to upgrade to concrete pavement is the difference in cost between asphalt and concrete:

$2,080,000 - $1,404,000 = $676,000
Determine cost to upgrade thru lanes from asphalt to PC concrete (independent of Selmon Extension)

Assumptions:
Remove existing asphalt pavement and rebuild subbase
Final design = 12% of construction cost. CEI = 15% of construction cost

Pavement area:
From Sta. 600+60 to Sta. 606+00, 48’ (add 20% to allow for shoulders)
From Sta. 606+00 to Sta. 623+00, 84’ (add 20% to allow for shoulders)
From Sta. 623+00 to Sta. 635+50, 52’ (includes shoulders)

Area = ((540’ x 48’ x 1.2) + (1700’ x 84’ x 1.2) + (1250’ x 52’)) ÷ 9 = 29,718 SY

Removal of existing asphalt pavement:
29718 SY @$5 = $148,600

Type B Stabilization:
29718 x 1.1 = 32,690 SY
32690 SY @ $3 = $98,100

Concrete pavement (10”):
29718 SY @ $65 = $1,931,700

Mobilization: (8%):
$174,300

Maintenance of Traffic (5%):
$108,900

Mics. Items and contingency (10%):
$217,800

Construction subtotal:
$2,679,400

Final Design and CEI:
$321,500 + $401,900 = $723,400

Cost to upgrade to concrete pavement:
$2,679,400 + $723,400 = $3,402,800
Determine cost to raise profile of Gandy Blvd. to elev. 14’ (as part of Selmon Extension)
PD&E profile currently below elev. 14 (as low as 9) from approx. Sta. 609+00 to Sta. 632+00
Outside lanes east of Sta. 625+00 to/from Gandy business district would not be raised

Additional earthwork (fill) calculated based on approximating the width of the typical section for segments through the study area and calculating the volume between the PD&E profile and the adaptation profile

<table>
<thead>
<tr>
<th>Segment</th>
<th>Width of Typ. Section</th>
<th>Area under profile</th>
<th>Fill volume, CY</th>
</tr>
</thead>
<tbody>
<tr>
<td>609+00 to 612+00</td>
<td>148</td>
<td>891</td>
<td>4885</td>
</tr>
<tr>
<td>612+00 to 622+00</td>
<td>148</td>
<td>5388</td>
<td>29533</td>
</tr>
<tr>
<td>622+00 to 629+00</td>
<td>66</td>
<td>3756</td>
<td>9180</td>
</tr>
<tr>
<td>629+00 to 633+00</td>
<td>66</td>
<td>2548</td>
<td>6228</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>49827</td>
</tr>
</tbody>
</table>

Assume marginal cost of additional earthwork at $15/CY → 49827CY @ $15 = $747,000

Guard rail, 2500 LF, each side → 2500 x 2 @ $20 = $100,000

Retaining wall, assume 5’ height, 200 LF on south side → 5 x 200 @$40/SF = $40,000

Access Road extensions, 4 x 150 LF = 600 LF
Use FDOT Long Range Estimating System Cost per Mile models to generate approximate cost:
Divided Rural 2 lane → 600 LF ÷ 5280 @ $2,044,000/mile = $232,000

Total cost to raise profile → $747,000 + $100,000 + $40,000 + $232,000 = $1,119,000
Determine cost to raise profile of Gandy Blvd. to elev. 14’ (Independent of Selmon Extension)
PD&E profile currently below elev. 14 (as low as 9) from approx. Sta. 609+00 to Sta. 632+00
Outside lanes east of Sta. 625+00 to/from Gandy business district would not be raised
Earthwork (fill) calculated by approximating the width of the typical section through the study area and calculating the volume between the PD&E profile and the adaptation profile

<table>
<thead>
<tr>
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<td>622+00 to 629+00</td>
<td>66</td>
<td>3756</td>
<td>9180</td>
</tr>
<tr>
<td>629+00 to 633+00</td>
<td>66</td>
<td>2548</td>
<td>6228</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>49827</td>
</tr>
</tbody>
</table>

Earthwork @ $15/CY
49827CY @ $15 = $747,400

Type B Stabilization: 29718 x 1.1 = 32,690 SY
32690 SY @ $3 = $98,100

Asphalt pavement: 29718 SY x 5” x 110 ÷ 2000 = 8172 Ton → 8172 T @ $110 = $899,000

OGB: 29718 SY @ $17 = $505,000

Pavement total $1,502,000

Guard rail, 2500 LF, each side → 2500 x 2 @ $20 = $100,000

Retaining wall, assume 5’ height, 200 LF on south side → 5 x 200 @$40/SF = $40,000

Access Road extensions, 4 x 150 LF = 600 LF

Use FDOT Long Range Estimating System Cost per Mile models to generate approximate cost:

Divided Rural 2 lane → 600 LF ÷ 5280 @ $2,044,000/mile = $232,000

Mobilization (8%) $209,700

Maintenance of Traffic (5%) $131,100

Construction subtotal → $2,962,200

Final design & CEI: $355,500 + $444,300 = $799,800

Cost to raise profile $3,762,000
Determine cost to reconstruct segment from Gandy Bridge to Connector

Use FDOT Long Range Estimating System Cost per Mile models to generate approximate cost

Divided Rural 6 lane → 3490 LF ÷ 5280 @ $5,011,000/mile = $3,312,000

Table 2
FDOT Generic Cost Per Mile Models

<table>
<thead>
<tr>
<th>Models</th>
<th>Cost Per Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Directional, 12' Shared Use Path</td>
<td>$231,278.63</td>
</tr>
<tr>
<td>Rails to Trails project (12' width)</td>
<td>$210,966.24</td>
</tr>
<tr>
<td>Sidewalk construction; 5' one side, 4 inch depth</td>
<td>$110,391.99</td>
</tr>
<tr>
<td>Mid-Block Crossing</td>
<td>$99,148.12</td>
</tr>
<tr>
<td>New Construction Undivided 2 Lane Rural Road with 5' Paved Shoulders</td>
<td>$2,044,323.20</td>
</tr>
<tr>
<td>New Construction Undivided 3 Lane Rural Road with 5' Paved Shoulders, Center Turn Lane</td>
<td>$2,484,384.61</td>
</tr>
<tr>
<td>New Construction Undivided 4 Lane Rural Road with 5' Paved Shoulders</td>
<td>$3,051,267.01</td>
</tr>
<tr>
<td>New Construction, 4 Lane Divided Rural Road with 2' Paved Shoulders Inside and 5' Paved Shoulders Outside</td>
<td>$4,060,786.20</td>
</tr>
<tr>
<td>New Construction Divided Rural 4 Lane Interstate with Paved Shoulders 10' Outside and 4' Inside</td>
<td>$4,968,872.34</td>
</tr>
<tr>
<td>New Construction Undivided 5 Lane Rural Road with 5' Paved Shoulders, Center Turn Lane</td>
<td>$3,615,172.71</td>
</tr>
<tr>
<td>New Construction, 6 Lane Divided Rural Road with 5' Paved Shoulders Inside and Out</td>
<td>$5,011,296.20</td>
</tr>
<tr>
<td>New Construction Divided Rural 6 Lane Interstate with 10' Paved Shoulders Inside and Out</td>
<td>$5,900,872.50</td>
</tr>
<tr>
<td>New Construction Extra Cost for 1 Single Additional Lane on Rural Arterial</td>
<td>$519,043.17</td>
</tr>
<tr>
<td>New Construction Extra Cost for 1 Single Additional Lane on a Rural Interstate</td>
<td>$584,282.01</td>
</tr>
</tbody>
</table>

Disclaimer: These models are generic in nature, and not based on actual construction projects. They are for reference purposes only, and are not intended to predict or support future estimates.
Appendix D – Cost and Maintenance of Living Shorelines

Presented by Debbie L. DeVore, South Florida Coastal Program Coordinator, U.S. Fish and Wildlife Service
COST AND MAINTENANCE OF LIVING SHORELINES

Photo: C. Verlinde, University of Florida Sea Grant Extension

Debbie L. DeVore
South Florida Coastal Program Coordinator
What are Living Shorelines?

- Shoreline stabilization using living plant material (emergent and submerged aquatic vegetation), oyster shells, earthen material or a combination of natural structures with rip rap or offshore breakwaters to protect the shoreline against erosion.
- Living shorelines provide a more natural approach for erosion control, while allowing access for coastal and estuarine organisms.
Decision Steps

- Conduct Site Assessment
  - Including bank erosion, bank elevation, bathymetry, fetch, wave energy, prevailing wind direction, vegetation presence, soil type, etc
- Project Design
- Cost Estimate
- Apply and Receive Permits
- Hire Contractor
- Construct Project
What are the options for shoreline protection? (and how much do they cost??)

Do nothing. Set structures back from the edge of the river, bay, or beach.
Plant vegetative cover such as submerged aquatic vegetation (e.g., seagrass) or emergent intertidal vegetation (e.g., cordgrass sp.)

- Typically use in low-energy environments (tidal creeks, tributaries, streams, rivers)
### Vegetative Cover

<table>
<thead>
<tr>
<th>Plant</th>
<th>Unit</th>
<th>Cost Range ($/unit)</th>
<th>Cost Installed ($/unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth cordgrass (Spartina alterniflora)</td>
<td>Plug</td>
<td>1.25</td>
<td>$2-3 Plug $3 Gallon</td>
</tr>
<tr>
<td>Marshay cordgrass (S. patens)</td>
<td>Plug</td>
<td>$1.25</td>
<td>$2-3 Plug $3 Gallon</td>
</tr>
<tr>
<td>Mangrove</td>
<td>Gallon pot</td>
<td>$10</td>
<td>$5 Gallon</td>
</tr>
<tr>
<td>Salt grass (Distichlis spicata)</td>
<td>Plug</td>
<td>2” - $.60 4” - $1</td>
<td>$2 Plug $3 Plug</td>
</tr>
<tr>
<td>Bitter panicum (Panicum vaginatum)</td>
<td>Node</td>
<td>$1</td>
<td>$2 Plug $3 Plug</td>
</tr>
<tr>
<td>Freshwater species</td>
<td>Gallon pot</td>
<td>$5-6</td>
<td></td>
</tr>
</tbody>
</table>

**Spacing:** Varies for species & depending on site objective (typically 2’, 3’, or 4’ centers)

**Maintenance:** Minimal maintenance typically required; supplemental planting, remove debris, trimming, fertilize, minimize disturbance
Other Soft, Non-structural Stabilization

- Use natural, nonstructural, or biodegradable materials
- Typically use in low-energy environments (tidal creeks, tributaries, streams, rivers)
Other Soft, Non Structural Stabilization

- Use natural, nonstructural, or biodegradable materials
- Typically use in low-energy environments (tidal creeks, tributaries, streams, rivers)

January 2001

April 2004
## Other Soft, Non Structural Stabilization

<table>
<thead>
<tr>
<th>Technique</th>
<th>Unit</th>
<th>Cost Range ($/unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Snow” fencing</td>
<td>100’</td>
<td>$45.00</td>
</tr>
<tr>
<td>Coir Log</td>
<td>10’ lengths</td>
<td>$57.25</td>
</tr>
<tr>
<td>Erosion Control Blankets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straw Blanket</td>
<td>Yd$^2$</td>
<td>$0.29</td>
</tr>
<tr>
<td>Coconut Straw Blend</td>
<td></td>
<td>$0.52</td>
</tr>
<tr>
<td>Coconut Fiber</td>
<td></td>
<td>$0.65</td>
</tr>
<tr>
<td>Geotextile tube</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15’ circumference</td>
<td>Linear foot</td>
<td>(2007 prices)</td>
</tr>
<tr>
<td>22’ circumference</td>
<td></td>
<td>$115-175</td>
</tr>
<tr>
<td>30’ circumference</td>
<td></td>
<td>$175-225</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$140-200</td>
</tr>
</tbody>
</table>

**Misc. Costs:** Delivery and freight charges; mobilization and demobilization ($40-50k per project for Geotextile tubes)

**Maintenance:** Most of these fabrics are biodegradable, some require removal; geotextiles have a longer life, but are UV sensitive.
Offshore/Nearshore Breakwaters

- Structure built parallel to the shoreline that protects land by reducing wave energy
- Use in medium and higher energy environments
# Offshore/Nearshore Breakwaters

<table>
<thead>
<tr>
<th>Technique</th>
<th>Unit</th>
<th>Cost Range ($/unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oyster Shell</td>
<td>Loose Shell (yd³)</td>
<td>$50-60</td>
</tr>
<tr>
<td></td>
<td>Bag</td>
<td>$5 ($30 for bag w/spat)</td>
</tr>
<tr>
<td>Concrete Bags</td>
<td>Bag</td>
<td>$4-6 (~$12-16/lf)</td>
</tr>
<tr>
<td>Limestone Rock</td>
<td>Linear foot</td>
<td>$125-200</td>
</tr>
<tr>
<td>Reef Balls</td>
<td>Linear foot</td>
<td>$44 installed</td>
</tr>
<tr>
<td></td>
<td>Delivery</td>
<td>($~$36-38 w/volunteers)</td>
</tr>
<tr>
<td>ReefBlk</td>
<td>Linear foot</td>
<td>$150 installed</td>
</tr>
<tr>
<td>Wave Attenuation Device</td>
<td>Linear foot</td>
<td>$180-250</td>
</tr>
</tbody>
</table>

**Misc. Costs:** freight and delivery charges (these tend to fluctuate); installation; filter fabric for sediment stabilization

**Maintenance:** possible need for additional shell or rock over time; possible repair after storms
Hybrid Structures

- Soil stabilization method that combines hard structures with more natural materials
- Cost = shoreline or marsh planting + price of breakwater installed
Bulkhead, Seawall, Revetment
Bulkhead, Seawall, Revetment
# Bulkhead, Seawall, Revetment

<table>
<thead>
<tr>
<th>Type</th>
<th>Unit</th>
<th>Cost Range ($/unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl*</td>
<td>Linear foot</td>
<td>$125-200</td>
</tr>
<tr>
<td>Vinyl w/toe protection</td>
<td>Linear foot</td>
<td>$210-285</td>
</tr>
<tr>
<td>Wooden</td>
<td>Linear foot</td>
<td>$115-180</td>
</tr>
<tr>
<td>Wooden w/toe protection</td>
<td>Linear foot</td>
<td>$200-265</td>
</tr>
<tr>
<td>Concrete</td>
<td>Linear foot</td>
<td>$500-1,000</td>
</tr>
<tr>
<td>Sheetpile</td>
<td>Linear foot</td>
<td>$700-1,200</td>
</tr>
<tr>
<td>Revetment</td>
<td>Cubic yard (yd³)</td>
<td>$25-45 ($120-180/lf installed)</td>
</tr>
</tbody>
</table>

* Costs based on 4-8’ height

**Misc. Costs:** possible earthwork or backfill; labor and materials included

**Maintenance:** scour typically occurs, toe protection likely needed, additional fill and vegetation may need to be installed over time
How do we promote and install successful Living Shoreline projects?

- Determine appropriate sites
- Make products available and advertise
- Promote growing and planting native, regional vegetation
- Create design alternatives
- Low maintenance yards
- Educate homeowners and contractors
- Incentives (tax breaks, possible grants)
QUESTIONS?

DEBBIE DEVORE
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Vero Beach, Florida

Debbie_DeVore@fws.gov
772-562-3909 x324
http://www.fws.gov/verobeach/coastal.htm
Appendix E – Permeable Pavement Fact Sheet

Provided by University of Maryland Extension, Howard County Master Gardeners
Permeable Pavement Fact Sheet
Information for Howard County, Maryland Homeowners

Purpose of this Fact Sheet:

To provide objective information about permeable pavement for Howard County, Maryland homeowners who may wish to install or retrofit a permeable pavement driveway, patio or sidewalk on their property.

Some of the references cited apply to commercial or public spaces and are provided only to give the homeowner background information about permeable pavement. Vendor information was excluded except for some illustrations.

What is permeable pavement?

In this document the term “permeable pavement” will be used most often for the sake of consistency, however the terms porous and pervious are often used in the literature. In this document these terms will be considered interchangeable. For those who will be doing further searching on the Internet or in other sources, terms often used are: pervious pavers, pervious concrete, porous asphalt, resin-bound paving, open-jointed blocks or cells and porous turf.

Permeable pavement is a method of paving that allows stormwater to seep into the ground as it falls rather than running off into storm drains, waterways and eventually the Chesapeake Bay.

“Permeable pavements function similarly to sand filters, in that they filter the water by forcing it to pass through different aggregate sizes and typically some sort of filter fabric. Therefore most of the treatment is through physical (or mechanical) processes. As precipitation falls on the pavement it infiltrates down into the storage basin where it is slowly released into the surrounding soil.” ¹

“Long term research on permeable pavers shows their effective removal of pollutants such as total suspended solids, total phosphorous, total nitrogen…zinc, motor oil, and copper. In the void spaces, naturally occurring micro-organisms break down hydrocarbons and metals adhere.” ²

“By stopping stormwater from pooling and flowing away, porous paving can help recharge underlying aquifers and reduces peak flows and flooding. That means that streams flow more consistently and at cooler temperatures, contributing to healthy ecosystems. Stormwater pollutants are broken down in the soil instead of being carried to surface waters.” ¹² Below is a graphic that illustrates the relationship between surface flow, groundwater flow and aquifers.
Illustration: [Link to image](http://imnh.isu.edu/digitalatlas/hydr/concepts/gwater/imgs/6comp.jpg)

For more information about aquifers see “What is an Aquifer?” (Idaho State University-Reference 3)

“Depending on design, paving material, soil type and rainfall, permeable paving can infiltrate as much as 70% to 80% of annual rainfall.” Combining permeable pavement with other Low Impact Development (LID) strategies, such as vegetated swales, increases the overall effectiveness of permeable paving. According to Mark W. Clark and Glenn A. Acomb (Reference 5) the percent of rainfall converted to runoff volume for various pavement scenarios is:

- Asphalt with no swale—51%
- Asphalt with swale—34%
- Cement with swale—32%
- Permeable pavement with swale—10%

“For the best success, a few key factors must be considered when undertaking a project involving permeable pavement alternatives:

1. **Choose the correct pavement for the task at hand.** Permeable pavement options vary depending upon whether the pavement will receive light, moderate, or heavy use. Therefore, it is imperative to choose the right material for the expected use.
2. **Prepare the subbase.** Choose the appropriate subbase preparation for the application. The type of subbase used and depth of the subbase materials determine the amount of infiltration provided, as well as durability over time. In locations with poor soils or numerous freeze-thaw cycles, a thicker subbase is usually required.
3. **Install properly.** In many cases, the manufacturer will install, oversee the installation, or recommend certified contractors.
4. **Understand and carry out maintenance requirements.** Appropriate maintenance is critical to the continued effectiveness and durability of permeable pavement materials.”

A homeowner might consider permeable paving for a driveway or walkway. A patio that does not adjoin the house might also be considered. Permeable paving immediately adjacent to the house may not be advisable since water should always be directed away from the house. As mentioned above it is important to choose the correct pavement for the planned project.
Permeable pavement is designed to carry **moderately** heavy loads, such as automobiles. "If permeable pavement will be used in a setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir." 7

"Concrete block pavers...have the highest load bearing capacities, followed by porous asphalt and concrete pavements and then plastic grid pavers." 6

Three of the major types of permeable pavements are compared in the table below from The Virginia DCR Stormwater Design Specification No. 7 7

<table>
<thead>
<tr>
<th>Table 7.2. Comparative Properties of the Three Major Permeable Pavement Types</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Factor</strong></td>
</tr>
<tr>
<td>Scale of Application</td>
</tr>
<tr>
<td>Pavement Thickness</td>
</tr>
<tr>
<td>Bedding Layer</td>
</tr>
<tr>
<td>Reservoir Layer</td>
</tr>
<tr>
<td>Construction Properties</td>
</tr>
<tr>
<td>Design Permeability</td>
</tr>
<tr>
<td>Construction Cost</td>
</tr>
<tr>
<td>Min. Batch Size</td>
</tr>
<tr>
<td>Longevity</td>
</tr>
<tr>
<td>Overflow</td>
</tr>
<tr>
<td>Temperature Reduction</td>
</tr>
<tr>
<td>Colors/Texture</td>
</tr>
<tr>
<td>Traffic Bearing Capacity</td>
</tr>
<tr>
<td>Surface Clogging</td>
</tr>
<tr>
<td>Other Issues</td>
</tr>
</tbody>
</table>
1 Individual designs may depart from these typical cross-sections, due to site, traffic and design conditions.
2 Reservoir storage may be augmented by corrugated metal pipes, plastic arch pipe, or plastic lattice blocks.
3 ICPI (2008)
4 NVRA (2008)
5 WERF 2005 as updated by NVRA (2008)

6 Based on pavement being maintained properly. Resurfacing or rehabilitation may be needed after the indicated period.
7 Depends primarily on on-site geotechnical considerations and structural design computations.
8 Stone sizes correspond to ASTM D 448: Standard Classification for Sizes of Aggregate for Road and Bridge Construction.

“Sources: CWP and CSN (2008) and CWP (2007)”

Why would a homeowner choose permeable pavement?
- To prevent/remedy erosion on property
- To minimize excessive pooling in low lying areas due to runoff
- To retain water on property which will
  - Benefit plants on property
  - Return water to the water table on property
  - Contribute to the improvement of the environment by
    - Diminishing stormwater contaminants in streams, rivers and the Chesapeake Bay
    - Providing “groundwater recharge and reduc(ing) stormwater runoff volume”
    - Preserving and preventing erosion of stream beds and river banks if property drains directly into a stream

What materials/methods are used for permeable paving?
- Porous asphalt
  Homeowner use: driveways, parking areas

Porous asphalt is the same as regular asphalt except it is manufactured with the fine material omitted, leaving open spaces that allows water to filter through to a “recharge” or drainage bed.

• **Pervious concrete**
  Homeowner use: driveways, parking areas, sidewalks, patios not adjoining house, pool decking

Pervious concrete is composed of materials that result in voids when it is dry, thus allowing water to drain through. Installation requires the same type of drainage bed as that described under Porous Asphalt.

Porous concrete pavement at Robinson Nature Center, Cedar Lane, Columbia, MD

Illustration: [http://www.uri.edu/cve/ritrc/wpe2.jpg](http://www.uri.edu/cve/ritrc/wpe2.jpg)
- **Concrete/brick pervious pavers**
  Homeowner use: Parking areas, patios not adjoining house, sidewalks, pool decks
  Driveways--Snow removal equipment may catch edges, rollers may be needed

Precast concrete or brick manufactured in many sizes and shapes are laid with a drainage base and permeable joint material, allowing water to slowly seep into the ground. “Pervious pavers are most effective with other LID (Low Impact Development) treatment... (e.g. vegetated swales, cisterns or exfiltration tanks)”  


Permeable concrete/brick paver driveway at Howard County residence. This driveway has been in place for several years.
Open-Celled pavers

Homeowner use:
- Parking areas: Only for overflow parking if grass fill is used; grass will die if there is not enough sun
- Patios not adjoining house: For summer use, and only with furniture that has legs wider than the cells

Open-celled pavers are made by installing a plastic or concrete grid over a bed of drainage material and soil. Then the voids are seeded with grass or turf plugs are embedded. Alternatively the voids may be filled with aggregate. They must be constructed with a drainage bed similar to the illustration shown above under Concrete/Brick Pervious Pavers.

Illustration: [http://www.grassypavers.com/pavclose.jpg](http://www.grassypavers.com/pavclose.jpg)


Grass pavers used in parking area at Centennial Park, Howard County, MD, off Old Annapolis Road
What maintenance does permeable pavement require?

In order to maintain porosity it is imperative that sediment not be allowed to accumulate on the pavement. "[Permeable pavement] should be used carefully where frequent winter sanding is necessary because the sand may clog the surface of the material. Periodic maintenance is critical and surfaces should be cleaned with a vacuum sweeper at least three times per year."

“If clogging occurs in porous pavement and the surface infiltration rate is reduced lower than the rainfall rate, then either water will pond or runoff will be produced. Therefore, periodic maintenance is required for continuing functioning.”

Maintenance checklist for all types of permeable pavements

“Post signs identifying porous pavement areas.

Keep landscape areas well-maintained and prevent soil from being transported onto the pavement.”

“Clean the surface using vacuum sweeping machine” [except grass pavers]) or “with high pressure hosing”

“Monitor regularly to ensure that the paving surface drains properly after storms,

Do not reseal or repave with impermeable materials.

Inspect the surface annually for deterioration.”

Additional maintenance of specific permeable pavement types

Porous Asphalt and Pervious Concrete
“Potholes and cracks can be filled with patching mixes unless more than 10% of the surface needs to be repaired.”

“Spot clogging may be fixed by drilling 0.5” holes through the pavement layer every few feet.”

Concrete/brick pervious pavers
“…periodically add joint material (sand) to replace material that has been transported,”

Open-Celled Pavers with aggregate fill
Refill displaced gravel when necessary
Plastic cells may need to be replaced periodically

Open-Celled Pavers with grass fill
“Needs mowing, irrigation, fertilization and seeding”
Plastic cells may need to be replaced periodically

For more detailed information about maintenance see references 4, 6 and 8 below
(Massachusetts Low Impact Development Fact Sheet, California Coastal Commission—Permeable Pavement, What’s It Doing on My Street, New Jersey Stormwater Best Practices Manual)
What other factors should be considered?

**Frost heave**

“In cold climates the potential for frost heave may be a concern...Some design manuals recommend excavating the base course to below the frost line, but this may not be necessary in rapidly permeable soils. In addition the dead air and void spaces in the base course provide insulation so that the frost line is closer to the surface”.

**Contiguous Drainage Areas**

“Permeable paving should not receive stormwater from other drainage areas, especially any areas that are not fully stabilized”.  

Permeable pavements are only capable of infiltrating precipitation that falls directly on them. A backup channel or infiltration area for overflow should be designed so they don’t flood during major storms or long periods of rain. This can be a swale of turfgrass, sand, gravel or fine mulch sloping downward from the paved area. This swale can also catch uphill runoff to prevent it from reaching the paved area.

{Permeable pavement} “should not be used on stormwater “hot spots” with high pollutant loads because stormwater cannot be pretreated prior to infiltration”

For a list of potential “hot spots” see Table 5 in Minnesota Pollution Control Agency ISSUE PAPER “H” Potential Stormwater Hotspots

**Heavy Loads**

[Permeable pavement] “cannot be used...where it will be subject to heavy axle loads.”

**Site Slope**

“Permeable paving can only be used on gentle slopes (<5%)”

**Snow Removal**

“Snow plows can catch the edge of grass pavers and some paving stones. Rollers should be attached to the bottom edge of a snowplow to prevent this problem”

**Construction details**

A good overview of various types of permeable pavement alternatives and comparisons of permeable pavement commercial products, available as of 2007, can be found at: [http://www.coastal.ca.gov/nps/lid/PermeablePavement-What'isItDoingonMyStreet.pdf](http://www.coastal.ca.gov/nps/lid/PermeablePavement-What'isItDoingonMyStreet.pdf) (Reference 6)

A brief description of construction details is available in Massachusetts Low Impact Development Fact Sheet #6 (Reference 4) and in Montgomery County Permeable Paver Retrofit (Reference 11)

Much more detailed information is available in The New Jersey Stormwater Best Practices Manual (Reference 8) and Virginia DCR Stormwater Design Specification No.7 (Reference 7)
What is the cost of permeable pavement?
Although costs are constantly changing some types of permeable pavement can be compared using the data from a 2009 EPA study (Reference 10)

<table>
<thead>
<tr>
<th>Pavement</th>
<th>Paved Area (sq ft)</th>
<th>Quote ($)</th>
<th>Quote ($) sq yd</th>
<th>Quote ($)</th>
<th>Quote ($) sq yd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Mix Asphalt</td>
<td>36,225</td>
<td>96,600</td>
<td>92,620</td>
<td>24.50</td>
<td>23.01</td>
</tr>
<tr>
<td>Porous Asphalt</td>
<td>5,328</td>
<td>28,650</td>
<td>18,352</td>
<td>48.40</td>
<td>31.00</td>
</tr>
<tr>
<td>Porous Pavers</td>
<td>5,328</td>
<td>67,960</td>
<td>61,755</td>
<td>114.80</td>
<td>104.32</td>
</tr>
<tr>
<td>Porous Concrete</td>
<td>7,988</td>
<td>63,200</td>
<td>53,919</td>
<td>71.21</td>
<td>60.75</td>
</tr>
</tbody>
</table>

Source: Permeable Pavement Research –Edison New Jersey, Amy Rowe EPA National Risk Management Research Laboratory     Final proposed costs reported by Kirit Shaw, S Services, Inc, June 2009 (2)

The Virginia DCR Stormwater Design Specification Table 7.2 (Reference 7) gives these cost comparisons as of 2007.

| Construction Cost          | Porous Concrete $ 2.00 to $6.50/sq. ft. | Porous Asphalt $ 0.50 to $1.00/ sq. ft. | Interlocking Pavers $ 5.00 to $10.00/ sq. ft. |

References:
2. Capital Regional District, Victoria, British Columbia Permeable Pavement [http://www.crd.bc.ca/watersheds/lid/permeable.htm]
3. Idaho State University-What is an Aquifer? [http://imnh.isu.edu/digitalatlases/hydr/concepts/gwater/aquifer.htm]

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Further information about permeable pavement can be found at the web sites listed below. As noted earlier some of these references include information that is applicable to commercial and government installations and are provided as a source for the homeowner to obtain more detailed information about permeable pavement.

Please note that the web is a constantly changing environment and addresses might have been changed or documents might have been removed. The following information was current as of August 13, 2011.

  [http://www.americantrails.org/resources/trailbuilding/PermPavers.PDF](http://www.americantrails.org/resources/trailbuilding/PermPavers.PDF)
- California Permeable Asphalt Pavements with Stone Recharge
  [http://www.californiapavements.org/Files/Milar_0804_Perma_Ashalt_Present_CA_Coast.pdf](http://www.californiapavements.org/Files/Milar_0804_Perma_Ashalt_Present_CA_Coast.pdf)
- Howard County MD Centennial and Wilde Lake Watershed Restoration
  [http://www.howardcountymd.gov/DPW/Docs/Section3_Study_Methods_and_Assessment_Results.pdf](http://www.howardcountymd.gov/DPW/Docs/Section3_Study_Methods_and_Assessment_Results.pdf)
- Idaho State University-What is an Aquifer?
  [http://imnh.isu.edu/digitalatlas/hydr/concepts/gwater/aquifer.htm](http://imnh.isu.edu/digitalatlas/hydr/concepts/gwater/aquifer.htm)
- Marcus De La Fleur web site--landscape architect featured in Organic Gardening article (below)
  [http://www.delafleur.com/168_Elm/05_P_Pvmt_01.html](http://www.delafleur.com/168_Elm/05_P_Pvmt_01.html)
- Minnesota Permeable Pavement research 2007
- Minnesota Pollution Contol Agency, ISSUE PAPER “H” Potential Stormwater Hotspots, Pollution Prevention, Groundwater Concerns and Related Issues V.3 (final)
- Montgomery County MD Permeable Pavement Help Guide
- North Carolina State University Permeable Pavement Research Update 2008
- North Carolina State University Interlocking Concrete Fact Sheet
  [http://www.ncsu.edu/picp/FactSheets/DesignProfessionals-PICP.pdf](http://www.ncsu.edu/picp/FactSheets/DesignProfessionals-PICP.pdf)
- North Carolina State University Interlocking Pavement site
  [http://www.ncsu.edu/picp/](http://www.ncsu.edu/picp/)
- North Carolina State University Permeable Pavement Research web site
  [http://www.bae.ncsu.edu/info/permeable-pavement/](http://www.bae.ncsu.edu/info/permeable-pavement/)
- North Carolina State University Hydrologic and Water Quality Comparison of Four Types of Permeable Pavement and Standard Asphalt in Eastern North Carolina
- North Carolina State University Surface Infiltration Rates of Permeable Pavement
- Organic Gardening Permeable Pavement article
- Permeable Pavement Research Study Summary Lake County Forest Reserves 2003
http://atfiles.org/files/pdf/PermPavers.PDF

Toronto Permeable Pavement Fact Sheet

University of Florida Permeable Pavement Study 2005
http://www.stormwater.ucf.edu/

University of Washington--Derek Booth describes several options for stormwater management including permeable pavement 2007
https://digital.lib..edu/dspace/handle/1773/16583

University of Washington Permeable Pavement Fact Sheet
http://water.washington.edu/Outreach/FactSheets/permeablepavements.pdf

Virginia DCR Stormwater Design Specification No.7--Permeable Pavement Version 1.8, March 1, 2011
http://vwrcc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec7PERMEABLEPAVEMENT.html

Watuaga County Extension North Carolina Permeable Pavement Workshop
http://www2.mountaintimes.com/entertainment_focus/About_Those_Permeable_Pavers_..._id_003643

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