Evidence-Driven Utility Policy with Regard to Storm Hardening Activities: A Model for the Cost-Benefit Analysis of Underground Electric Distribution Lines

Theodore Kury, Public Utility Research Center, University of Florida

Introduction

In 2008, wind storm events in the United States caused nearly $5.5 billion[1] in property damages and more than 27 million customers[2] to lose electrical power. In addition to losses due to property damage from storms events, customers tend to suffer ancillary losses with interruptions in their electrical service. Furthermore, these losses tend to grow exponentially as the outage persists. Outages that persist for an hour or two may not result in ancillary losses. However, as outages persist for hours, or days, residential customers, restaurants and grocery stores may lose perishable items through spoilage. Customers will incur additional expenses through the purchase of necessities such as batteries or potable water. Many businesses may be forced to suspend operations, and their workers may suffer an interruption in their income. Customers who are fortunate enough to have access to on-site generation must still incur fuel expenses in order to run their generators. Storm events can cause significant financial losses and disruptions to everyday life.

In the aftermath of any storm event, there are inevitable questions. Customers ask why damage occurred and what, if anything, could have been done to prevent it. Customers and utilities seek ways to mitigate the effects of storm events in the future. Often, the relative costs and benefits of these mitigation strategies aren't clear, and that can prevent utilities or regulators from enacting public policies that could benefit customers and utilities. The application of evidence-based utility policy and the quantification of these benefits can be essential to improving utility service and reducing costs for the service provider and the customer alike.

Following the storm seasons of 2004 and 2005, regulators and utilities in the state of Florida embarked on an initiative to study the effects of storm damage mitigation strategies. One outcome of this initiative is a model that can be used to quantify the benefits of storm hardening activities. The model is capable of simulating hurricane years and assessing how the distribution of storm damages to a project area changes with the application of storm hardening strategies. The changes in this distribution can be considered with the cost of that strategy to assess its cost-effectiveness.

The 2004 and 2005 Hurricane Seasons in Florida

The hurricane seasons of 2004 and 2005 had a marked effect on the state of Florida. These seasons saw 10 named storms impact the state and cause $28 billion in property damages alone, as shown in Table 1. On January 23, 2006, the staff of the Florida Public Service Commission (FPSC) conducted a workshop

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[1] National Climatic Data Center Events database

[2] OE-417 Major Disturbance Database maintained by the United States Department of Energy's Energy Information Administration. The 27 million customers represents outages related to transmission system failures only.

with State and local government officials, independent technical experts, and representatives of the electric utilities. The purpose of this workshop was to discuss damage to electric utility facilities resulting from the recent hurricanes and to explore ways of mitigating the effects of future storm damages and customer outages.

Year	Named Storm	Damage[3] (million $)
2004	Bonnie	0.100
	Charley	5,533.680
	Frances	5,602.120
	Ivan	4,090.400
	Jeanne	840.205
2005	Arlene	3.740
	Cindy	0.300
	Dennis	1,569.232
	Katrina	208.600
	Wilma	10,215.700
Total		28,064.077

Table 1: Florida Storm Damage Costs 2004-05

On April 25, the FPSC issued Order Number PSC-06-035 1-PAA-E1 requiring that each investor owned utility file a plan, and the associated implementation costs, for a storm preparedness program with ten initiatives:

- a three- year vegetation management cycle for distribution circuits;
- an audit of joint-use attachment agreements;
- a six-year transmission structure inspection program;
- hardening of existing transmission structures;
- a transmission and distribution geographic information system;
- post-storm data collection and forensic analysis;
- collection of detailed outage data differentiating between the reliability performance of overhead and underground systems;
- increased utility coordination with local governments;
- collaborative research on effects of hurricane winds and storm surge; and
- a natural disaster preparedness and recovery program.

In their Order, the FPSC observed that:

"During the January 23rd staff workshop, the utilities appeared to be unaware of work being done by universities to study the effects of hurricane winds and storm surge

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[3] National Climatic Data Center Events database

within Florida. Each utility appeared engaged in independent efforts to gather its own data with little, if any, coordination of resources and information.

Florida would be better served by consolidating utility resources through a centrally coordinated research and development effort with universities as well as research organizations. The purpose of such effort would be to further the development of storm resilient electric utility infrastructure and technologies that reduce storm restoration costs and outages to customers."[4]

The FPSC, therefore, recognized not only the communication gap that existed between the utilities, but also the economies of scale in collaborative research. By requiring this collaboration to capture these scale economies, the FPSC order also mitigated the free rider problem often associated with the provision of public goods.

The Utilities' Response

As a result of this order, eight Florida utility sponsors, the Florida Electric Cooperative Association, the Florida Municipal Electric Association, Florida Power & Light, Florida Public Utility Company, Gulf Power, Lee County Electric Cooperative, Progress Energy Florida, and Tampa Electric Company contracted with the Public Utility Research Center at the University of Florida to begin a collaborative research effort. These utilities formed the Steering Committee for the Research in Electricity Infrastructure Hardening, and began to pursue the initiatives outlined in the FPSC Order.

The projects initiated by this collaborative have been diverse in both their scale and their scope. The group has conducted 2 vegetation management workshops that have allowed utilities to share challenges, opportunities, and best practices in vegetation management. Vegetation management techniques are important for mitigating the effects that trees and other growth can have on overhead power lines, transformers, and other elements of the utility infrastructure. These positive effects are especially valuable during wind storms, when flying debris poses additional hazards to property. In these workshops, participants have had the opportunity to share thoughts on the frequency of tree trimming (often referred to as cycles), trimming techniques, policies to encourage public participation and cooperation in management programs, and the importance of municipal involvement at the local and state level.

The collaborative has also recognized the dearth of reliable data on wind storms and their aftermath. Through a second initiative, the group has attempted to enhance the available data for utilities in the state of Florida. Through the University of Florida's Civil and Coastal Engineering Department and Weatherflow, the collaborative has promoted the deployment of 50 high resolution wind monitoring stations, as shown in Appendix A. These stations allow for the collection of highly granular surface wind speed data, and allow researchers to construct more detailed wind maps and study the depreciation of storm events. In addition, the collaborative has established a database for the collection of post-storm

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[4] FPSC Order Number PSC-06-035 1-PAA-E1, Page 9

forensic data. The application was built by researchers at the Public Utility Research Center in cooperation with the sponsoring utilities, and the forms used by this application are shown in Appendix B. This data will be used in conjunction with the high resolution wind data to enable utilities to build advanced empirical damage curves for utility equipment and identify areas that impose greater risks to utility property. Such areas could potentially serve as priority target areas for preventative maintenance, improving reliability of the utility system.

Perhaps the most ambitious project has been the development of a model to quantify the benefits associated with relocating overhead power lines beneath the ground. The question of whether to relocate power lines is prevalent following any wind storm that results in customer outages. Frustrated customers and municipal officials may ask why power lines can't simply be located underground, where they would be relatively safe from potential wind damage. While it is easy to understand this frustration, reason suggests that the costs and benefits of this relocation should be studied before any decision is made, and resources expended. While the costs to relocate the power lines are relatively well known, the benefits associated with this relocation are not often understood. The economic benefits of this relocation are primarily the decreased restoration costs associated with wind damage and a reduction in the ancillary customer costs associated with prolonged power outages due to wind damage. However, there are also aesthetic benefits, and the economic value of these aesthetics will vary greatly between communities. In addition, the relocation of power lines comes with costs in addition to the expense associated with the physical relocation. Relocation of the power lines makes them more susceptible to corrosive storm surge and flooding. Restricted access makes it more expensive to maintain them and to diagnose service problems. Seeking an analytical framework with which to evaluate these costs and benefits, the utilities began looking for a model that could aggregate the economic value of all of these factors. After conducting survey research to determine that a satisfactory model did not exist, the collaborative contracted with the Public Utility Research Center and Quanta Technology to begin development of such a model. Over the next 12 months, Quanta and PURC worked with the group to scope, plan, build, and parameterize a Monte Carlo simulator that could form the basis for this analytical framework. The result was an Underground Assessment Model. Since the model's initial construction, the utilities have continued to work with PURC to test, verify, and expand the model beyond its initial capability.

As a result of the testing process, the utility working group realized how difficult it was to evaluate the accuracy of damage estimates resulting from an average hurricane year, the common denominator of the simulator. Utilities tend to track damage on a per year, or a per storm, basis. An average hurricane year in the state of Florida is approximately 0.79 storms and therefore never actually occurs. As a result, the damage results coming from the initial model, while useful for performing comparative analyses, did not match up well with actual utility damage data. Therefore it was decided that the ability to simulate particular storms from history would be a valuable tool in assessing the plausibility of the damage estimates produced by the model. Therefore, PURC has added the capability to simulate historical storms, as well as the capability to conduct scenario analyses with the existing storm data. The model can therefore simulate, for example, the effects of a particular storm, such as Hurricane Andrew, on a

particular project area. The model can also simulate the effects of a particular type of storm, such as a Category 4 hurricane, on a given area of the state.
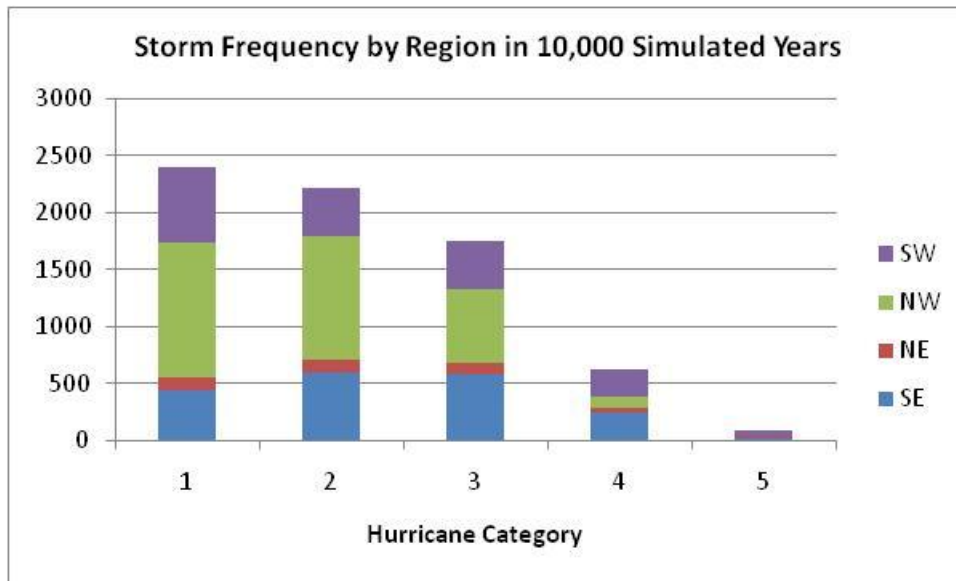
The Model

The Underground Assessment Model consists of two distinct modules. The first module is the Simulation Module. This module utilizes Monte Carlo methods to simulate a number of "hurricane-years" for the state of Florida. The second module is the Damage Module. This module uses the characteristics of the utility infrastructure project, such as its location, the number and type of utility poles, length of conductor span, and the number and type of transformers, and the results of the Simulation Module to assess the distribution of damage to the utility's infrastructure as a result of the winds, storm surge, and flooding that accompany the hurricane. The basic flowchart for the model is shown as Figure 1.
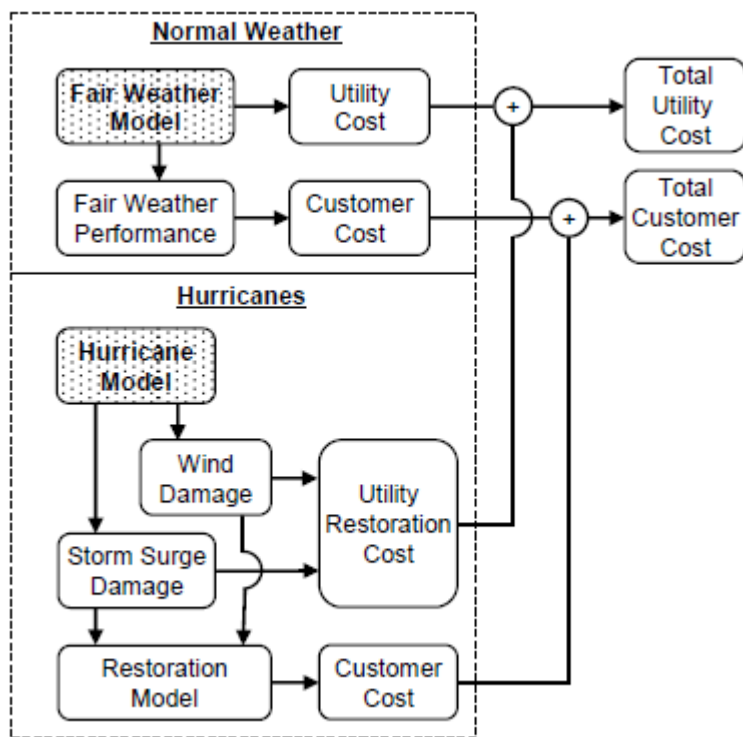
Figure 1: Underground Assessment Model Flowchart

The Simulation Module simulates an entire hurricane season, spanning June 1 to November 30, for the period of one year; a so-called "hurricane-year" for the state of Florida. For each hurricane-year, the model draws, from a Poisson distribution, the number of hurricanes that make landfall in each of the four regions in Florida. As Florida is affected by, on average, 0.79 hurricanes per year, this number is frequently zero within a simulated year. Each region has a different probability of experiencing a hurricane, according to historical probabilities. The northeast region, for example, has a relatively low frequency of hurricanes, and thus has a low probability to experience one in the model. The panhandle and southeast regions, however, have a much greater chance of hurricane landfall. Once the model determines the number of hurricanes, the model randomly determines the angle of approach and the

longitude and latitude of landfall, as well as the strength, radius of maximum winds, speed, and rate at which the hurricane will weaken. The model then uses these characteristics of the hurricane to determine the resultant wind field for the state due to this hurricane. Figure 2 shows sample output from a simulation of 10,000 hurricane years. This graph shows the number, and severity of the hurricanes by region of the state. Note that relatively few hurricanes affect the northeast portion of the state, and that while a number of hurricanes affect the panhandle, the most severe storms affect the southern portion of Florida.

Figure 2: Storm Frequency by Severity and Region in 10,000 Simulated Hurricane Years

The Damage Model of the Assessment Tool is further segmented into two Modules. The first of these Sub-Modules tabulates the normal maintenance costs associated with the utility infrastructure and the outages not related to hurricanes (the "Fair Weather Model"). The restoration and maintenance costs associated with these outages are classified as utility costs, while the customer costs of these outages and associated maintenance are classified as the customer costs. If a comparative analysis is being performed (e.g. analysis of system performance of overhead power lines as opposed to underground), then these costs and damages are calculated for each configuration of the system.

The Hurricane Sub-Module is the second part of the Damages Module. The Hurricane Sub-Module utilizes the simulated wind fields, storm surge, and information about the utility project to assess the damage as a result of each simulated storm. Damage to utility poles and spans, for example, increases exponentially as the wind speed increases. Underground power lines and pad mounted transformers can be damaged by storm surge and flooding, and this damage increases with the severity of the water incursion. The restoration costs of this damage are tabulated as the utility's costs. The customer opportunity costs associated with the time to repair these outages are tabulated as the customer costs. This damage is tabulated for each simulated hurricane-year and combined with the calculation of the Non-Storm Sub-Module to determine the probability density of the hurricane damages from the utility

and the customer point of view. We can then compare how the distribution of damages changes with the application of storm hardening activities to assess the relative efficiency of these strategies.

**The Costs and Benefits Associated with an Underground Project**

There are many different metrics that can be used to assess the value of an underground project to a utility. The first metric is the change in the repair costs. Storms can be expected to cause damage to the utility's system, and relocating equipment from above ground to below can affect the amount of damage and the costs to repair that damage. The second metric is the change in the utility's annual maintenance expenses. Utilities incur costs necessary to maintain their electrical system, and moving equipment can affect those costs as well. Finally, utility customers incur costs when their power is not available. Customers may incur costs in securing alternate sources of electricity and may suffer costs from the loss of food to spoilage, for example. All of these metrics are reported by the model in order to assess the value of a particular project.

Utility Annual Cost	Before	After	Benefit
Equipment O&M	$65,000.00	$29,000.00	$36,000.00
Other O&M	$1,653.72	$3,564.00	($1,910.28)
Lost Revenue (Storm)	$15,011.14	$13,108.73	$1,902.41
Lost Revenue (Non-Storm)	$6,827.06	$2,730.19	$4,096.87
Repairs (Storm)	$2,679.56	$1,653.35	$1,026.21
Repairs (Non-Storm)	$14,240.00	$6,400.00	$7,840.00
Others	$0.00	$0.00	$0.00
Total	**$105,411.48**	**$56,456.27**	**$48,955.21**
Customer Opportunity Cost			
Storm	$296,847.74	$259,227.06	$37,620.68
Non-Storm	$135,005.95	$53,989.88	$81,016.08
Total	**$431,853.70**	**$313,216.93**	**$118,636.76**
Customer Reliability			
CMI (Storm)	5,956,809	5,201,883	754,926
CMI (Non-Storm)	2,709,150	1,083,409	1,625,741
Total	**8,665,958**	**6,285,292**	**2,380,667**

Figure 3: Sample Model Output

Figure 3 shows the change in storm damage metrics, reported by the model, for a particular (fictional) underground project. This particular project is located in south Florida, in the Fort Lauderdale area, the electrical equipment is completely above ground, and the value of the utility equipment is roughly $250,000. The scope of the project is to move roughly 65% of the equipment under ground. In this case, you can see that the utility has saved $36,000 per year on equipment O&M as a result of the undergrounding project. Other O&M has increased, but Lost Revenue and Damage Repair in both Storm and Non-Storm years has decreased. Further, the Customer Minutes Interrupted has decreased, and as a result, so has the Customer Opportunity Cost, which represents the opportunity cost of power

outages. In the aggregate, then, the undergrounding project has saved approximately 2.3 million customer minutes and $170,000 annually.
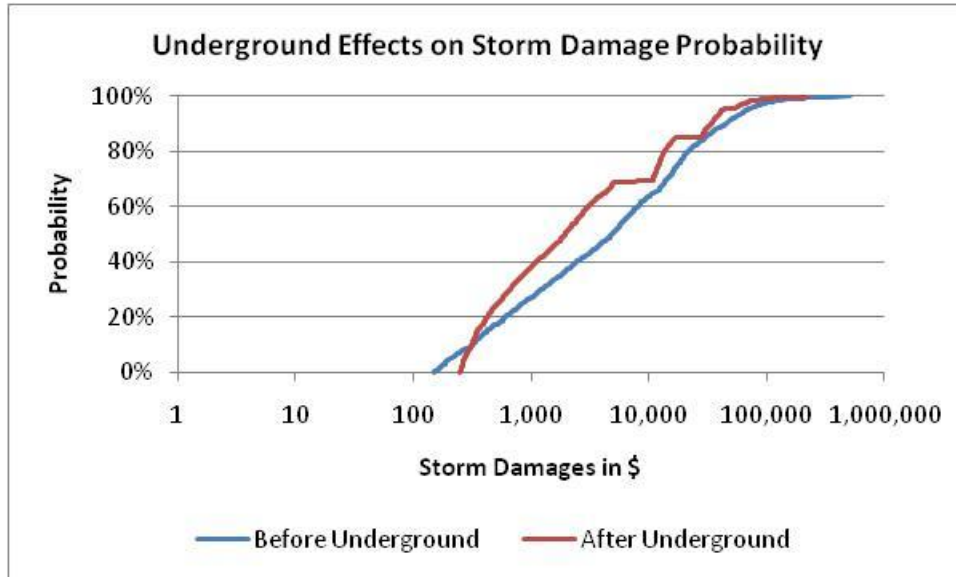
Figure 4: The Effects of Underground Power Lines on Storm Damage

Figure 4 shows the change in the probability of storm damage, given that a storm has hit, for the underground project. Note that the horizontal axis is presented on a logarithmic scale. Over the course of 10,000 simulated hurricane years, roughly 1,780 storms hit this particular project area. In any year, then, in which a storm did not affect the project area, there was no difference in the amount of damage incurred with or without the underground project. Both damage amounts were zero. As a result, if we were to look at the average amount of storm damage incurred in this project area before the undergrounding, it is roughly $2700, or just over 1% of the total equipment value. This is the weighted average of the $16,000 worth of damage incurred when a storm hits, and zero damage when it does not. After the underground measures have been implemented, the average amount of storm damage suffered by this area is approximately $1700. This is the weighted average of the $10,000 worth of damage incurred when a storm hits, and zero damage when it does not. The average damage when a storm hits has dropped from $16,000 to $10,000, and this is amount reflected in the shift from the blue line to the red one.

In terms of expected value, then, this particular underground project saves an average of $1000 per year. This distribution is heavily skewed, however, in that there is no effect in most years, i.e. the years where no hurricane hits the area. However, the utility, customers, and regulators may be interested in more than just the expected amount. As we have already seen, if a storm does actually hit the area, then the project saves $6000 in restoration costs. This might be seen as a relevant benefit to the system. Further, in the instances where the most severe storms hit, the effect is even greater. We can examine the damage that results at the 95th percentile, that is, the amount of damage that is exceeded 1 time in 20 storms. At the 95th percentile, the storm damage before the underground project is $67,000. After the underground project, it is $42,000. Therefore, when the most severe storms hit, the damage is

reduced by $24,000. A planner, therefore, might be interested in more than just the expected damage when determining whether an underground project should be implemented. The cost, of course, is also an important component of the decision, but generally easier to quantify. The decision to whether to implement the above project will change depending on whether the cost is $1000 or $100,000. But cost or benefit alone are only parts of the story. The decision ultimately depends on both.

The model can also be used to help to clarify the context of a given project. It is nearly impossible to universally characterize storm hardening activities as a 'good' or 'bad' idea. The context of the project is critical in any cost benefit analysis. We assumed that the above (hypothetical) project was located in southeast Florida, in the Fort Lauderdale area. We can take this same project and simulate the effects of undergrounding if this project was implemented in other regions of Florida, and observe how the benefits associated with the project change. As shown in Figure 2, the types and magnitude of hurricanes will vary depending on the area of the state. As a result, the benefits of hardening projects will vary as well. These simulations were conducted assuming that the project is located in Pensacola, Jacksonville, and Naples as well, and we have summarized the results of these simulations in Table 2.

Region	Southeast (Ft. Lauderdale)	Northeast (Jacksonville)	Southwest (Naples)	Northwest (Pensacola)
Storms Affecting Project Area in 10,000 Hurricane Years	1,778	806	427	896
Average Annual Damage before Hardening	$2,700	$900	$1,000	$2,500
Average Annual Damage after Hardening	$1,700	$600	$600	$1,700
Average Storm Damage before Hardening	$16,000	$12,000	$23,000	$29,000
Average Storm Damage after Hardening	$10,000	$8,000	$14,000	$19,000
95th Percentile Storm Damage before Hardening	$67,000	$57,000	$96,000	$85,000
95th percentile Storm Damage after Hardening	$42,000	$38,000	$64,000	$60,000

Table 2: Comparison of Storm Damage Results

If the absolute values of these damage estimates do not seem significant, consider that this project area contains only $250,000 in utility equipment, so during one storm in 20, nearly 40% of the utility equipment is damaged in the Naples area, before the storm hardening project is implemented. Note the significant variation in the effects of this project, depending on where it is located. The largest average damage occurs in the Fort Lauderdale area, where more storms affect the area. However, the most severe storms affected the Naples and Pensacola areas, so the damage when a storm actually hits are higher there. Also note that while 800 storms affected the Jacksonville area, most of them were storms that made landfall on the Gulf Coast of Florida and then traveled across the state, so that by the time they get to Jacksonville, they are considerably weaker. This can be seen in the lower storm damage amounts for this area.

Conclusion

The damage that affects utility infrastructure after a hurricane causes emotional reactions in operators, customers, politicians, and regulators alike. It is quite reasonable to look back at a severe storm event and its aftermath and ask if anything can be done to mitigate the damage. However, it is just as important to make informed decisions of what can be done, and to ask the question whether something should be done. The leadership shown by regulators in Florida in addressing these questions led to a cooperative effort among electric utilities in the state. This effort brought practitioners, academics, and policymakers together to address the issue for the betterment of consumers and utilities alike.

The effort led to a number of programs, including workshops in vegetation management and the establishment of a database that can be used to collect storm damage data in great detail. It also led to the development of a simulation tool that could be used to assess the costs and benefits of storm hardening activities, including the underground placement of electric distribution lines. In the case of enhancements to the infrastructure of the utility to mitigate storm damage, the costs are often straight forward. The benefits, however, may be more difficult to quantify, and require detailed analysis. Moreover, it is difficult, if not impossible, to universally declare the relocation of distribution lines below ground as 'good' or 'bad'. There are many factors such as the frequency and magnitude of the storms that affect the area, the degree to which the geography is susceptible to storm surge and flooding, and the characteristics of the surrounding landscape that have a profound impact on the efficacy of the project. In this paper, we have described some of the efforts to quantify the benefits of changes to utility infrastructure, in the hope that these models will allow utilities, customers, and regulators to make more informed decisions in the question of how to allocate scarce resources to provide the greatest benefit.

Appendix A – Wind Monitoring Stations in Florida

Appendix B – Sample Data Forms for Storm Damage Database

General Information | Location

Information on Location

A. Location of Observation:

Overhead or underground?   Select One ▾

Latitude in decimal degrees: [   ]

Longitude in decimal degrees: [   ]

B. Soil Type: Unknown ▾

C. Surface Grade: Unknown ▾

D. Topology: Unknown ▾

E. Flood Zone: Unknown ▾

F. Exposure Level: Unknown ▾

G. Attach pictures/video: Unknown ▾

H. Tree density: Unknown ▾

← Previous   → Next

Utility Name: [Select One ▼]

Date of Data Gathering: [/ /]

Storm Information

A. Storm Name: [_____]

B. Wind Information (Note: Provide these data if known. They will be updated with later meteorlogical analysis)

    1. Predominant Wind Direction: [Unknown ▼]

    2. Intensity (mph): [Unknown ▼]

    3. Tornadoes: [Unknown ▼]

C. Rain (Note: Provide these data if known. They will be updated with later meteorlogical analysis)

    1. Amount (inches): [Unknown ▼]

    2. Duration (hours): [Unknown ▼]

D. Storm (Note: Provide these data if known. They will be updated with later meteorlogical analysis)

    1. Translation Velocity (i.e., travel speed) (mph): [Unknown ▼]

    2. Peak 3-second gust open exposure (mph): [Unknown ▼]

    3. Peak 3-second gust actual terrain (mph): [Unknown ▼]

General Information

A. General info regarding type of construction: [_____]

B. Nature of failure: [_____]

C. Non-utility damage observed in area: [_____]

D. Other observations: [_____]

[➜ Next]

Underground Facilities Information

A. What was the object that failed?

1. Equipment type: [Unknown ▾]

   a. Other (please describe): [＿＿＿＿＿]

2. Enclosure type: [Unknown ▾]

   b. Other (please describe): [＿＿＿＿＿]

3. Conduit? [Unknown ▾]

4. Direct buried cable? [Unknown ▾]

5. Underground vault? [Unknown ▾]

B. Attributes of facilities

1. Type: [Unknown ▾]

2. Anchoring Equipment:

   a. Type of pad (describe): [＿＿＿＿＿]

   b. Type of attachment to pad (describe): [＿＿＿＿＿]

3. Age of facilities (years): [＿＿＿＿＿]

4. Pre-storm condition:

   a. Date of last inspection (year): [＿＿＿＿＿]

     1) Year received treatment? [＿＿＿＿＿]

     2) Describe? [＿＿＿＿＿]

   b. Cable depth relative to surrounding area (feet): [＿＿＿＿＿]

   c. Hardened?: [Unknown ▾]

   d. Installer (name or unknown): [＿＿＿＿＿]

C. Observed cause of failure? (Y/N): [Unknown ▾]

1. Source of water (check all that apply):

   Storm surge ☐

   Flood water ☐

2. Type of water (check all that apply):

   Fresh water ☐

   Salt water ☐

3. Tree uprooting? [Unknown ▾]

[💾 Save]