Chapter 5

RESULTS AND ANALYSIS

5.1 Analysis for Trails

Trails are considered as areas that motor vehicles are not allowed to use. Trails are pathways that are designed to be suitable for non-motorized transportation means such as bicycle, skates, scooters, and pedestrians. As it was mentioned earlier, the ultimate goal of this research is to estimate the vulnerability of these facilities against sea level rise in 2100. The results are classified by counties to be more convenient to use for management corporations.

5.1.1 Assessment of Trails' Affection for Sea Level Rise Projections

The following table shows the number of affected trails under three different sea level rise scenarios. The trails are classified by county so local government and management agencies could plan adaptation strategies and budget allocations accordingly. It is observable that the number affected facilities in the Sussex county is more than two other counties.

Table 5.1: Number of affected trails by sea level rise in the Delaware

County	Total Number of Trails	Number of Affected Facilities under Three SLR Projections		
		Low (2ft)	Medium (4ft)	High (6ft)
New Castle	539	38	49	53
Kent	122	34	38	40
Sussex	248	76	113	128

5.1.2 Assessment of Trails' Inundation Distance for Sea Level Rise Projections

The State of Delaware has 713.5 (mile) of trails. Figure 1, demonstrates the total distance of affected facilities under three scenarios as well as the portion of the land that will remain on land and the distance that is going to be inundated. The total distance of the land that is going to be inundated for the high sea level rise scenario (6 feet) by the end of 2100 which is 103 (mile) is more significant than the inundation distance for the low sea level rise scenario (2 feet) which is estimated to be 30 (mile).

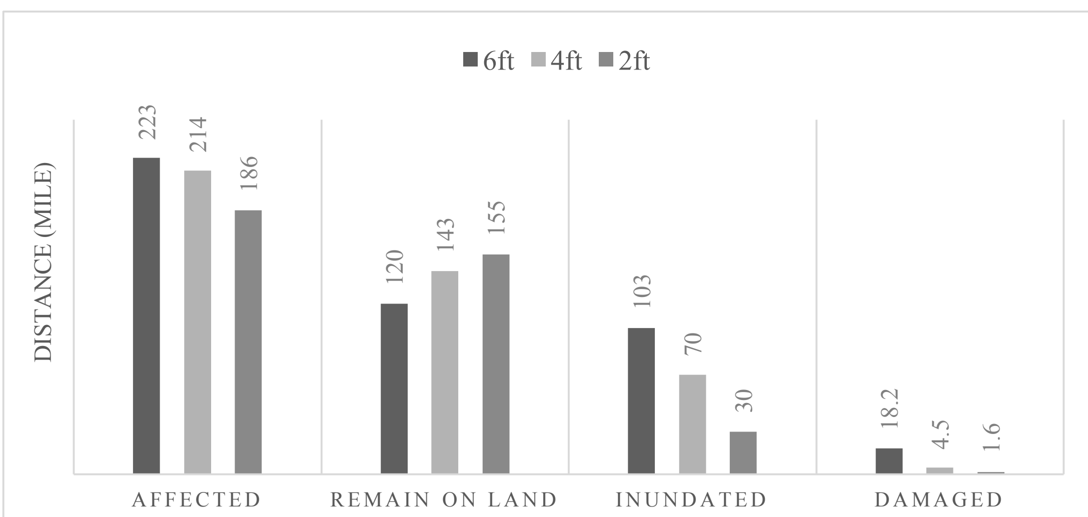

Figure 5.1: Distance of affected trails by sea level rise in Delaware (mile)

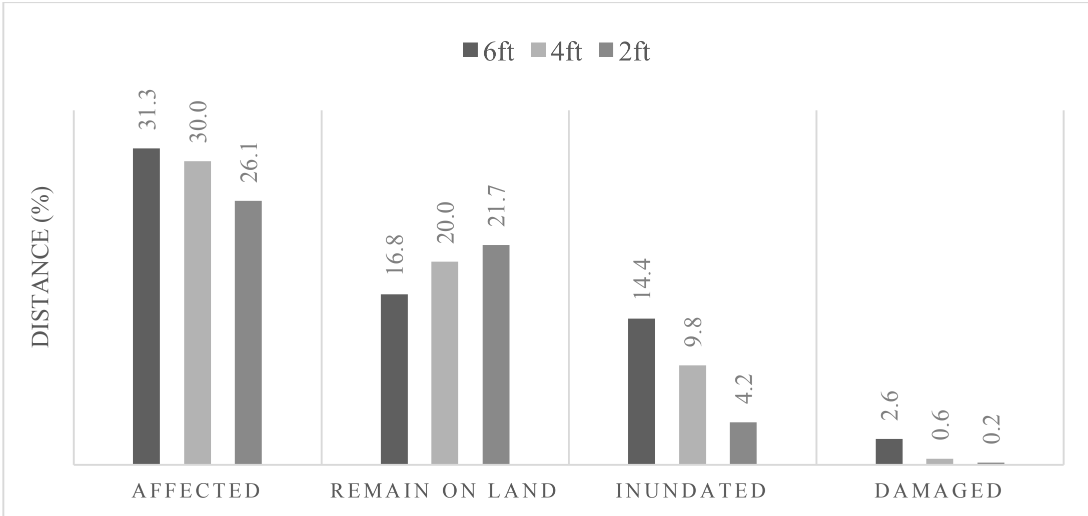

Figure 5.2: Distance of affected trails by sea level rise in Delaware (percent)

5.1.3 Damaged Trails under Sea Level Rise Projections

As mentioned, one of the objectives of this research is identifying those trails that will be vanished due to different sea level rise projections. Following tables represent completely collapsed trails. In these tables each trail is addressed by its ID, and name. In addition, the facility distance and the county where it locates is addressed in this table.

Table 5.2: Fully inundated trails under low sea level rise projection (2 feet)

Trail ID	Trail Name	Distance of Trail (mile)	County
426	Peterson Refuge Boardwalk	0.312	New Castle
25	Bear Swamp	0.121	Kent
26	Boardwalk	0.219	Kent
78	Boardwalk	0.195	Kent
270	AREC Trail	0.18	Kent
287	St. Jones Reserve	0.171	Kent
288	Unnamed Trail	0.021	Kent
5	Unnamed Trail	0.045	Sussex
84	Natter Park Trail	0.08	Sussex
85	Natter Park Trail	0.08	Sussex
179	Canalfront Park Pathway	0.113	Sussex
717	Mispillion Riverwalk	0.032	Sussex
777	Governors Walk	0.016	Sussex
780	Governors Walk	0.048	Sussex
781	Governors Walk	0.022	Sussex
783	Memorial Park Loop	0.112	Sussex
Total Distance (mile)		1.765	

Table 5.3: Fully inundated trails under medium sea level rise projection (4 feet)

Trail ID	Trail Name	Distance of Trail (mile)	County
2	Port Penn	0.152	New Castle
386	Connector	0.074	New Castle
426	Peterson Refuge Boardwalk	0.312	New Castle
24	Bear Swamp	0.138	Kent
25	Bear Swamp	0.121	Kent
26	Boardwalk	0.22	Kent
68	Raymond Pool	0.151	Kent
69	Shearness	0.13	Kent
185	Dirt Road	0.25	Kent
186	Unnamed Trail	0.034	Kent
270	AREC Trail	0.18	Kent
287	St. Jones Reserve	0.171	Kent
288	Unnamed Trail	0.021	Kent
743	Mispillion Riverwalk	0.078	Kent
477	Pedestrian Beach Crossing	0.026	Kent
5	Unnamed Trail	0.045	Sussex
84	Natter Park Trail	0.08	Sussex
85	Natter Park Trail	0.08	Sussex
107	Dirt Road	0.317	Sussex
109	Unnamed Trail	0.222	Sussex
176	Janosik Park Path	0.235	Sussex
179	Canalfront Park Pathway	0.113	Sussex
243	Connector	0.292	Sussex
245	Fred Hudson Road Trail	0.074	Sussex
273	Connector	0.034	Sussex
345	Connector	0.235	Sussex
347	Connector	0.017	Sussex
356	Gordons Pond Trail	0.051	Sussex
375	Unnamed Trail	0.008	Sussex
442	Photography Blind	0.303	Sussex
561	Richard Hall Memorial Park Path	0.112	Sussex
592	James Farm Ecological Preserve Trail	0.017	Sussex
717	Mispillion Riverwalk	0.032	Sussex
777	Governors Walk	0.016	Sussex
780	Governors Walk	0.048	Sussex
781	Governors Walk	0.022	Sussex
783	Memorial Park Loop	0.112	Sussex
Total Distance (mile)		4.52	

Table 5.4: Fully inundated trails under high sea level rise projection (6 feet)

Trail ID	Trail Name	Distance of Trail (mile)	County
2	Port Penn	0.152	New Castle
117	Port Penn	0.515	New Castle
271	Delaware City Promenade	1.142	New Castle
386	Connector	0.074	New Castle
426	Peterson Refuge Boardwalk	0.312	New Castle
24	Bear Swamp	0.138	Kent
25	Bear Swamp	0.121	Kent
26	Boardwalk	0.22	Kent
67	Parsons Point	0.482	Kent
68	Raymond Pool	0.151	Kent
69	Shearness	0.13	Kent
78	Boardwalk	0.194	Kent
183	Boardwalk Trail	0.08	Kent
185	Dirt Road	0.25	Kent
186	Unnamed Trail	0.034	Kent
266	Unnamed Trail	0.259	Kent
270	AREC Trail	0.18	Kent
285	St. Jones Reserve	0.456	Kent
287	St. Jones Reserve	0.171	Kent
288	Unnamed Trail	0.021	Kent
467	AREC Trail	0.099	Kent
468	AREC Trail	0.335	Kent
476	Dune Crossing	0.023	Kent
477	Pedestrian Beach Crossing	0.026	Kent
478	Pedestrian Beach Crossing	0.022	Kent
566	Unnamed Trail	0.21	Kent
716	Mispillion Riverwalk	0.163	Kent
742	Mispillion Riverwalk	0.041	Kent
743	Mispillion Riverwalk	0.078	Kent
5	Unnamed Trail	0.045	Sussex
66	Burton Island Trail	0.951	Sussex
84	Natter Park Trail	0.08	Sussex
85	Natter Park Trail	0.08	Sussex
107	Dirt Road	0.317	Sussex
108	Refuge	2.757	Sussex
109	Unnamed Trail	0.222	Sussex
175	Broad Creek Greenway	0.067	Sussex

Table 5.4: Continued

Trail ID	Trail Name	Distance of Trail (mile)	County
176	Janosik Park Path	0.235	Sussex
179	Canalfront Park Pathway	0.113	Sussex
180	Canary Creek Trail	0.641	Sussex
182	Sidewalk or Pathway	0.218	Sussex
242	Connector	0.207	Sussex
243	Connector	0.292	Sussex
244	Fred Hudson Road Trail	0.312	Sussex
245	Fred Hudson Road Trail	0.074	Sussex
246	Fred Hudson Road Trail	0.588	Sussex
248	Prickly Pear Trail	0.016	Sussex
250	Prickly Pear Trail cut-off	0.09	Sussex
252	Access Trail	0.051	Sussex
253	Access Trail	0.092	Sussex
256	Connector	0.019	Sussex
273	Connector	0.034	Sussex
275	Pathway	0.024	Sussex
278	Sidewalk or Pathway	0.492	Sussex
316	Sidewalk or Pathway	0.218	Sussex
345	Connector	0.235	Sussex
347	Connector	0.017	Sussex
351	Connector	0.363	Sussex
356	Gordons Pond Trail	0.051	Sussex
373	Sidewalk or Pathway	0.068	Sussex
374	Unnamed Trail	0.023	Sussex
375	Unnamed Trail	0.008	Sussex
440	Boardwalk	0.483	Sussex
441	Dike Trail	0.506	Sussex
442	Photography Blind	0.303	Sussex
444	Unnamed Trail	0.566	Sussex
446	Dirt Road	0.586	Sussex
524	Seaford Riverwalk	0.102	Sussex
561	Richard Hall Memorial Park Path	0.112	Sussex
592	James Farm Ecological Preserve Trail	0.017	Sussex
594	James Farm Ecological Preserve Trail	0.17	Sussex
717	Mispillion Riverwalk	0.032	Sussex
777	Governors Walk	0.016	Sussex
780	Governors Walk	0.048	Sussex
781	Governors Walk	0.022	Sussex
783	Memorial Park Loop	0.112	Sussex
Total Distance (mile)		18.151	

5.1.4 Level of Service for Sea Level Rise Projections

As it was explained in the previous chapter, the vulnerability assessment is done for each facility separately based on the inundation distance and maximum depth of water for three sea level rise projections (Low, medium, and high).

Table 6, represents all the elements of vulnerability assessment. This table contains trail's name, ID, length, county, length remaining on land after sea level rise, length of inundation after sea level rise, maximum depth of water, and level of service that was processed for one trail as a sample. For all existing trails throughout the State this table is developed.

Table 5.5: Vulnerability assessment of a sample trail under three sea level rise scenarios

			Low (2ft)	Medium (4ft)	High (6ft)
		Distance on Land (mile)	------	0.024	------
		Inundated Distance (mile)	------	0.077	------
Trail's Name	Seaford Riverwalk	**Land Loss (%)**	------	75.904	------
Trail's ID	524.000	**Min Elevation (ft)**	------	1.247	------
Distance (mile)	0.102	**Max Depth (ft)**	------	2.753	------
County	Sussex	**Level of Service**	LOS A	LOS F	Out of Service

The scope of this research covers trails and bike routes through the state of Delaware. Since the result of this study is applicable by the Delaware Department of Transportation (DelDOT) and other management organizations responsible for maintenance and rehabilitation of these facilities, trails' results are classified by counties: New Castle, Kent, and Sussex.

Following graphs show the trails level of service under low (2 feet), medium (4 feet), and high (6 feet) sea level rise for each county.

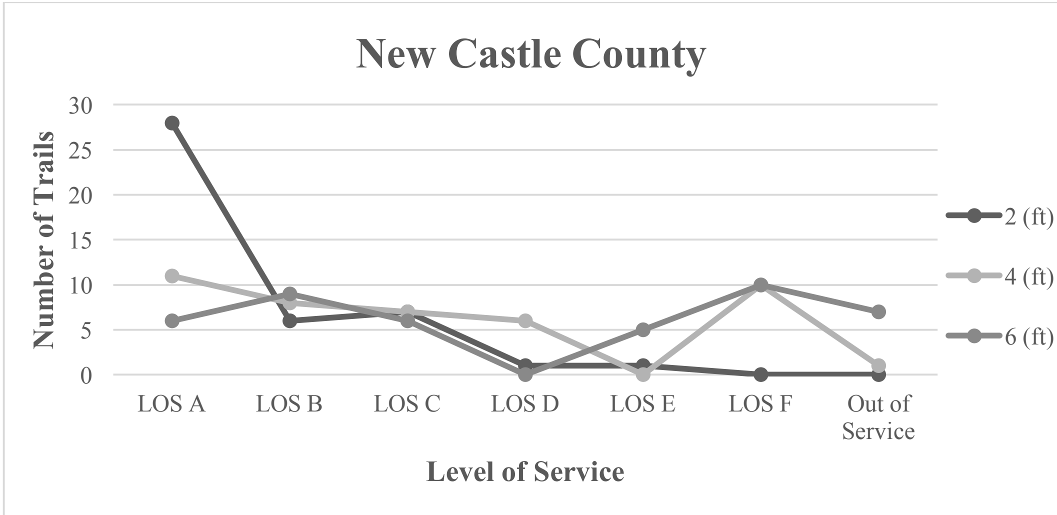

Figure 5.3: Trail's level of service under three sea level rise scenarios in New Castel County

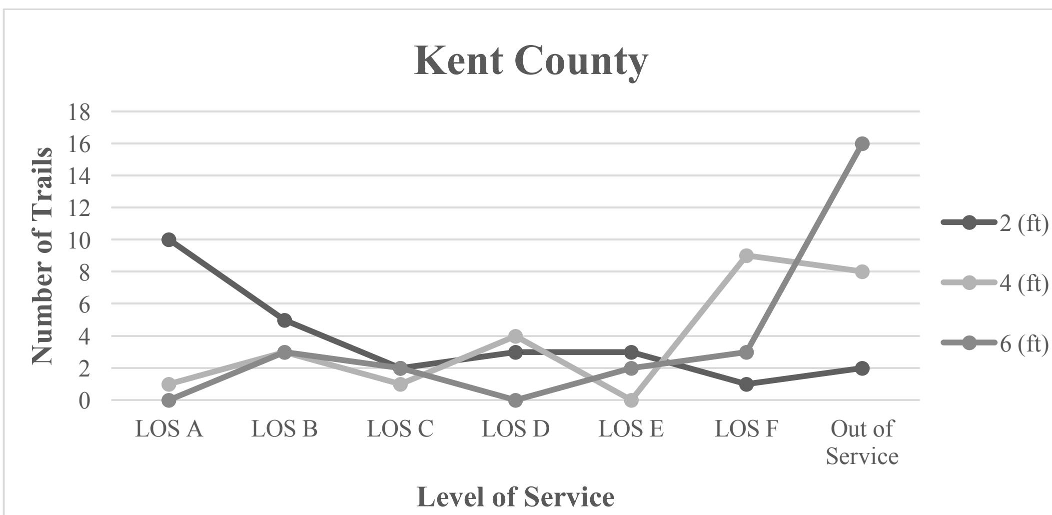

Figure 5.4: Trail's level of service under three sea level rise scenarios in Kent County

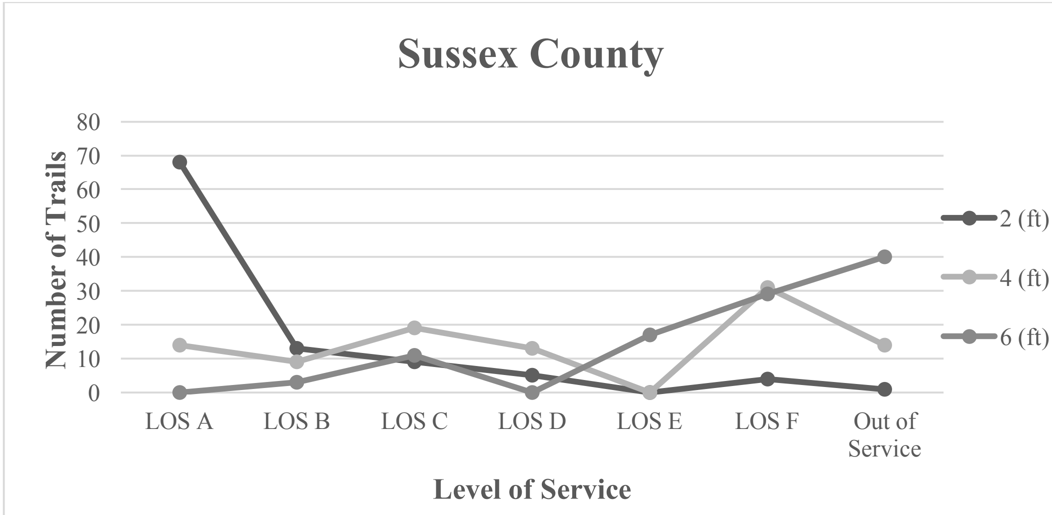

Figure 5.5: Trail’s level of service under three sea level rise scenarios in Sussex County

5.1.5 Maps of Affected Trails under Sea Level Rise Projections

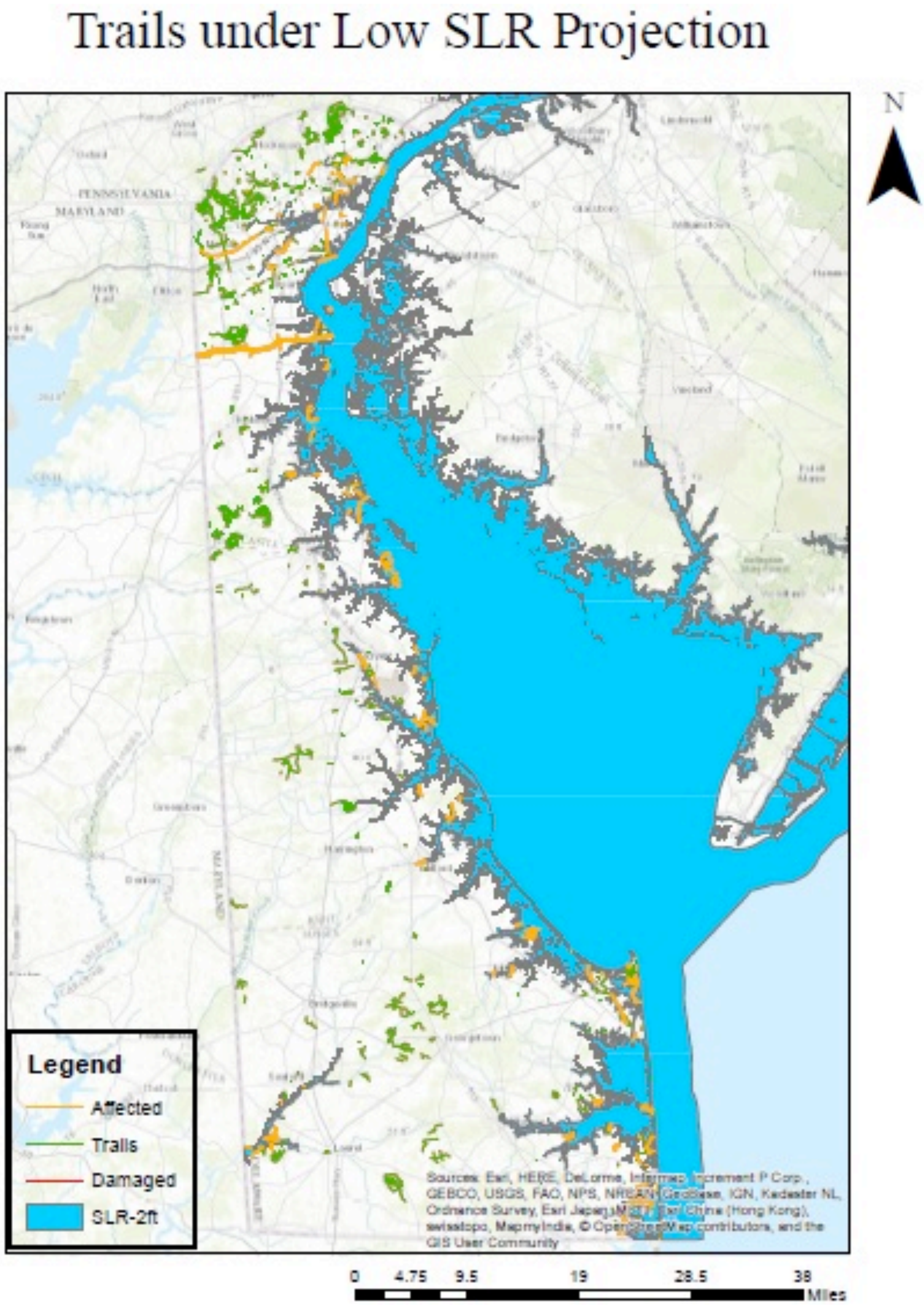

Figure 5.6: Trails condition under low sea level rise scenario (2 feet)

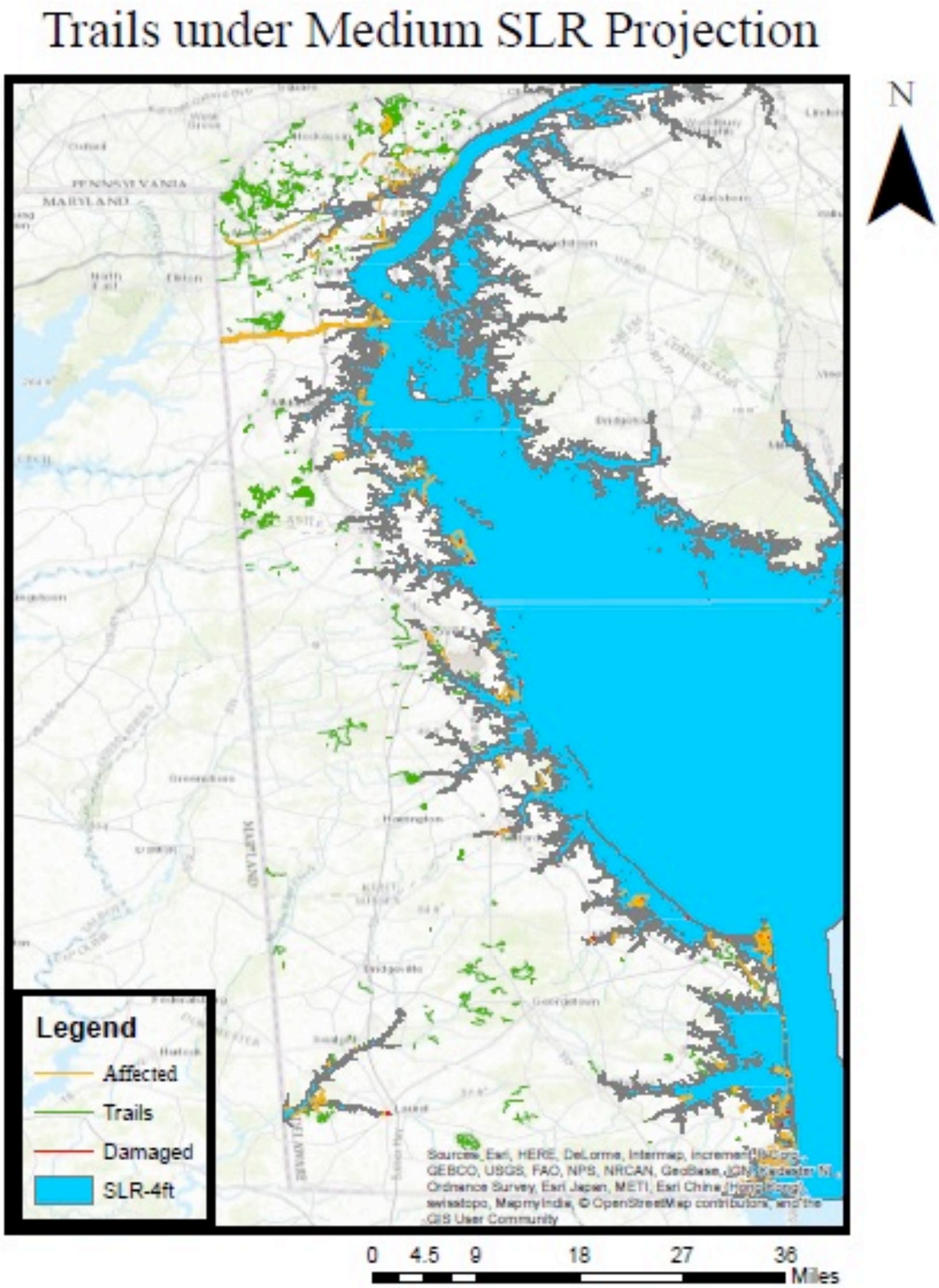

Figure 5.7: Trails condition under medium sea level rise scenario (4 feet)

Trails under High SLR Projection

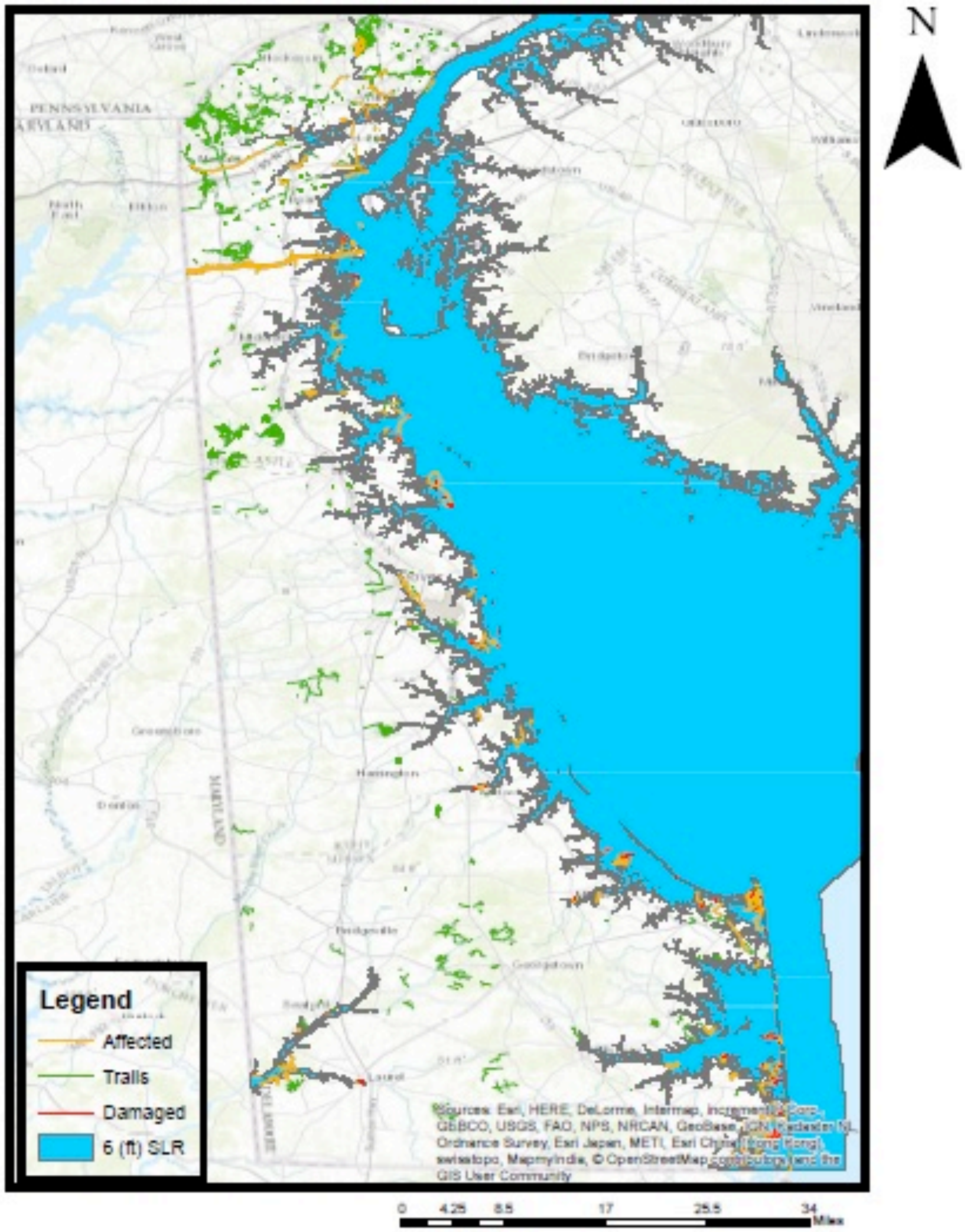

Figure 5.8: Trails condition under high sea level rise scenario (6 feet)

5.2 Analysis for Bike Routes

Bike routes are roadways that are considered as safe and suitable roads for cycling. As it was mentioned earlier, the ultimate goal of this research is to estimate the vulnerability of these facilities against sea level rise in 2100. The results are classified by DOT class (statewide, regional, and connector) so they will be more convenient to use for management corporations.

5.2.1 Assessment of Bike Routes' Affection under Sea Level Rise Projections

The following table shows the number of affected bike routes under three different sea level rise scenarios. The bike routes are classified by Department of Transportation (DOT) type so local government and management agencies could plan adaptation strategies and budget allocations accordingly.

Table 5.6: Number of affected bike routes by sea level rise in the Delaware

DOT Class	Total Number of Bike Routes	Number of Affected Facilities under Three SLR Projections		
		Low (2ft)	Medium (4ft)	High (6ft)
Connector	497	57	74	83
Regional	145	24	28	32
Statewide	211	24	35	38

5.2.2 Assessment of Bike Routes' Inundation Distance under Sea Level Rise Projections

The State of Delaware has 1715.49 (mile) of Bike Routes. Figure 10, demonstrates the total distance of affected facilities under three scenarios as well as the portion of the land that will remain on land and the distance that is going to be inundated. The total distance of the land that is going to be inundated for the high sea level rise scenario (6 feet) by the end of 2100 which is 90 (mile) is more significant than the inundation distance for the low sea level rise scenario (2 feet) which is estimated to be 30 (mile).

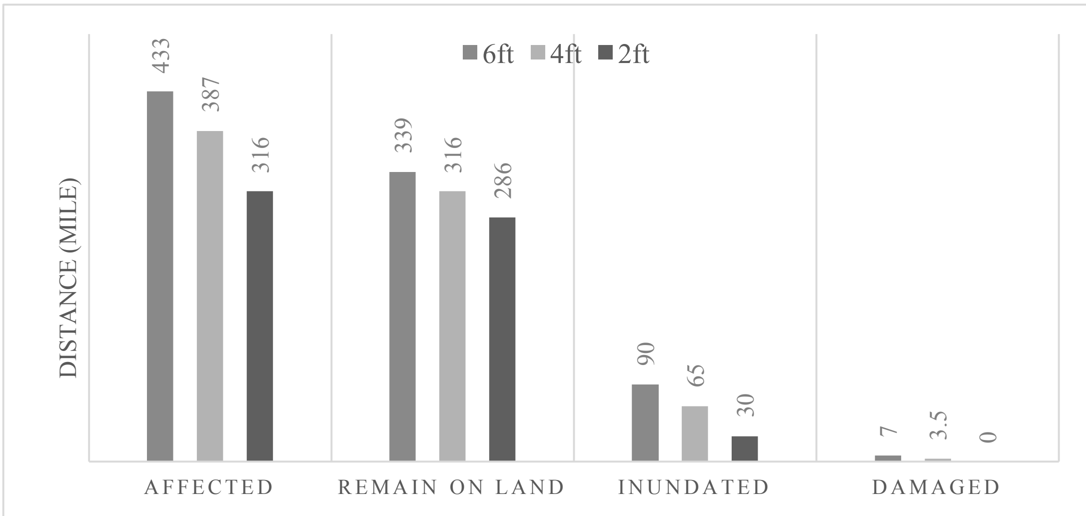

Figure 5.9: Distance of affected bike routes by sea level rise in Delaware (mile)

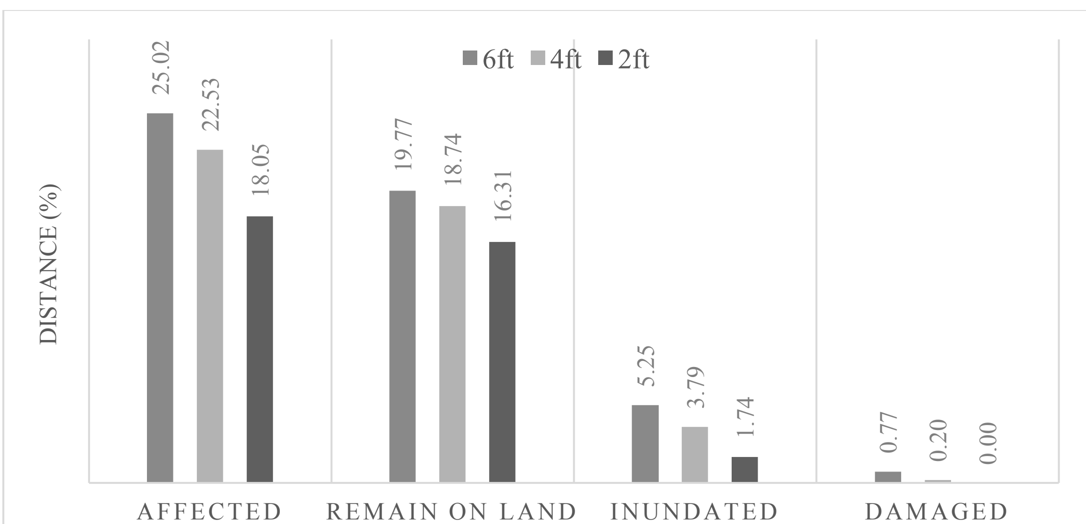

Figure 5.10: Distance of affected bike routes by sea level rise in Delaware (percent)

5.2.3 Damaged Bike Routes under Sea Level Rise Projections

As mentioned, one of the objectives of this research is identifying those bike routes that will be vanished due to different sea level rise projections. Following tables represent completely collapsed bike routes. In these tables, each bike route is addressed by its ID. In addition, the facility's distance and DOT's classification is addressed in this table.

Under the low projection of sea level rise (2 feet), bike routes will not be damaged or completely inundated.

Table 5.7: Fully inundated bike routes under medium sea level rise projection (4 feet)

Bike Route ID	DOT Classification	Bike Way	Distance (mile)
131	Connector	no	1.121
391	Connector	no	0.533
485	Connector	yes	1.236
667	Statewide	yes	0.273
668	Statewide	yes	0.28
Total Distance (mile)			3.114

Table 5.8: Fully inundated bike routes under high sea level rise projection (6 feet)

Bike Route ID	DOT Classification	Bike Way	Distance (mile)
189	Connector	yes	1.919
131	Connector	no	1.121
391	Connector	no	0.533
485	Connector	yes	1.236
648	Regional	no	0.193
264	Statewide	no	0.658
626	Statewide	yes	0.229
643	Statewide	no	0.553
667	Statewide	yes	0.273
668	Statewide	yes	0.28
Total Distance (mile)			6.995

5.2.4 Level of Service under Sea Level Rise Projections

As it was explained in the previous chapter, the vulnerability assessment is done for each facility separately based on the inundation distance and maximum depth of water for three sea level rise projections (Low, medium, and high).

Table 6, represents all the elements of vulnerability assessment. This table contains bike route's ID, length, DOT classification, length remaining on land after sea level rise, length of inundation after sea level rise, maximum depth of water, and level of service that was processed for one bike route as a sample. For the existing bike routes throughout the State this table is developed.

Table 5.9: Vulnerability assessment of a sample bike route under three sea level rise scenarios

			Low (2ft)	Medium (4ft)	High (6ft)
		Distance on Land (mile)	------	0.048	0.000
Bike Route's ID	626	**Inundated Distance (mile)**	------	0.066	0.229
Distance (mile)	0.229	**Land Loss (%)**	------	29.041	100.000
DOT Class	Statewide	**Min Elevation (ft)**	------	1.629	------
		Max Depth (ft)	------	2.371	------
		Level of Service	LOS A	LOS C	Out of Service

The scope of this research covers trails and bike routes through the state of Delaware. Since the result of this study is applicable by the Delaware Department of Transportation (DelDOT) and other management organizations responsible for maintenance and rehabilitation of these facilities, bike routes' results are classified by counties: Connector, Regional, and Statewide.

Following graphs show the trails level of service under low (2 feet), medium (4 feet), and high (6 feet) sea level rise for each county.

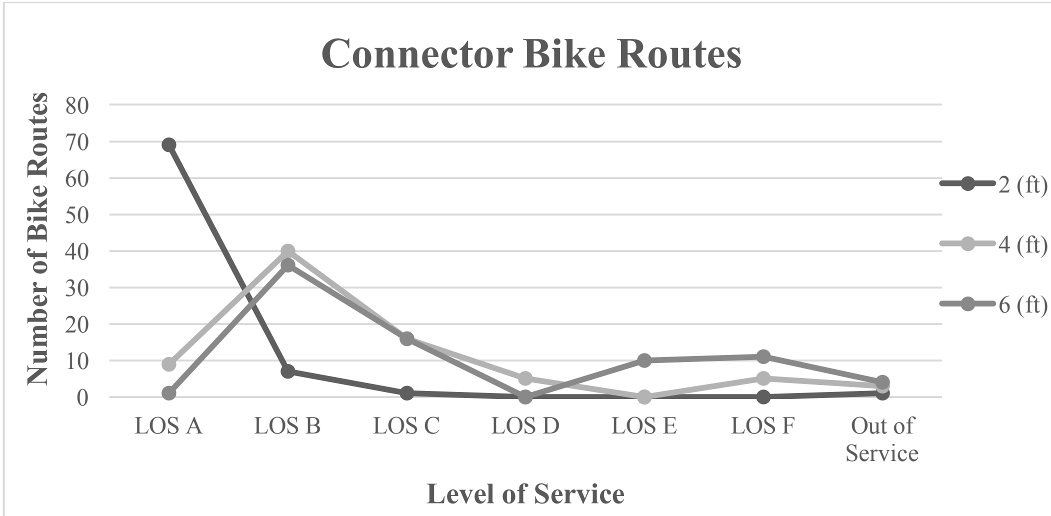

Figure 5.11 Connector bike routes' level of service under three sea level rise scenarios

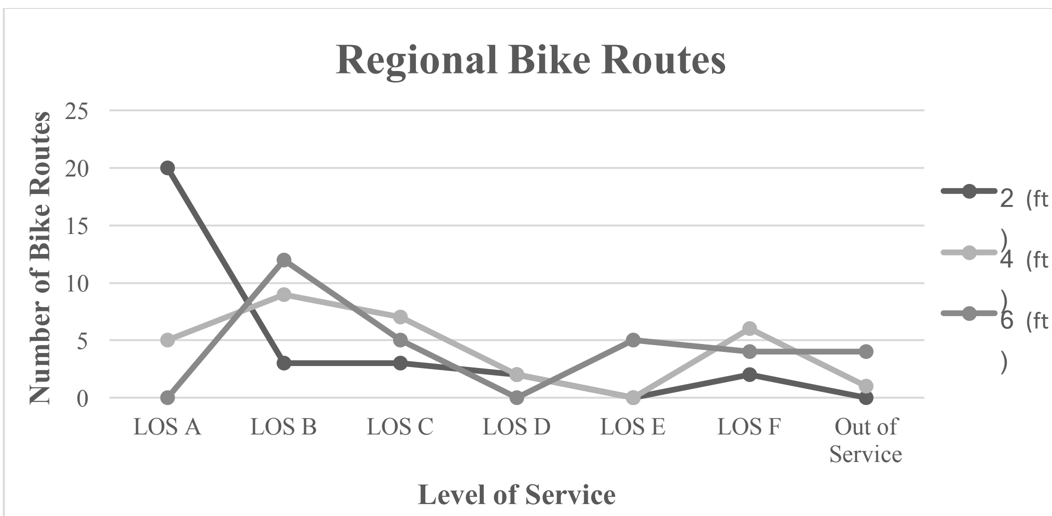

Figure 5.12: Regional bike routes' level of service under three sea level rise scenarios

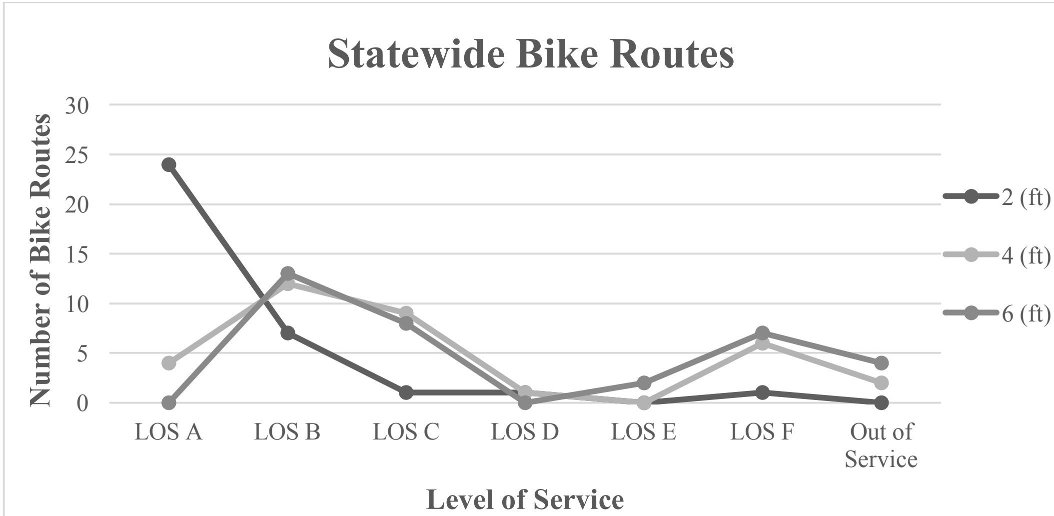

Figure 5.13: Statewide bike routes' level of service under three sea level rise scenarios

5.2.5 Maps of Affected Bike Routes under Sea Level Rise Projections

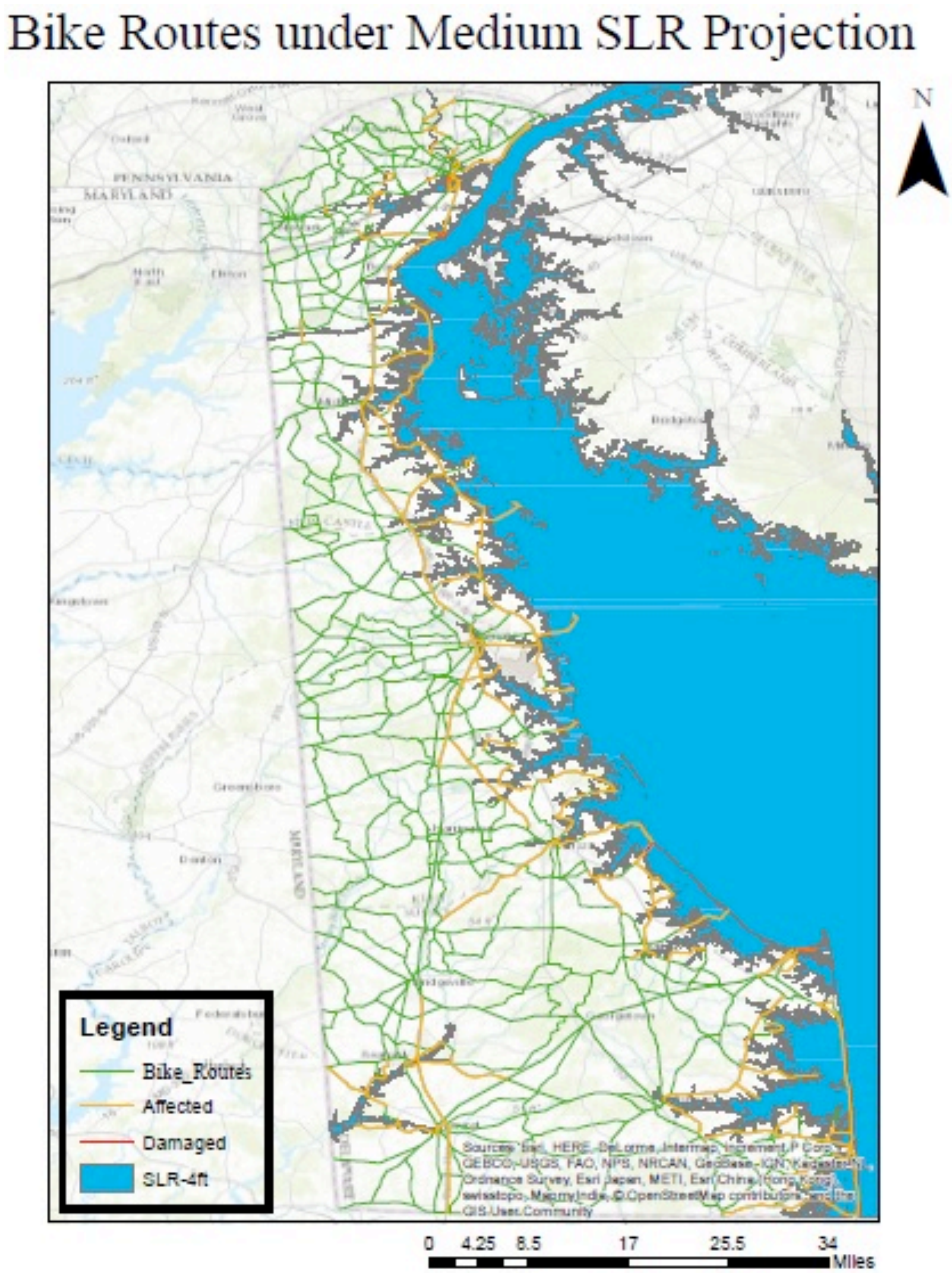

Figure 5.14: Bike routes condition under medium sea level rise scenario (4 feet)

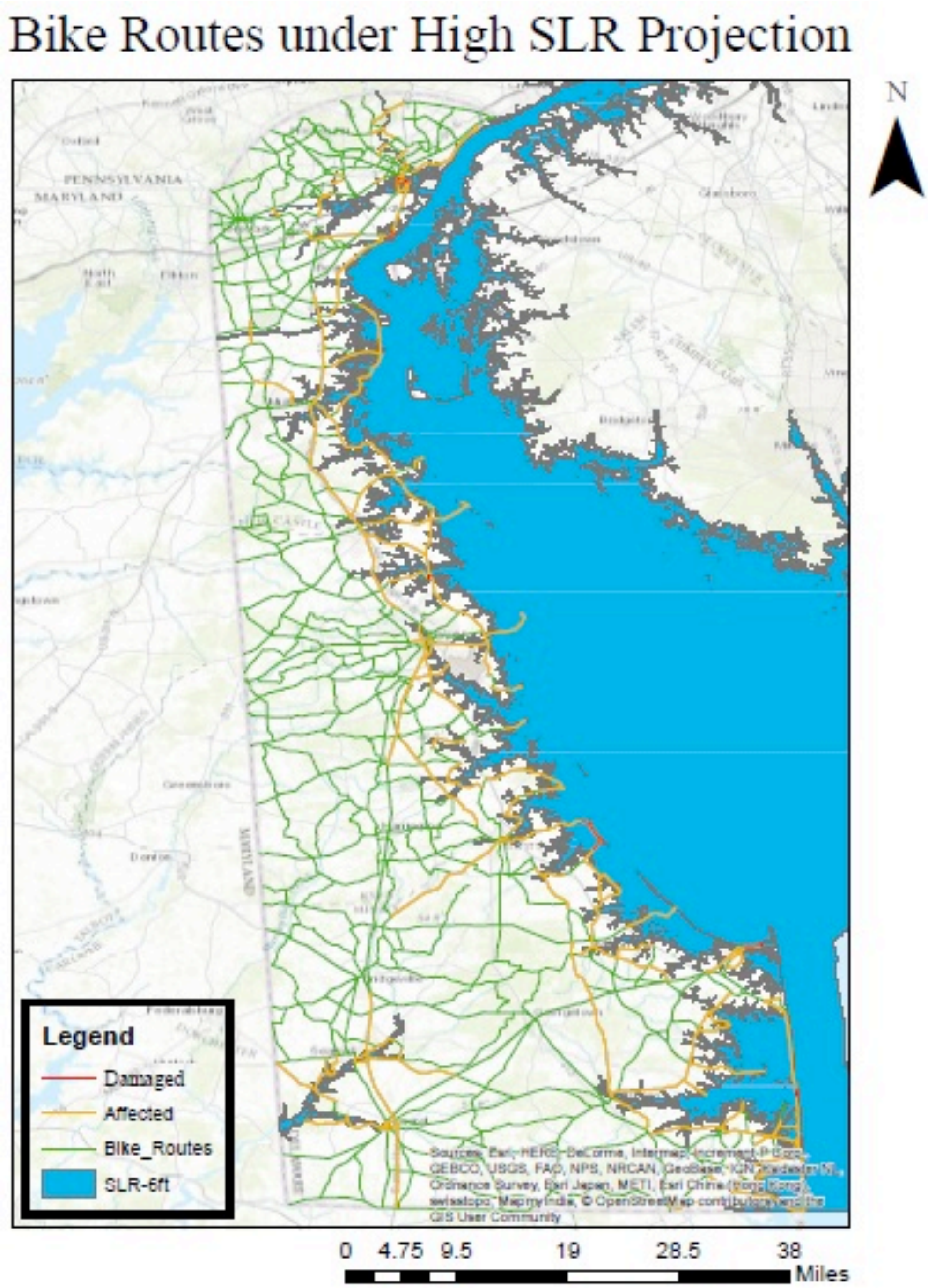

Figure 5.15: Bike routes condition under high sea level rise scenario (6 feet)

5.3 Summary of the Chapter

This chapter provides a comprehensive report of the GIS-based analysis and results of this study for trails and bike routes respectively. For all three sea level rise projections, there are tables containing number of affected facilities, and completely damaged facilities. The mileage of affected facilities, the distance that will remain on land, the distance that will be inundated, and the distance of damaged facilities under three sea level rise projections were reported in charts for trails and bike routes separately. These values were presented in a different chart based on percentage too.

The results of vulnerability assessment against sea level rise were presented in the form of level of service in different graphs for trails and bike routes respectively.

This section of the thesis includes maps that shows the condition of non-motorized transportation facilities (trails and bike routes) under sea level rise projections.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

Climate refers to weather patterns in a long period of time and climate change refers to any extreme changes in these patterns. Over past centuries especially last century, human activities have caused drastic changes in weather patterns by increasing atmosphere temperature. Anthropogenic activities like transportation produce cast amount of greenhouse gases (carbon dioxide, methane, nitrous oxide, fluorinated gases, perfluorocarbons, and sulfur hexafluoride) which eventually result in increased temperature.

Increased temperature has caused different climatic stressors such as sea level rise, more frequent flooding, intense precipitation, droughts, and heat waves. Different regions in the world are experience different climate change stressors for instance while in Mid-Atlantic region sea level rise in coastal areas is of a great importance, droughts and its consequences are noticeable.

As Environmental Protection Agency reported, transportation is responsible for about one-third of carbon dioxide emissions in the United States. Also, transportation is responsible for the emissions of other greenhouse gases. Five types of climate change impacts that have the most influence on transportation are increases in very hot days and heat waves, increases in arctic temperatures, rising sea levels, increases in intense precipitation events, and increases in hurricane intensity.

Surface transportation is affected by these climatic stressors in different ways. Sea level rise will cause more frequent interruption of roadway traffic and railroads, and inundation of roads, rail lines and tunnels in low-lying regions. Intense precipitation causes increase in travel time due to congestion. As it was thoroughly explained in this chapter one the most important stressors that affects infrastructure is increase temperature. Also, it has a great influence on travel behavior for different modes of transportation.

Air transportation has a reciprocal relation with climate change meaning that it contributes to the production of greenhouse gases which cause global warming and it is impacted by the consequences of climate change. Climate change has two most important effects on avian transportation. First, it results in damage and deterioration of facilities such as runways. Second, it causes disruption in airport's services due to various weather extremes such as storms.

Non-Motorized transportation or in other word active transportation is defined as walking or cycling. Sidewalks, walkways, bike lanes, and trails can be addressed as facilities for this mode of transport. Climate change has drastic effects on this mode since pedestrian and cyclists are more exposed to weather extremes. Temperature, humidity, and precipitation are identified as weather measures that has the most effects on pedestrian and cyclists' travel behavior.

The practice of reducing the amount of emissions is defined as mitigation. There are different sets of mitigation strategies for different modes of transportation like energy efficiency techniques, land use changes aligned with smart growth, use of renewable energy such as wind, solar, geothermal, or hydropower. A summary of mitigation strategies for road transportation and other modes are discussed Although these strategies will cause reduction in the production of greenhouse gases and alleviate the climate change, the impacts of climate change are already tangible all around the world. Thus, adaptation strategies are required to live with these impacts for example road elevation is one method of surviving against sea level rise.

Although there are several climatic stressors, the effect of sea level rise on non-motorized transportation facilities is studied in this research. Other impacts such as increased temperature or more frequent flooding can be studied in future.

For further analysis, trails' and bike routes' geospatial data were obtained from multiple sources such as Delaware Department of Transportation (DelDOT). The model that represents sea level rise in 2100 was obtained from National Oceanic and Atmospheric Administration (NOAA). Digital elevation model (DEM) is used to assign elevation to the existing GIS-based inventory of trails and bike routes.

Based on the GIS model developed using the geospatial data and sea level rise projection, the distance of each facility that will be inundated under three sea level rise scenarios (low, medium, high) is estimated. We used the same datum for assigning elevation to trails and bike routes as the sea level rise projection's datum. As result, the maximum depth of water on each facility was estimated. These two measures (inundation distance, and maximum depth of water) are required to assess the vulnerability of each facility against sea level rise. Bases on the vulnerability assessment which thoroughly explained in chapter four, all non-motorized facilities in the State is assigned with a level of service.

6.2 Conclusions

The most important objective of this research is to estimate the condition of trails and bike routes in the State. The results of analysis can be used by management authorities to plan for their future maintenance programs and their future developments.

Since there is a great amount of uncertainty around sea level rise (SLR), the analysis was done for three sea level rise projections. The number of damaged trails under the medium SLR projection shows an increase of 56.76% compared to the number of damaged trails under low SLR scenario. This percent increases to 78.9% when the comparison was done between low and high SLR projections. To investigate the severity of different projections, we compared the total distance of damaged trails. Analysis showed that there will be 60.95% increase in mileage of damaged trails under medium SLR scenario compared to low scenario and this percent will be 90.3% if the comparison was done between the lowest and the highest SLR projections. The analysis results for the bike routes showed that under the low scenario bike routes will not vanish. However, the number of damaged bike routes will increase by 50% if sea level rises 6 feet rather than 4 feet. Also, there will be a 55.48% increase in distance of damaged bike routes when the comparison is made between medium and high sea level rise projections. These drastic changes prove that management corporations should plan their adaptation strategies for the worst scenario because the gap between low and high future sea level rise projections is considerable.

All the analysis results prove that as sea level rise projection gets higher the number of trails with lower level of service increase. For instance, in Kent county, Delaware there is 87.5% increase in number of out of service facilities when the sea level rise projection changes from medium to high. This percent is 97.5% for Sussex County, Delaware which has a long coastal line and is more vulnerable to sea level rise. In addition, GIS-based analysis for bike routes shows that there is a 100% increase in the number of out of service bike routes as the sea level rise projection changes from medium to high.

Since the results of this research is operational for management corporations which are responsible for trails and bike routes in the State, it is essential for them to pay more attention to Sussex county because the number of trails affected by sea level rise in this region is almost twice as New Castle county and about four times more than Kent county.

Connector bike routes show a high vulnerability against sea level rise. DelDOT should invest in maintaining these facilities not only because they are more exposed to sea level rise but also because connector routes provide connection between statewide and regional network. This connection is substantial for the performance of the entire network. By investing in adapting connector bike routes to sea level rise, the performance of the whole system will be improved.

6.2.1 Merits

This research is the first study that evaluates the effect of sea level rise due to climate change on non-motorized transportation facilities in the state of Delaware. Thus, as it was mentioned earlier the result of this study is applicable for future planning of non-motorized transportation facilities. Also, the methodology that is used to assess the vulnerability of trails and bike routes against sea level rise is unique and it is applicable for any management corporations to evaluate the conditions of facilities.

6.2.2 De-merits

The uncertainty around the climate change is one of the features that can be counted as disadvantages of this research. There are other non-motorized transportation facilities that are not addressed in this research such as sidewalks, walkway, shared used path, etc. The scope of this study was limited to trails and bike routes.

6.3 Recommendations

This is a case by case study meaning that management corporations could refer to this research to find out the condition of each non-motorized facilities. Thus, it is recommended for them to use the results if they want to plan any adaptation strategies for trails and bike routes. For example, if a facility's level of service will be F in 2100 under projections, then there is no value in investing adapting the facility against sea level rise. Instead, new facilities can be built using the available funds.

In addition, based on the literature review, there are two other climate change stressors that affect transportation, flooding due to intense precipitation, and increased temperature. The effects of these climatic stressors on non-motorized facilities, pedestrians and cyclists' travel behavior can be estimated in future researches. For the purpose of evaluating the condition of trails and bike routes against intense flooding the same analysis path can be followed. Instead of using a GIS sea level rise model, the GIS flood frequency model should be used. There are different methods of assessing travel behavior under extreme conditions such as increased temperature. For example, a survey can be conducted asking people how their walking and cycling habits change when the temperature goes up.

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