Environmental Stressors and Infrastructure Resilience for Active Transport and Micromodal Facilities Using Artificial Intelligence

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16. Abstract

Urbanization, coastal inundation, extreme heat, and flooding poses critical threats to non-motorized transportation facilities (NMTFs) and micromobility infrastructure in Delaware. These environmental stressors pose unique challenges to micromobility facilities and their users, straining infrastructure integrity, elevating health risks, and causing service disruptions. Urbanization further compounds these vulnerabilities through increased impervious surfaces, degraded natural drainage, and concentrated populations in environmentally exposed areas.

Using GIS-based geospatial analysis, this study evaluates NMTF exposure under coastal inundation scenarios of 1–7 feet, identifying significant corridor intersections with high-risk flood zones. Spatial analysis reveals strong overlaps between high-exposure zones and regions where walking, biking, and micromobility compose a greater share of daily trips, underscoring the need for adaptive infrastructure like shaded pathways, elevated bike lanes, and flood-resilient surfaces. To complement these geospatial findings, a public survey captured perceived environmental impacts on active transportation behavior, with AI-driven analysis applied to extract patterns and community insights. Findings offer actionable guidance for planners and policymakers advancing resilient urban mobility.

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1. Introduction

Active transportation, including walking, bicycling, and micromobility, are rapidly expanding components of modern urban mobility systems [1]. Micromobility includes small, lightweight vehicles such as bicycles, e-bikes, and electric scooters that are typically used for short-distance travel. These modes of transportation are increasingly recognized for their potential to reduce congestion and promote resilient urban transport solutions. The integration of Mobility-as-a-Service (MaaS) platforms is further facilitating access to shared transportation by combining public transit, bike-sharing, and car-sharing into unified, user-friendly systems [2].

Figure 1. Different modes of micromobility based on FHWA definition

Internationally, the transition toward micromobility is accelerating. Cities such as Kelowna, Canada, have implemented large-scale shared e-scooter programs, resulting in over a million rides and measurable reductions in car usage. Electric bikes, though they comprise a relatively small portion of total bicycles, account for a disproportionately large share of trips, highlighting their growing influence. In the United States, micromobility is gaining popularity in dense urban environments, where demand for cycling infrastructure and pedestrian pathways is rising. Cities like New York and San Francisco are leading efforts to incorporate shared micromobility options into the broader transportation landscape [3].

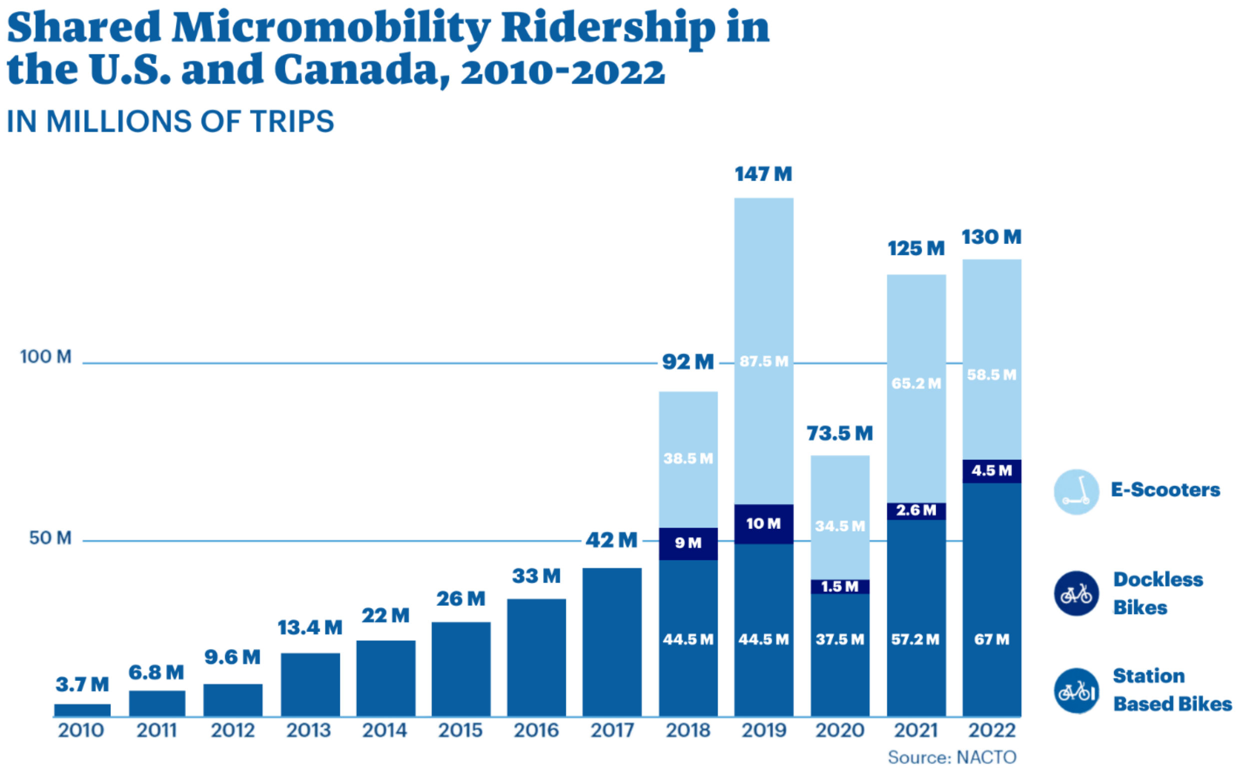

Figure 2. Increasement of shared micromobility usage among people in North America (California Active Transportation Safety Information Page)

Investment in safe, dedicated infrastructure such as protected bike lanes, secure parking, and reliable charging stations are a precondition for effective micromobility deployment. It also relies on robust data collection to understand usage patterns and support informed planning. At the policy level, regulatory frameworks have been developed in several cities to address speed limits, vehicle parking, and safety protocols. These regulations aim to reduce accident risks and improve the user experience by ensuring proper infrastructure is in place [4]. Infrastructure planning plays a critical role in maximizing these gains. Urban areas that incorporate micromobility-friendly designs often see improved connectivity and reduced strain on conventional transportation systems.

In Delaware, cities such as Wilmington and Dover are taking steps to expand micromobility deployment and improve cycling infrastructure. These efforts align with broader strategies aimed at enhancing transportation resilience in the face of environmental stressors, including coastal inundation, temperature increases, flooding, and urbanization. Technological innovations such as GPS integration, mobile apps, and dockless vehicle systems are helping make micromobility more efficient and accessible across an array of settings.

In addition to its transportation function, micromobility contributes to public health by encouraging physical activity and offering alternatives to car travel. As these systems continue to evolve, they are becoming a foundational element in urban development. With continued investment in infrastructure, technology, and planning, micromobility and active transportation can play a key role in building resilient cities that are more adaptable to environmental stressors.

1.1 Coastal Inundation

Environmental stressors pose increasing threats to transportation infrastructure, particularly in low-lying and coastal areas [5]. Coastal inundation, intensified storm surges, and more flooding events are of particular concern, as they can disrupt mobility networks and degrade infrastructure performance. Non-motorized transportation facilities, such as trails and bike routes, are especially vulnerable due to their surface exposure and proximity to natural features.

This study focuses on evaluating the vulnerability of trails and bike routes to NOAA projected sea level rise (SLR) scenarios using Geographic Information System (GIS)-based analysis. By estimating potential inundation extents and depths under multiple projections, this work aims to support proactive planning and inform infrastructure adaptation strategies in the context of ongoing environmental stressors.

1.2 Temperature

Global temperature trends continue to reflect the intensifying impacts of environmental stressors on public infrastructure [6]. The summer of 2024 marked the hottest on record globally, with a global-average surface air temperature anomaly of +0.69°C above the 1991–2020 baseline for the June–August period, surpassing the previous record set in 2023 [7]. This report examines how elevated temperatures intersect with non-motorized travel behavior across Delaware. Using spatially joined temperature and commuting data at the census-tract level, this analysis identifies areas where rising temperatures coincide with higher reliance on walking, cycling, and other non-motorized modes, to inform planning efforts that improve comfort and system resilience for these travelers. Delaware has experienced a similar pattern of rising temperatures, with the state's average annual temperature increasing by around 2°F since the early 20th century [7][8]. This trend is consistent with broader patterns observed throughout the northeastern United States. Delaware is now facing more frequent and intense heatwaves, which impact multiple sectors, including health, agriculture, infrastructure, and energy systems. Projections indicate elevated risks for coastal and urban areas due to heat stress and associated environmental pressures. These changes highlight the need for robust planning and infrastructure adaptation to maintain resilience in the face of ongoing environmental stress.

1.3 Flooding

In the United States, flooding represents the costliest category of natural disasters. Between 1996 and 2023, approximately 70% of flood-related disasters were attributed to heavy rainfall. Coastal areas along the Gulf and Atlantic coast are especially affected by rising flood levels. Nationally, average precipitation has increased by about 10% since the early 20th century, though this change varies regionally. The northeastern U.S. has seen the most significant rise in heavy precipitation events, whereas the Southwest has experienced more prolonged dry spells.

Delaware is especially susceptible to coastal flooding because of its low elevation and coastal geography. Over the past 30 years, the state has observed a 20% increase in the frequency of flood events. When combined with episodes of heavy rainfall, these floods place considerable stress on transportation systems, buildings, and other infrastructure. Delaware has also recorded an upward trend in annual precipitation, with heavy rainfall events becoming 20% more common since the 1990s. This change elevates the risk of localized flooding, particularly in urban areas with limited drainage capacity. These conditions highlight the importance of long-term planning and infrastructure improvements to manage flood-related challenges linked to environmental stressors.

1.4 Urbanization

Urbanization is a defining global trend with far-reaching implications for ecological systems, infrastructure planning, and transportation development. As of 2023, over 57% of the world's population lives in urban areas, a figure projected to increase to 64% by 2040 and 68% by 2050. This expansion is shaped by rural-to-urban migration, economic opportunities, and population growth, particularly in developing regions. In contrast, developed regions such as North America and Europe are experiencing slower urban growth, with more emphasis on optimizing existing urban systems [9].

Urban areas are key drivers of global economic activity, but they also present challenges such as overcrowding, infrastructure strain, resource depletion, and pollution. To address these, many cities are adopting smart technologies including artificial intelligence (AI), the Internet of Things (IoT), and data-driven urban planning, to improve transportation, infrastructure management, and overall resiliency. For instance, cities like Barcelona have successfully implemented digital solutions to enhance urban living through integrated mobility systems, efficient energy use, and responsive public services. Moreover, resilience is becoming a central pillar of urban planning. Cities are increasingly investing in energy-efficient buildings and infrastructure that can adapt to environmental stressors.

In the United States, approximately 83% of the population resides in urban areas, making it one of the most urbanized countries globally. Major metropolitan areas such as New York, Los Angeles, and Chicago lead in both population size and economic output. At the same time, mid-sized cities like Austin and Raleigh are experiencing rapid growth driven by factors such as access to services, employment, and urban amenities. However, urban expansion, particularly low-density development or sprawl, can lead to increased infrastructure demands. Cities across the U.S. are implementing policies that promote more compact urban development to reduce these pressures. Cities such as San Francisco and Portland are at the forefront of integrating public transit with pedestrian and micromobility infrastructure to support long-term urban growth.

In Delaware, over 80% of the population lives in urban areas, placing the state among the most urbanized in the country. Urban growth continues through migration and economic development, particularly around cities such as Wilmington, Dover, and Newark. Wilmington functions as a key economic and administrative hub, while suburban expansion contributes to regional urbanization. This growth brings challenges such as infrastructure strain, land use pressure, and increased flooding risk in low-lying developed areas.

To manage the environmental implications of urbanization, Delaware is actively working to improve public transportation and expand micromobility and pedestrian-friendly networks [10]. These efforts support the state's broader strategy to build resilience in response to environmental stressors while maintaining urban functionality and efficiency.

2. Coastal Inundation

The effects of coastal inundation extend far beyond occasional storm-related flooding. In many low-lying areas, even modest increases in baseline water levels can result in more frequent "sunny day" or high-tide flooding, which occurs in the absence of storms. As coastlines become more regularly submerged, transportation facilities designed for dry-ground operations, such as roads, sidewalks, trails, and bike routes, face chronic disruptions. The structural integrity of pavements is compromised when repeatedly exposed to saltwater, and the presence of standing water increases wear and shortens the lifespan of infrastructure. Drainage systems often become overwhelmed, where impervious surfaces dominate especially in urbanized coastal zones.

Active transportation facilities are particularly vulnerable in this context. Trails and bike lanes are often constructed along scenic or environmentally sensitive corridors, such as waterfronts, riverbanks, and converted railways, that place them directly in harm's way. These areas, while attractive for recreation and mobility, are also some of the first to experience flooding during high tides or storm surges. Inundation reduces the usability of these facilities not only by direct submersion but also through erosion, sedimentation, and the accumulation of debris, which can make them unsafe or impassable. Even intermittent flooding events can discourage use, reduce reliability, and lead to long-term deterioration if not properly maintained.

In addition to the physical risks, coastal inundation also undermines the connectivity and continuity of non-motorized transportation networks. When a key segment of a trail or bike path is rendered unusable, whether temporarily or permanently, it can sever access to schools, workplaces, transit stations, or recreational destinations. This is particularly problematic in communities that have invested in integrated mobility systems where the biking and walking infrastructure serves as a crucial "last mile" connection to bus or rail services. The loss of such connections may force users to revert to motorized modes and reduce the attractiveness of active transportation overall.

The long-term consequences of coastal inundation also complicate infrastructure planning and investment. Municipalities and transportation agencies must now consider not only current flooding risks but also evolving projections that span decades. Designing resilience involves trade-offs between elevation, material choice, drainage design, and long-term maintenance. In some cases, trails and bike routes may need to be relocated entirely to higher ground. In others, they can be retrofitted with elevated boardwalks, permeable pavements, or water-tolerant vegetation buffers. These adaptation strategies often come with significant cost implications, especially when applied across entire networks, and their effectiveness may vary based on local topography and hydrology.

This research presents a GIS-based model designed to evaluate how coastal inundation could affect non-motorized and micromodal transportation facilities in Delaware, particularly trails and bike routes. The model integrates spatial inventories of these facilities with three sea level rise scenarios provided by NOAA. Using ArcMap's intersection tool, the analysis identifies which portions of the network intersect with projected flood zones.

Each facility is assessed individually. Two key factors are analyzed: (1) the length of trail or route projected to be submerged, and (2) the maximum depth of flooding on those segments. These two measures are used to assign a vulnerability rank to each facility. Routes with small impacted sections and shallow depths are considered more resilient and may require only minor, cost-effective adaptations. In contrast, facilities with longer submerged segments and deeper water levels are flagged as highly vulnerable and likely to require major investment to preserve.

The primary objective is to determine the vulnerability of active transportation corridors under low, medium, and high scenarios of coastal inundation. The outcome of the analysis is a level-of-service (LOS) classification, ranging from A to F, assigned to each facility. This classification depends on the degree of inundation and depth, helping to inform decisions about maintenance feasibility and long-term usability.

These insights provide a decision-support tool for transportation authorities such as state DOTs. For instance, a trail rated as LOS-F may be recommended for decommissioning, with resources redirected toward creating a new facility in a safer, less exposed location. This strategic planning helps improve resilience across the active transportation network in response to future environmental stressors.

Table 1. Level of service estimation based on depth of water and length of flow for three coastal inundation scenarios

		Inundation Distance (%)					
		0-10	**10-30**	**30-50**	**50-70**	**70-90**	**90-100**
Low (2ft)	**Maximum Depth of Water less than 1 (ft)**	LOS A	LOS A	LOS B	LOS D	LOS E	Out of Service
	Maximum Depth of Water More than 1 (ft)	LOS A	LOS B	LOS C	LOS D	LOS F	Out of Service
Medium (4ft)	**Maximum Depth of Water less than 2 (ft)**	LOS A	LOS B	LOS D	LOS E	LOS F	Out of Service
	Maximum Depth of Water More than 2 (ft)	LOS B	LOS C	LOS D	LOS F	LOS F	Out of Service
High (6ft)	**Maximum Depth of Water less than 3 (ft)**	LOS A	LOS C	LOS D	LOS F	LOS F	Out of Service
	Maximum Depth of Water More than 3 (ft)	LOS B	LOS C	LOS E	LOS F	LOS F	Out of Service

The following table presents the number of trails affected under three distinct SLR scenarios derived from NOAA projections. These trails are categorized by the county, enabling local governments and infrastructure management agencies to effectively plan resilience strategies and allocate appropriate budgets. The data indicates that Sussex County contains a greater number of vulnerable facilities compared to the other two counties, highlighting the need for prioritized attention in that region.

Table 2. Number of affected trails by coastal inundation in Delaware State

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

The State of Delaware has approximately 713.5 miles of designated trails. Figure 3 illustrates the total length of facilities projected to be affected under three SLR scenarios, along with the portions expected to remain unaffected and those at risk of submersion. Under the high SLR scenario (6 feet by the year 2100), approximately 103 miles of trail infrastructure are projected to be exposed to flooding substantially more than the 30 miles estimated under the low scenario (2 feet). This comparison underscores the increasing vulnerability of active transportation corridors under more severe NOAA projections.

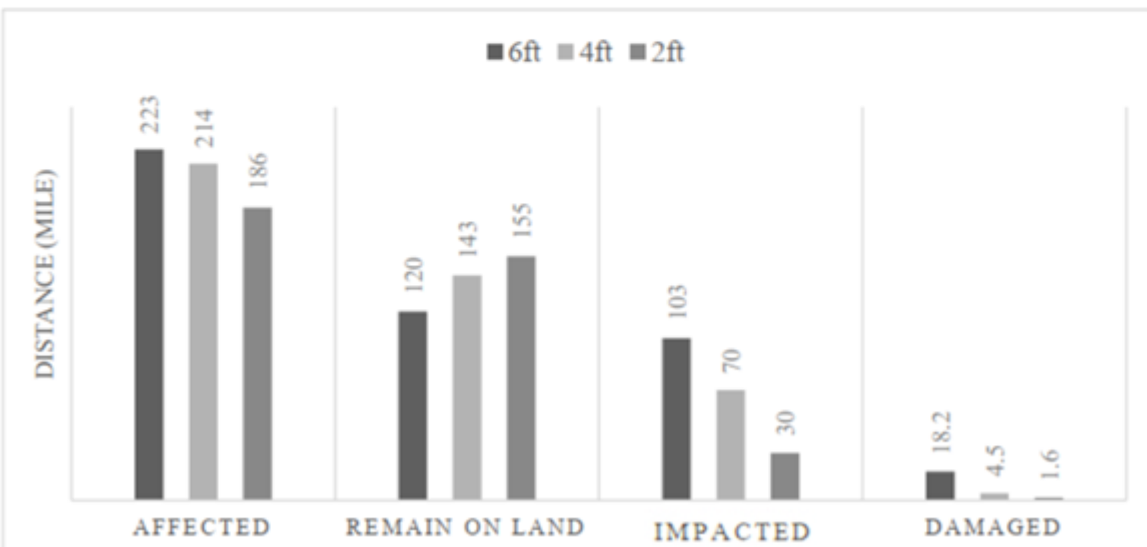

Figure 3. Distance of affected trails by coastal inundation in Delaware (mile)

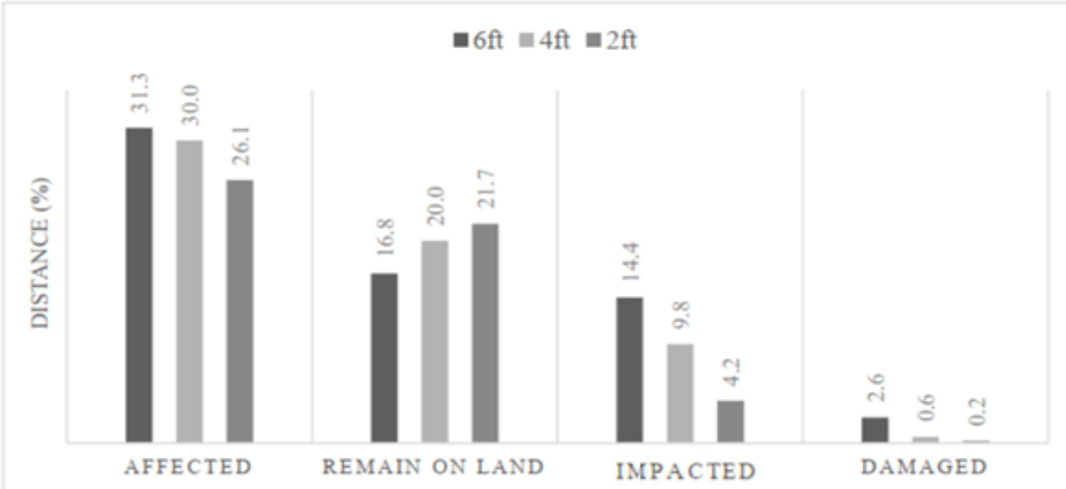

Figure 4. The distance of affected trails by sea level rise in Delaware (percent)

As previously noted, one of the key objectives of this research is to identify trail segments that will be fully lost under various SLR scenarios. The following tables present trails projected to experience complete submersion. Each entry includes the trail's identification number, name, total length, and the county in which it is located. This information is intended to support resiliency planning and resource prioritization at the local level.

Table 3. Fully impacted trails under low coastal inundation 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 4. Fully impacted trails under medium coastal inundation 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. Fully impacted trails under high coastal inundation 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 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	

The scope of this research includes trails and bike routes across the state of Delaware. Since the findings of this study are intended to support the efforts of the Delaware Department of Transportation (DelDOT) and other agencies responsible for maintaining and improving these facilities, the results for trails are categorized by county: New Castle, Kent, and Sussex.

The following graphs display the level of service for trails under low (2 feet), medium (4 feet), and high (6 feet) NOAA SLR scenarios for each county.

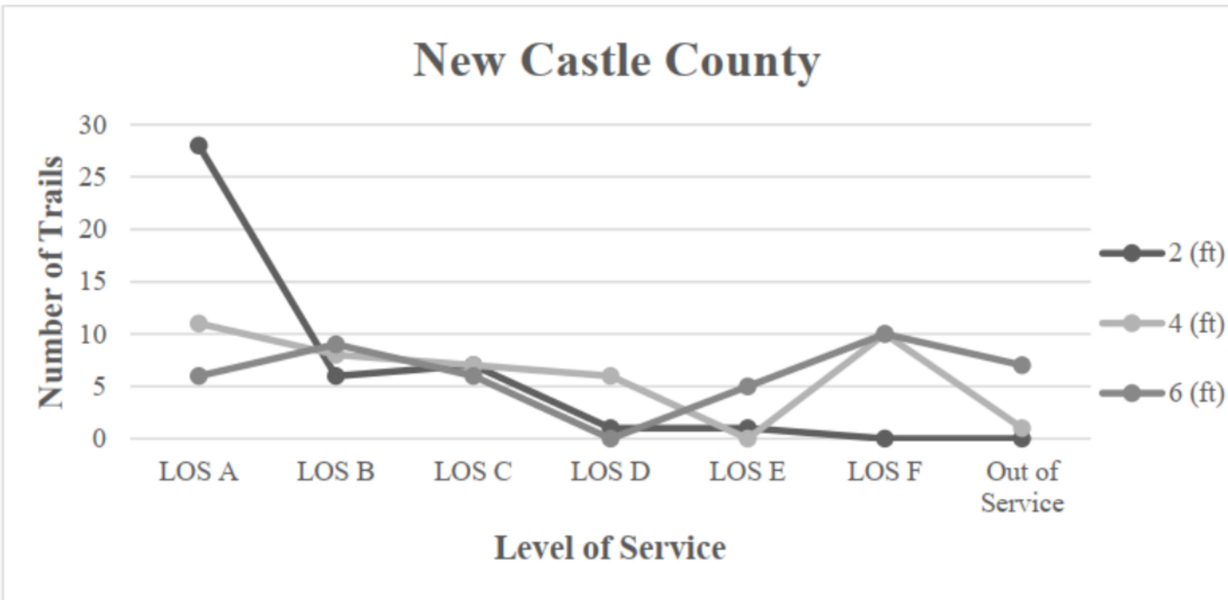

Figure 5. Trail's level of service under three coastal inundation scenarios in New Castle County

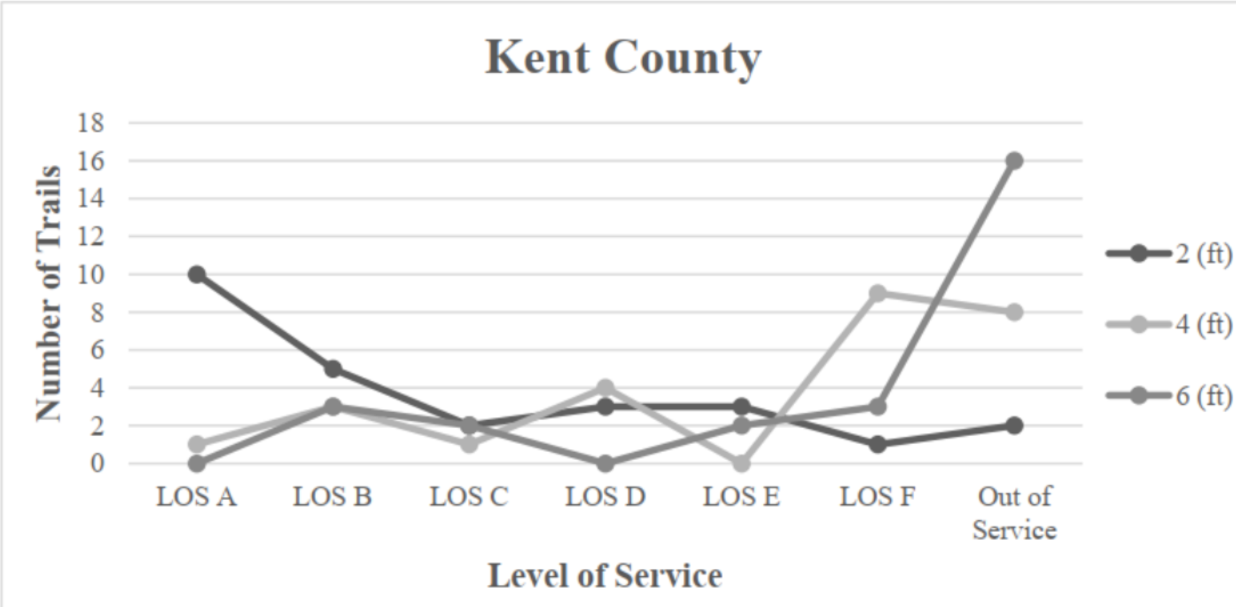

Figure 6. Trail's level of service under three NOAA SLR scenarios in Kent County

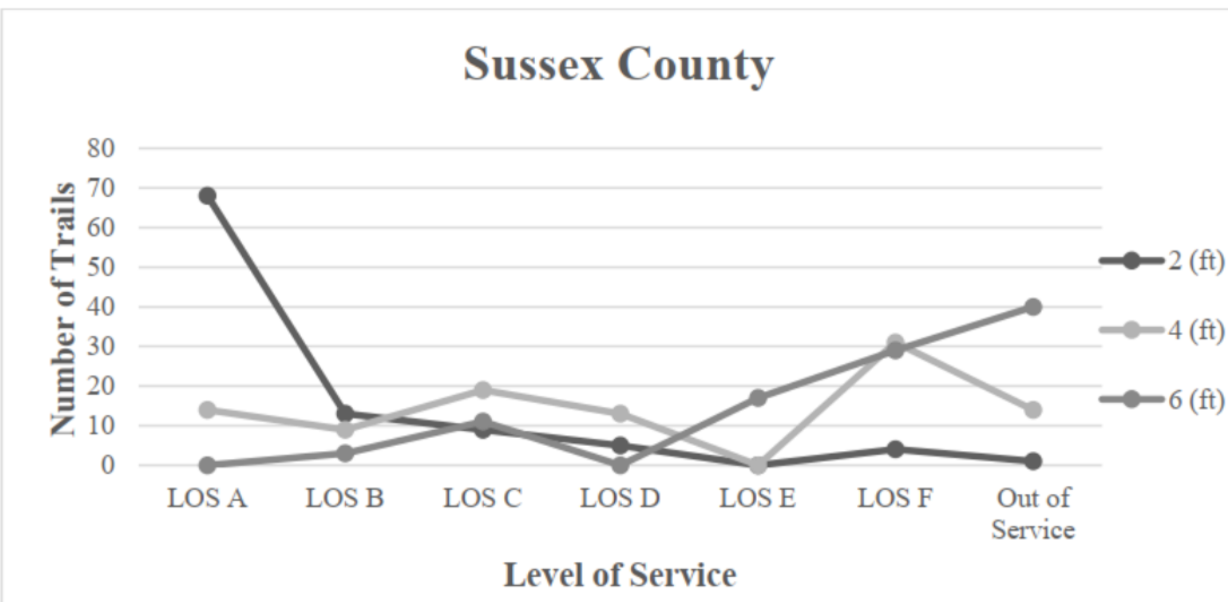

Figure 7. Trail's level of service under three NOAA SLR scenarios in Sussex County

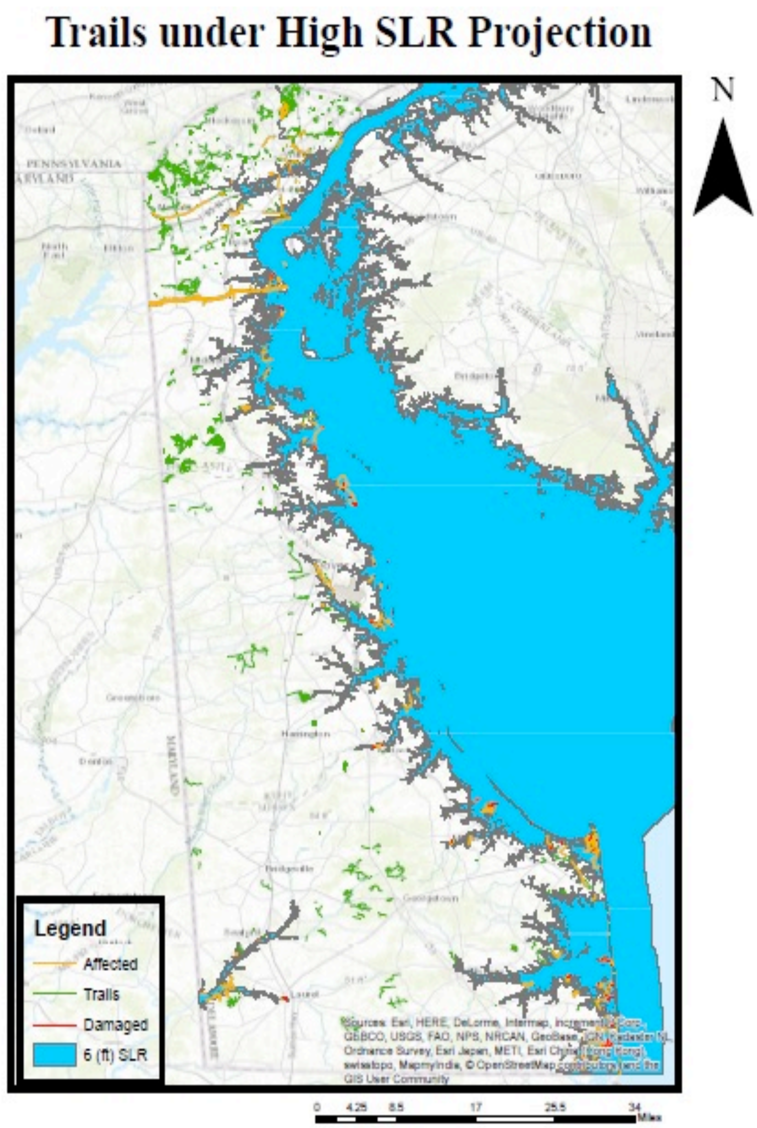

Figure 8. Trails condition under high NOAA SLR scenario (6 feet)

After considering Trails over Delaware, we continue with bike routes all over Delaware State.

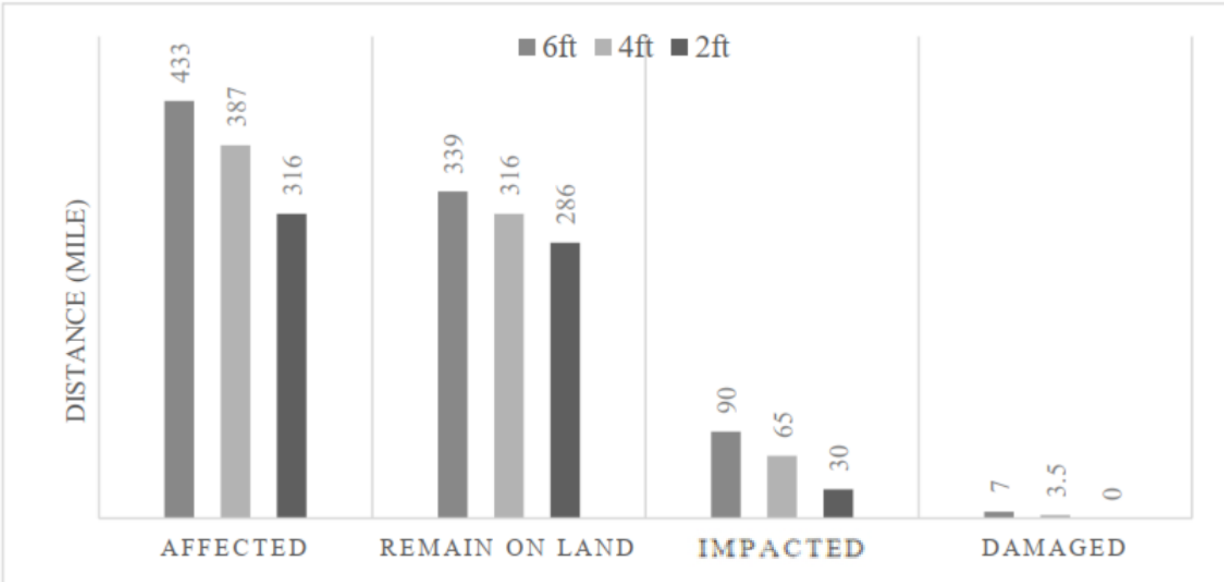

Figure 9. Distance of affected bike routes by coastal inundation in Delaware (mile)

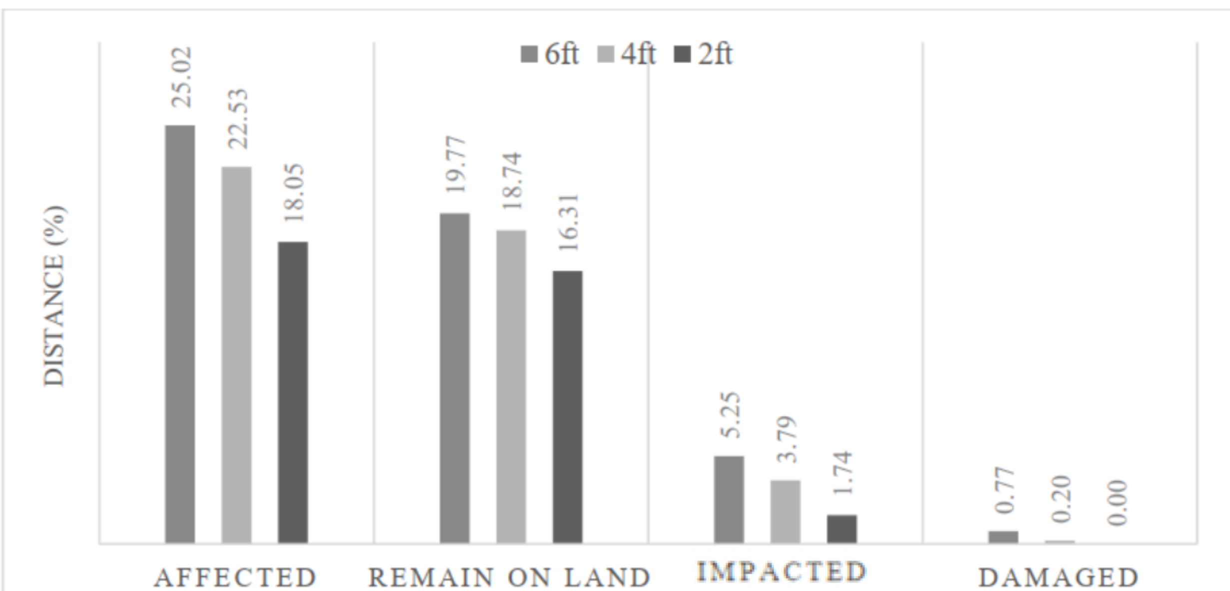

Figure 10. Distance of affected bike routes by coastal inundation in Delaware (percent)

The scope of this research includes trails and bike routes throughout the state of Delaware. As the findings are intended to inform the Delaware Department of Transportation (DelDOT) and other relevant agencies involved in the maintenance and improvement of these facilities, the results for bike routes are categorized based on their classification: Connector, Regional, and Statewide.

The following graphs illustrate the level of service for trails under low (2 feet), medium (4 feet), and high (6 feet) NOAA sea level rise scenarios for each classification.

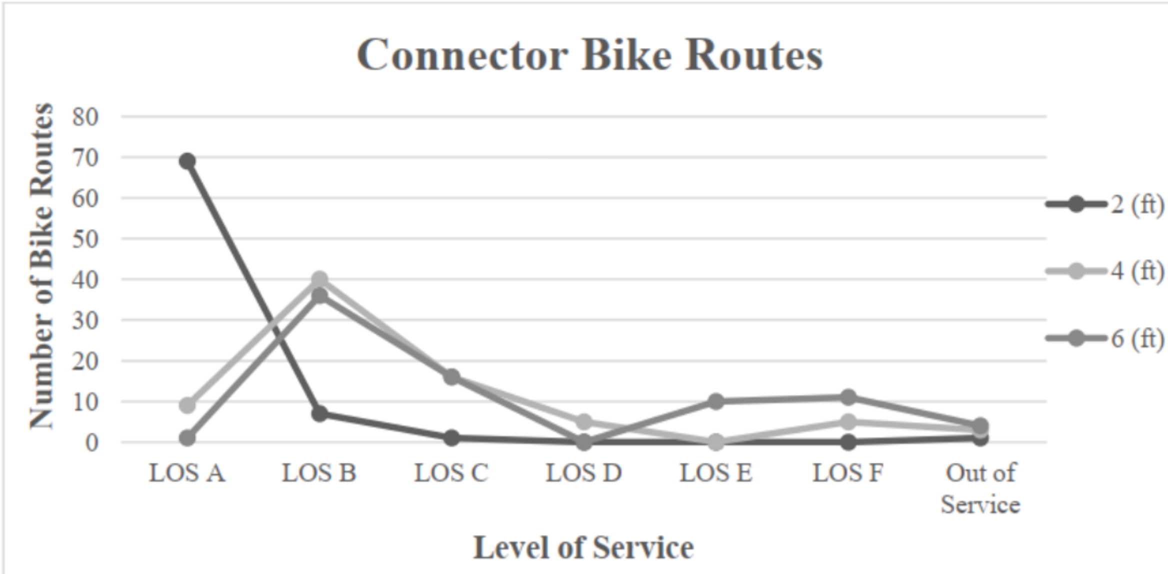

Figure 11. Connector bike routes' level of service under three NOAA SLR scenarios

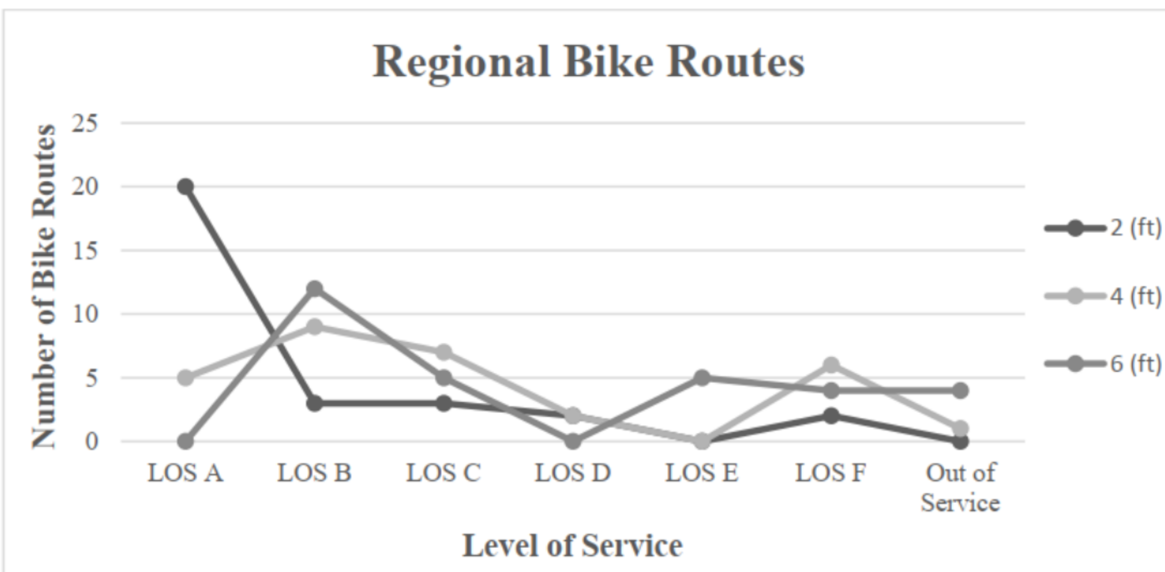

Figure 12. Regional bike routes' level of service under NOAA SLR scenarios

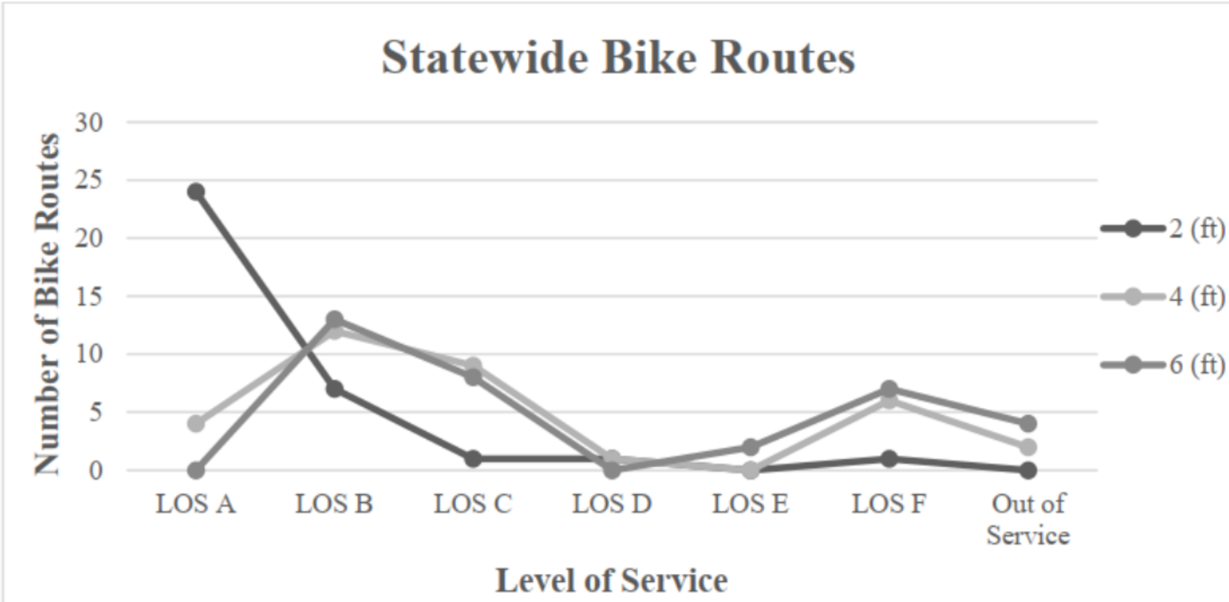

Figure 13. Statewide bike routes' level of service under three NOAA SLR scenarios

Now we are going to evaluate the effects of different coastal inundation scenarios for bike routes.

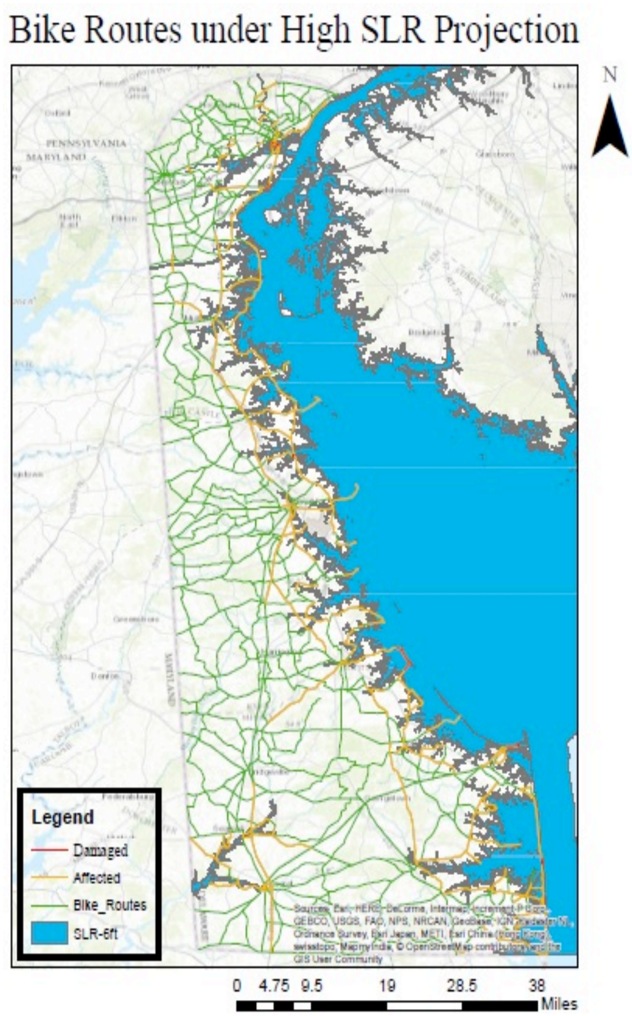

Figure 14. Bike routes condition under high NOAA SLR scenario (6 feet)

These findings show that as coastal inundation projections intensify, more facilities are expected to be affected, and service levels decrease accordingly. For example, the number of impacted trails rises by 56.76% from the low to medium scenario and by 78.9% from low to high. Similarly, the total affected distance increases by 60.95% and 90.3%, respectively. While no bike routes are fully impacted under the low scenario, the number of affected routes increases significantly under the higher projections.

County-level analysis reveals that Sussex County, with its extensive shoreline, is more exposed than Kent and New Castle Counties. In Sussex, the number of out-of-service facilities increases by 97.5% when comparing medium and high flow projections. Additionally, connector bike routes show higher exposure and are critical to maintaining the overall network functionality. Investing in adaptive measures for these connectors could enhance the performance and resilience of the entire system.

Finally, coastal inundation raises questions about the long-term resilience of urban and regional transportation systems. Active transportation is increasingly promoted as a solution for improving public health and enhancing mobility options. However, if these systems are not designed to withstand future environmental stressors, their role in mitigation may be undermined. Ensuring that non-motorized infrastructure remains viable and safe in the face of coastal inundation is therefore essential not only for adaptation but also for the success of broader environmental and transportation policy goals. Forward-thinking design, data-driven risk assessment, and cross-agency collaboration will be critical to safeguarding these networks in the decades to come.

3. Temperature

Prolonged exposure to elevated heat levels is increasingly a defining feature of daily life in urban environments. For the transportation sector, these conditions introduce new challenges with respect to infrastructure management, especially for facilities that are exposed to the elements, such as sidewalks, trails, and bike paths [11][12].

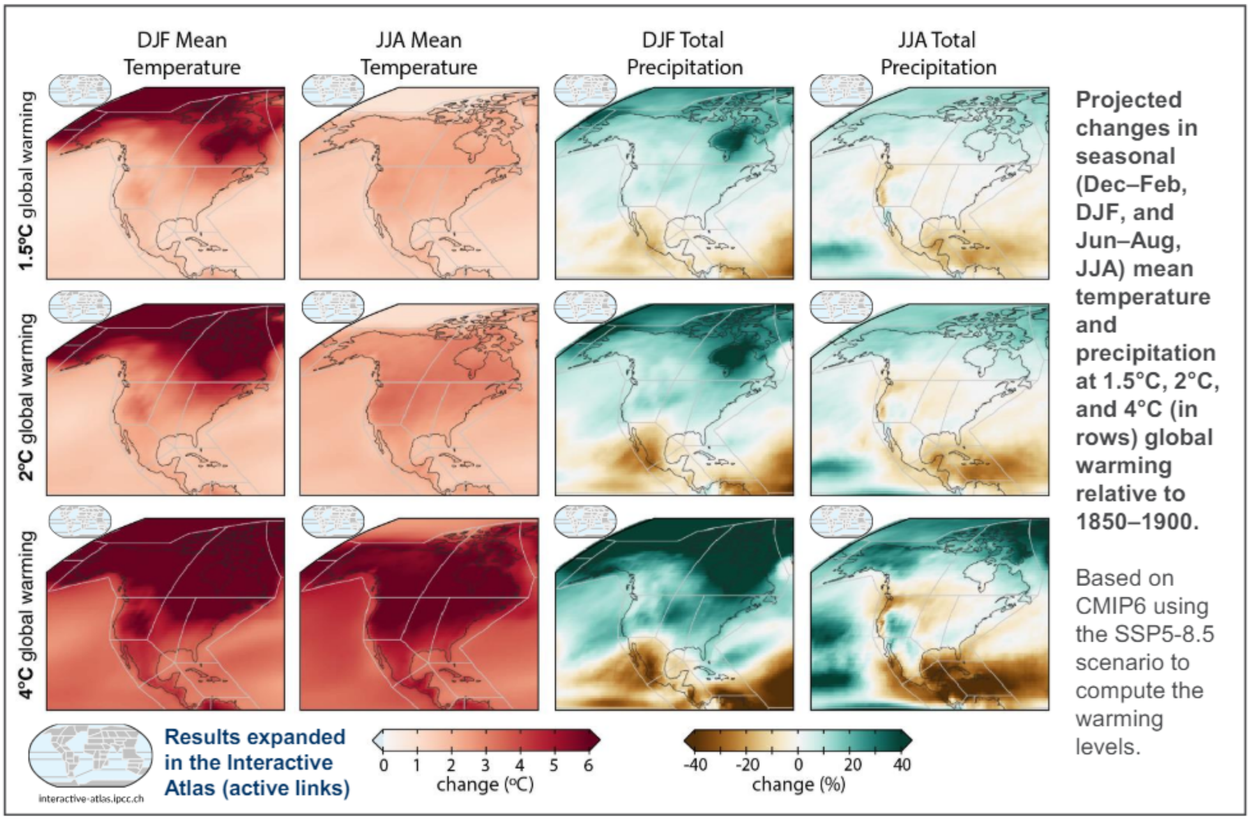

Figure 15. Different temperature rise scenarios in North America [13]

Warmer conditions, especially during summer months (June, July, and August), may increase stress in urban areas such as Wilmington, impacting residents who depend heavily on walking, cycling, and other active modes. According to the U.S. Census Bureau (ACS Report, 2021), approximately 5% of Delaware workers commute via public transportation. These commuters are more likely to experience the challenges associated with elevated outdoor conditions. The intensification of localized heat retention in urban areas could further reduce comfort and safety during peak daytime hours, potentially limiting the practicality of active transportation for these populations.

The materials used in active transportation infrastructure are highly sensitive to thermal stress. Asphalt and concrete, which are common materials for bike lanes and pedestrian walkways, can soften, expand, and crack under extreme heat. These forms of deterioration not only shorten the service life of the infrastructure but also create safety hazards for users. In addition, metal components such as signage, railings, and support structures may warp or become unsafe, especially when combined with direct solar exposure and poor ventilation. The cumulative effect of repeated hot days can be more damaging than isolated events, particularly in regions with aging or minimally maintained infrastructure.

User behavior also shifts in response to hotter conditions. People tend to reduce walking and biking activities during the hottest parts of the day and may avoid routes lacking shade or cooling features. This behavioral change can disrupt the intended functionality of active transportation networks, especially where these routes serve as important links to transit hubs, schools, or employment centers. For urban planners and transportation agencies, these changes complicate demand forecasting and service planning, as infrastructure designed to reduce motor vehicle dependency may see lower-than-expected usage during warmer seasons.

Urban heat islands intensify the challenge. In densely built environments with limited vegetation and high concentrations of pavement, surface temperatures can exceed surrounding rural areas by several degrees. Trails and bike paths that traverse these areas often lack tree canopy or cooling infrastructure, making them uncomfortable or even unsafe during hot periods. This not only discourages use but also exacerbates disparities in mobility access for individuals who rely on walking or cycling as a primary mode of transportation.

Design and planning decisions must now account for sustained heat exposure over long operational lifespans. Materials must be selected not just for durability but also for thermal performance. Cooling features such as permeable pavement, reflective surfaces, vegetated buffers, and shaded rest areas are becoming essential components of new infrastructure projects. Some municipalities are also experimenting with cooling stations, water mist systems, and green corridors that double as both mobility routes and heat mitigation zones. Without such adaptations, the functional reliability of active transportation facilities may decline, especially in the mid- to late-century planning horizon.

This section uses a GIS-based overlay analysis to examine how summer temperature patterns intersect with non-motorized travel reliance across Delaware. Census-tract-level summer temperature range data is spatially joined with tract-level commuting data from the U.S. Census Bureau's American Community Survey (5-year estimates) and with DOT-defined census tract classifications identifying areas with higher reliance on active transportation and micromobility. This approach makes it possible to visualize where elevated outdoor temperatures geographically coincide with populations most dependent on walking, cycling, and other non-motorized modes, offering planners a spatial tool for prioritizing heat-mitigation and infrastructure investments in the areas where they matter most. By leveraging geographic data, we can identify and visualize regions where external environmental stressors coincide with socioeconomic challenges [14]. This method enables a focused evaluation of how prolonged periods of high outdoor intensity may affect daily mobility patterns, particularly walking, cycling, and other forms of non-motorized transport and micromobility frequently used in these neighborhoods [15]. Such analysis is essential for informing transportation planning efforts that aim to enhance user comfort and system adaptability [16].

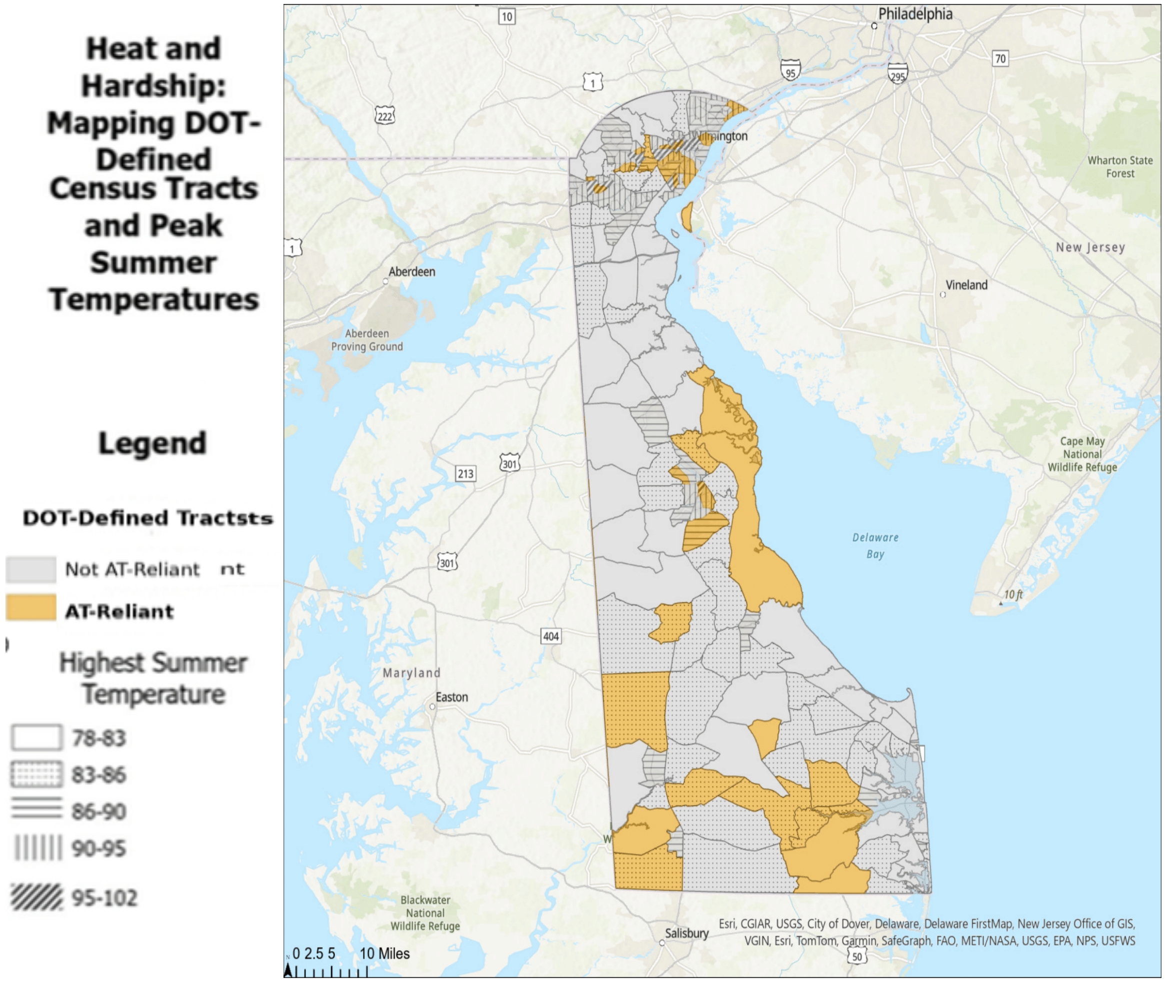

Figure 16. Heat and Hardship: Mapping DOT-defined tract classifications Census Tracts and Peak Summer Conditions

Figure 16 highlights a key overlap between DOT-defined tract classifications and environmental patterns across the state of Delaware. Temperature data is drawn from DNREC's Delaware Climate Impacts summary, commute mode share data comes from the U.S. Census Bureau's American Community Survey 5-year estimates, and active-transportation-reliant tract classifications are sourced from DelDOT's FirstMap GIS data portal. It demonstrates that communities designated as more reliant on active transportation and micromobility by the Department of Transportation are frequently located in areas that experience higher outdoor temperature ranges during summer months [17]. For example, the downtown region of Wilmington is prominently featured on the map as both active transportation reliant area and one where summer temperatures typically range between 95–102°F [18]. This spatial relationship emphasizes the importance of incorporating DOT-defined tract data into transportation and environmental planning efforts to support more effective infrastructure strategies.

The observed distribution of elevated summer temperature ranges in areas such as downtown Wilmington draws attention to the thermal retention effect commonly observed in dense urban zones. Previous research suggests that areas with limited vegetation and high concentrations of built infrastructure tend to retain more heat, influencing overall outdoor conditions (Stone et al., 2010). The patterns shown in the map reflect findings that areas with limited tree canopy and extensive impervious surfaces often exhibit higher ambient temperatures [19]. These insights point to the value of targeted planning actions, such as expanding shaded public spaces and refining construction guidelines, to enhance user comfort and system performance.

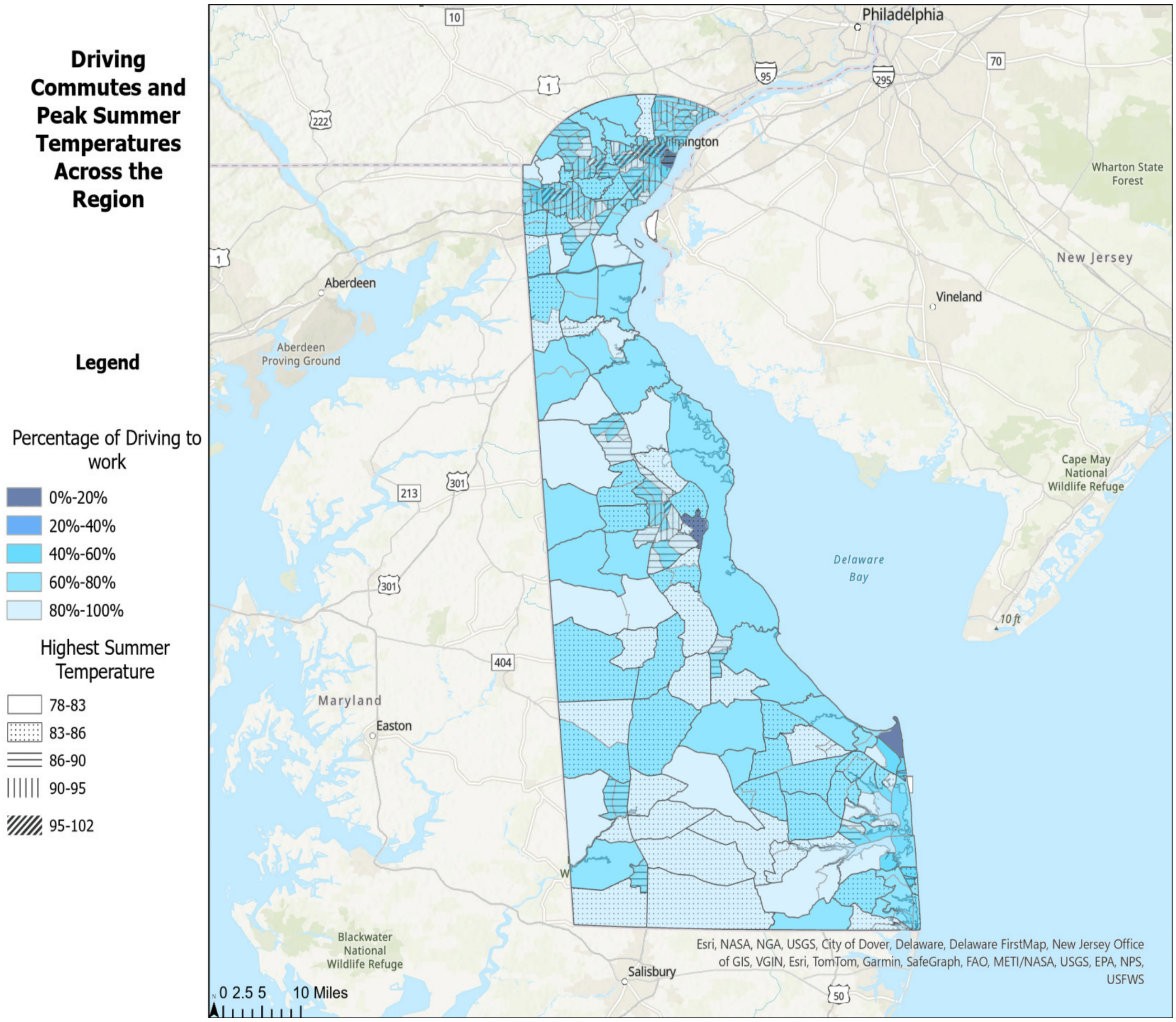

Figure 17. Driving Commutes and Peak Summer Conditions Across the Region

The Figure 17 explores the relationship between commuting behavior and seasonal temperature patterns in Delaware, with particular attention to urban–suburban contrasts. The data reveals a noticeable trend: areas with lower percentages of individuals commuting by personal vehicle, such as Wilmington, tend to correspond with zones that experience higher summer temperature ranges (90–95°F and 95–102°F). This suggests that populations with less access to private transportation, and potentially greater reliance on walking or public transit, may encounter more frequent exposure to elevated outdoor conditions during daily travel [20].

In contrast, areas with higher rates of automobile commuting, represented in lighter map shades, are generally associated with lower peak summer temperatures. These areas, often located in suburban settings, typically feature lower development density and more green space, factors that contribute to more moderate outdoor conditions. This pattern aligns with prior research noting that less compact development tends to retain less heat during the summer months.

These maps offer a descriptive, visual illustration of the well-established relationship between urban heat islands and non-motorized transportation reliance; without statistical testing, these patterns should be interpreted as consistent with, rather than confirmation of, the broader relationship between urban density, heat exposure, and travel mode observed in prior research.

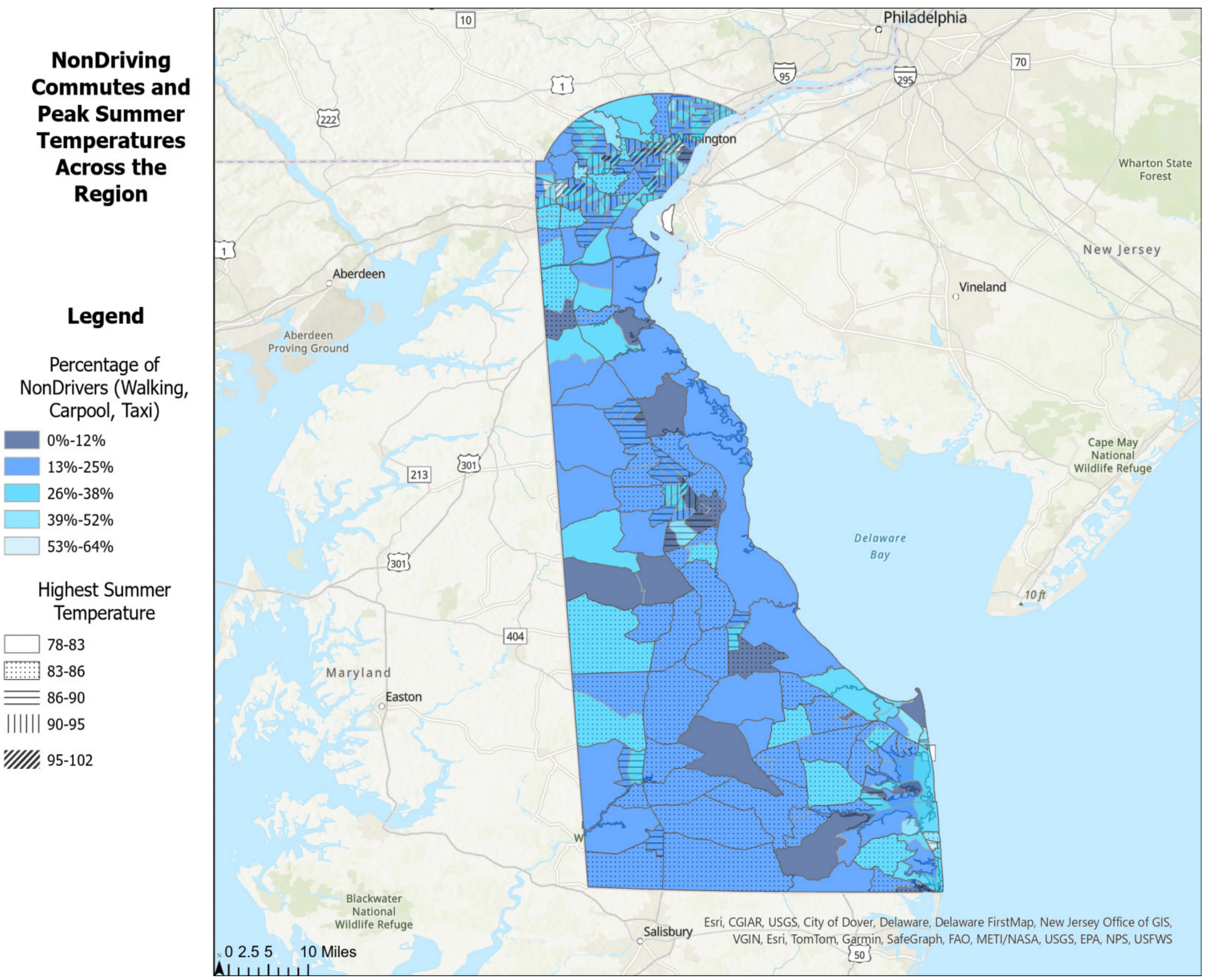

Figure 18. Nondriving Commutes and Peak Summer Conditions Across the Region

Figure 18 presents a detailed view of transportation patterns and their association with peak summer temperature ranges in Delaware, with a focus on populations relying on alternatives to personal vehicles such as walking, carpooling, or taxis. The analysis reveals that in urban centers like Wilmington, a notable proportion of the population (53%–64%) uses non-driving modes for daily commuting. These same areas also align with higher summer temperature ranges (95–102°F), suggesting that individuals traveling without private vehicles may encounter greater exposure to elevated outdoor conditions. This reflects ongoing urban design challenges, as dense city areas with higher rates of non-driving commutes often have limited green cover and fewer features that help moderate outdoor temperatures.

The data presented in the map highlights the value of adaptive design approaches, especially in high-density areas where many residents do not rely on private vehicles. Strategies such as increasing shaded street corridors, enhancing transit infrastructure, and improving pedestrian environments can support more comfortable travel conditions. These approaches not only encourage the use of resilient transportation modes but also help manage localized temperature buildup, contributing to improved urban experience and mobility. The observed association between higher outdoor temperature ranges and higher non-driver percentages supports prior findings that enhancements in urban infrastructure can positively influence travel safety and comfort for these populations. This visualization offers planners and policymakers an important tool for addressing infrastructure effectiveness in future transportation planning.

The connection between long-term temperature trends and active mobility is fundamental. Active transportation remains a cornerstone strategy for improving air quality and enhancing public health. However, if pedestrian and cycling infrastructure is not adapted to future weather conditions, its benefits may be undermined. A resilient transportation system must ensure that active modes remain viable and safe throughout the year, regardless of environmental stressors. This requires integrating temperature-informed engineering standards, proactive maintenance practices, and heat-conscious urban design into transportation planning frameworks at all levels of government.

4. Flooding

Flooding has become one of the most impactful and frequently observed environmental stressors affecting urban environments worldwide. Driven by changes in precipitation intensity, soil saturation levels, drainage limitations, and storm patterns, many cities now face water accumulation events that occur more often and last longer than in previous decades. These events are no longer confined to historically flood-prone regions but are increasingly affecting inland and coastal urban areas alike, disrupting infrastructure systems that were not designed to manage such conditions [21].

For the transportation sector, flooding presents operational and structural challenges. In particular, non-motorized infrastructure such as pedestrian paths, bike lanes, and recreational trails are highly exposed. These facilities are often located at lower elevations, near natural water features, or alongside roadways with minimal protective drainage. When floodwaters overflow curbs, trail surfaces become submerged, and pooled water may linger for hours or days, especially where stormwater systems are undersized or clogged. In such conditions, not only is access interrupted, but the materials themselves can degrade. Pavement erodes, painted surfaces fade, and foundation layers weaken [22].

Active transportation systems rely on continuity and accessibility. Unlike roadways that may have detour routes or elevated segments, bike and pedestrian paths typically offer limited alternatives once blocked by water. A single impacted segment can break a critical connection between residential areas, transit hubs, and community centers. In many cities, greenways and linear park trails are designed to serve both recreational and commuting purposes; when these are affected by water accumulation, their utility as everyday mobility corridors diminishes significantly. Moreover, prolonged wet conditions discourage public use even after the water recedes due to mud, debris, and safety concerns.

Flood conditions also create long-term damage that is less immediately visible. In areas where infrastructure is repeatedly exposed to water, there is a higher risk of mold, foundation subsidence, and vegetation overgrowth, all of which require ongoing maintenance. Trail surfaces may warp, form potholes, or develop soft spots that become hazardous to cyclists and pedestrians. Without proactive monitoring and repair, the quality and safety of the active transportation network declines, sometimes leading to full closures or costly reconstruction projects [23].

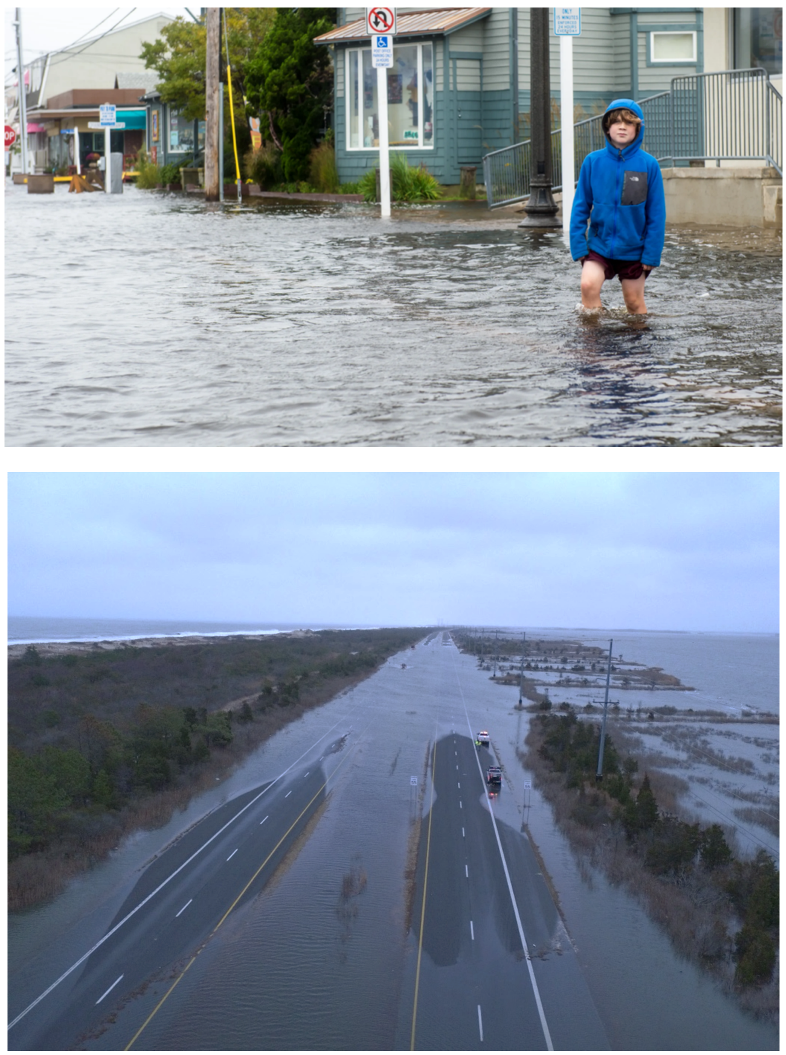

Figure 19. Flooding in Delaware (National Weather Service)

Designing for these evolving challenges requires a shift in planning strategies. New infrastructure must consider not only flood-resistant materials but also intelligent siting that avoids vulnerable areas where possible. Elevated boardwalks, permeable pavements, and integrated bioswales can help reduce water retention and improve resilience. In some cases, trail corridors are being co-designed as dual-purpose drainage zones or emergency access lanes, capable of serving transportation needs under normal conditions and flood management roles during storm events.

As active transportation and micromobility becomes more central to urban mobility, protecting its infrastructure from water-related damage is essential. Cities that prioritize walking and cycling must ensure that networks remain accessible year-round. This means anticipating flood-prone zones during the planning stage, implementing adaptable designs that withstand fluctuating environmental conditions, and allocating funding for rapid response and recovery following heavy rainfall. The resilience of active transportation infrastructure in the face of persistent flooding will play a key role in shaping the reliability and attractiveness of non-motorized mobility in the coming decades.

5. Urbanization

Urbanization continues to shape the structure and function of cities worldwide. As populations concentrate in urban centers, the built environment undergoes rapid transformation, with changes in land use, infrastructure demands, and transportation behavior. This shift is driven by a range of factors including economic opportunity, technological development, and shifting settlement patterns. While urbanization supports growth and connectivity, it also brings about new pressures on infrastructure systems, including those designed for walking, cycling, and other forms of active mobility [24].

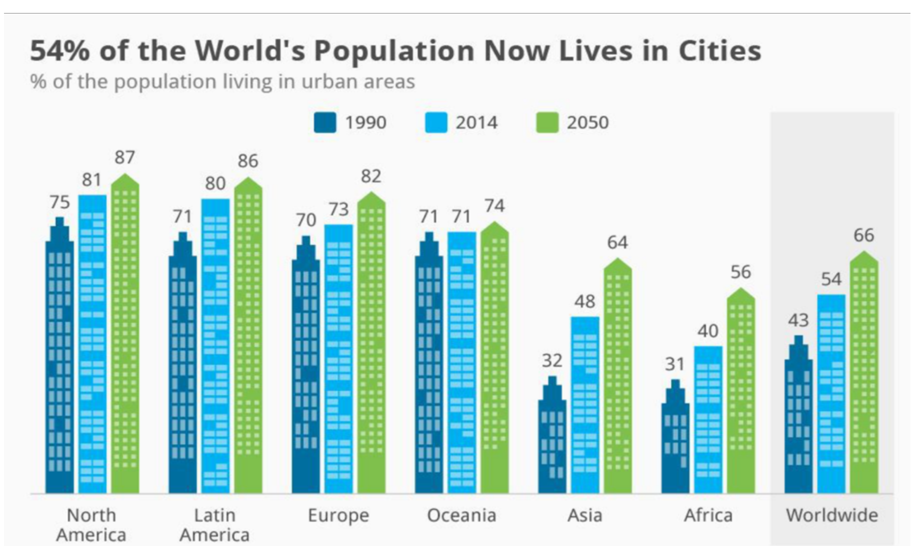

Figure 20. Urbanization trend globally (Statista)

As more land is developed to accommodate housing, commercial activity, and transportation corridors, natural surfaces are often replaced with impervious materials such as asphalt and concrete. This transformation alters local drainage patterns, increases surface runoff during storms, and elevates ambient surface temperatures. These effects are particularly pronounced in areas where urban growth occurs rapidly without adequate infrastructure planning. The outcome is an environment where non-motorized transportation systems, such as bike lanes and pedestrian walkways, are often fragmented, poorly maintained, or exposed to environmental stressors such as flooding and prolonged heat [25].

Urban expansion often leads to increased traffic congestion, which in turn strengthens the case for investment in active transportation alternatives. However, the design and layout of newly urbanized areas can either support or inhibit these alternatives [25]. Low-density development patterns that separate housing from workplaces and services often discourage walking and cycling due to distance and lack of direct connections. Moreover, wide roadways and car-centered infrastructure present physical and psychological barriers to non-motorized users. Without dedicated space and safety features, walking and biking become less viable, particularly for short- to medium-distance trips within urban zones [26].

Another critical impact of urbanization is the competition for space. As cities become more densely built, transportation infrastructure must coexist with utilities, green space, parking, and buildings. In this context, allocating space for active modes can be politically and logistically challenging. Yet studies show that compact, walkable urban forms not only reduce traffic but also support local economies and enhance public health. Integrated design that includes wide sidewalks, protected bike lanes, shaded corridors, and secure crossings can greatly enhance the functionality of active transportation in dense settings.

The relationship between urban growth and environmental conditions is also important. As cities develop, changes in land cover and water flow can increase exposure to environmental stressors such as coastal inundation and flooding. Infrastructure that is not designed to handle these conditions may experience chronic disruption, particularly in low-lying or poorly drained areas. For active transportation facilities, this may mean frequent closures, damage to surface materials, or long-term usability decline. Proactive designs such as raised paths and permeable surfaces can help mitigate these risks and ensure continuity of service [27].

As one of the earliest settled regions in the United States, Delaware has undergone significant urban growth, particularly over the past two decades. Satellite imagery analysis shows that urbanization has been a major driver of land cover change across the state. This expansion has contributed to a reduction in ecological services, correlating with increases in impervious surface coverage, urban hotspots, and a noticeable decline in the health of vegetation.

Delaware's urban development has exceeded the threshold of impervious surface (10%–15%) generally considered acceptable for long-term watershed health (Center for Watershed Protection, 2003). As impervious areas expand, they impact water systems such as the Delaware River by increasing pollutant levels, elevating flood risk, and contributing to erosion. A precise quantification of impervious surface expansion and corresponding drainage capacity in Delaware's developing areas was beyond the scope of this study. Future work should pair National Land Cover Database (NLCD) impervious surface data with local stormwater infrastructure records to establish a direct square-mile and drainage-capacity comparison, which would strengthen the infrastructure-focused framing of this section.

Once characterized by dense and healthy vegetation, Delaware now exhibits widespread vegetation loss, especially near the Delaware River and wetland regions. This shift has raised concerns related to air quality and habitat availability for native species. Key drivers of vegetation decline include land-use transformation, erosion, and diminished water quality (Kreeger et al., 2010). Together, these trends reflect the substantial environmental consequences of ongoing urban growth in the region.

Urbanization presents both challenges and opportunities for active transportation. On one hand, it can generate demand for alternatives to private vehicles, reduce travel distances, and make compact, multi-modal transport systems more feasible. On the other, if not managed thoughtfully, it can strain existing infrastructure, limit access to safe routes, and increase exposure to environmental hazards. To ensure that walking and biking remain viable modes of transport in growing cities, urban planners must integrate active mobility into the early stages of land use and transportation design. Doing so will help create urban environments that are more resilient, efficient, and accessible in the face of evolving environmental and social conditions.

6. The Survey

6.1 Overview and Purpose of the Survey Component

To complement the geospatial analysis of coastal inundation and temperature effects on non-motorized transportation facilities (NMTFs) throughout Delaware, a public survey was administered to capture community perceptions of environmental impacts on active transportation behavior and infrastructure. While the geospatial analysis of coastal inundation quantifies physical exposure of trail and bike route corridors, the survey provides critical first-person behavioral and attitudinal data, allowing the research team to triangulate infrastructure vulnerability with lived human experience.

The survey was designed and distributed by the University of Delaware research team under the SMARTER Center project. It targeted residents of Delaware and nearby communities who regularly use, or are affected by, active transportation systems including walking, cycling, and micromobility options. A total of 200 valid responses were collected across the survey distribution period, providing a robust sample for statistical and machine learning analysis.

The overarching goal of the survey component is threefold: (1) to characterize community awareness of environmental changes; (2) to measure perceived frequency of environmental disruptions to transportation routines; and (3) to identify infrastructure gaps and policy preferences that can inform planning recommendations. The full dataset of 200 responses was then subjected to machine learning (ML) classification analysis as described in Sections 4 and 5 of this supplement.

6.2 Survey Instrument Design

The survey was structured into five thematic sections, each targeting a distinct dimension of the research problem. The instrument included a combination of closed-ended (multiple choice, Likert-scale frequency, and rating) questions, along with optional open-ended comment fields to capture qualitative nuance. Below is a description of each section.

6.2.1 Respondent Demographics and Mobility Profile

The opening section collected basic sociodemographic information including age range, annual household income, and primary mode(s) of transportation. These variables serve as key control and stratification variables in the subsequent ML analysis. By understanding who the respondents are and how they primarily move through space, the research team can contextualize environmental impact perceptions within demographic groups.

6.2.2 Environmental stressors and Their Impact on Transportation

This section, comprising Questions 4 through 7, represents the core environmental exposure module of the survey. Respondents were first asked whether they had noticed neighborhood-level changes attributable to coastal inundation, temperature rise, or flooding (Q4). They were then asked to rate the frequency with which each of these three stressors specifically impacted their transportation infrastructure and routine mobility, using a five-point scale ranging from Never to Always (Q5 for coastal inundation, Q6 for temperature, Q7 for flooding).

These frequency ratings were later aggregated into a composite Environmental Impact Score used in the ML analysis, reflecting cumulative environmental disruption experienced by each respondent.

6.2.3 Urbanization and Community Changes

Questions 8 through 10 addressed the urbanization dimension of the study. Respondents were asked whether they had observed population growth in their area over the past decade (Q8). Those who answered affirmatively were prompted to evaluate whether their city's general infrastructure (Q9) and specifically its active transportation infrastructure (Q10) had kept pace with that growth. Respondents who had not observed population growth were automatically routed to Section 4, with their Q9 and Q10 responses recorded as "Does not apply."

6.2.4 Availability and Safety of Active Transportation and Micromobility

This section assessed infrastructure availability and perceived safety. Question 11 asked respondents to rate the availability of micromobility options such as shared bikes and scooters on a four-point scale from "Very available" to "Not available at all." Question 12 asked whether respondents felt safe using active transportation from a traffic standpoint. Question 13 then identified what interventions would make respondents more likely to adopt or increase active transportation, offering options including more affordable pricing, better infrastructure, greater availability, and enhanced safety.

6.2.5 Community Support Needs

The final survey section (Q14) asked respondents to identify what types of community support would best help their area adapt to environmental and urbanization pressures. Options included improved physical infrastructure, financial assistance, education and awareness campaigns, and local community programs. An optional open-ended comment field allowed respondents to provide additional context, describe their geographic situation, or elaborate on concerns not covered by the structured questions.

6.3 Survey Format

Please note that participation in this survey/questionnaire and/or any of the questions herein are voluntary.

This questionnaire is designed to gather public input on how environmental stressors such as coastal inundation, temperature, flooding and urbanization are affecting active transportation options like walking, biking, and the use of micromobility (e.g., scooters, skateboards and electric version of them). Your responses will help researchers assess challenges, identify different areas or populations, and support planning efforts to improve the resilience of non-motorized transportation and micromodal systems in the face of environmental stressors.

Active Transportation
Human-powered travel modes such as walking, biking, or using a wheelchair. It often includes short-distance travel for commuting, errands, or recreation.

Micromobility
Small, lightweight personal transportation devices typically used for short trips, including bicycles, e-bikes, scooters, and e-scooters, often part of shared or dockless systems.

Coastal inundation
The flooding of normally dry, low-lying coastal land due to the sea encroaching inland, often caused by storm surge or high tides.

Temperature
An increase in average air temperatures over time. Changes in air temperature can impact outdoor activity, infrastructure durability, and public health.

Flooding
The repeated or increasing occurrence of flood events in a specific area, typically poor drainage systems, or changing weather patterns.

Urbanization
The process by which cities grow as more people move into urban areas, often leading to increased construction, land development, and changes in transportation infrastructure.

Section 1: Demographic Information

1. What is your age range?

- a. Under 18
  b. 18–34
  c. 35–54
  d. 55+

2. What is your annual household income range?

- a. Below $25,000
  b. $25,000–$49,999
  c. $50,000–$74,999
  d. $75,000 and above

3. What is your primary mode of transportation? (Select all that apply)

- a. Car
  b. public transit
  c. Bicycle
  d. Walking
  e. scooters/ skateboards/ unicycle
  f. Other (please specify): ____________

Section 2: Ecological Shifts and Their Impacts

4. Have you noticed any changes in your neighborhood due to coastal inundation AND/OR flooding AND/OR temperature change?

- a. Yes → Please describe: ____________
  b. No

5. How often have coastal inundation events impacted your transportation infrastructure to impact your routine mobility (e.g., commuting, school, work, etc…)?

- a. Never
  b. Rarely
  c. Sometimes
  d. Often
  e. Always

6. How often have temperature impacted your transportation infrastructure to impact your routine mobility (e.g., commuting, school, work, etc…)?

- a. Never
  b. Rarely
  c. Sometimes
  d. Often
  e. Always

7. How often have flooding impacted your transportation infrastructure to impact your routine mobility (e.g., commuting, school, work, etc…)?

- a. Never
  b. Rarely
  c. Sometimes
  d. Often
  e. Always

More explanation if you want to provide…

Section 3: Urbanization and Community Changes

8. Have you noticed population growth in your urban area in the last 10 years?

- a. Yes
  b. No
- if no go to section 4

9. Do you think your city's infrastructure has kept up with population growth?

- a. Yes
  b. No

10. Do you think this population growth has specifically impacted the active transportation and micromobility infrastructure? (e.g. more flood coverage, more drainage issues, more congestion etc.)

- a. Yes
  b. No

if you want to give more explanation, use this space below.

Section 4: Availability and Safety of Active Transportation and Micromobility

11. How would you rate the availability of active transportation and micromobility options (e.g., shared bikes, scooters) in your area?

- a. Very available
  b. Somewhat available
  c. Not very available
  d. Not available at all

12. Do you feel safe from a traffic standpoint using active transportation (walking, biking, and …) in your area?

- a. Yes
  b. No → Please explain: ____________

13. What would make you more likely to use active transportation and micromobility solutions? (Select all that apply)

- a. More affordable pricing
  b. Better infrastructure (e.g., bike lanes)
  c. More availability
  d. Greater safety
  e. Nothing would change my behavior

more explanation is space below if needed

Section 5: Quality of Life and Future Outlook

14. What support would help your community adapt better? (Select all that apply)

- a. Improved infrastructure (e.g., bike lanes, drainage)
  b. Financial assistance
  c. Education and awareness campaigns
  d. Local community programs
  e. Other: ___________

6.4 Survey Administration and Data Collection

The survey was administered electronically through an online platform and distributed via university networks, community boards, and transportation-related social media channels targeting Delaware residents. Respondents were self-selected participants who completed the instrument voluntarily and anonymously. The collection period spanned several weeks, during which 200 complete responses were gathered from individuals across Delaware and surrounding communities.

Data quality was ensured through built-in skip logic that routed respondents based on their answers, for example, individuals who had not observed population growth in their area were automatically directed past the infrastructure adequacy questions, receiving a "Does not apply" designation for those items. Only fully completed responses were retained in the final dataset.

6.4.1 Response Distribution Summary

Table 6 below presents the distribution of responses across key survey questions. These distributions characterize the demographic and experiential profile of the 200 respondents and establish the baseline for all subsequent analysis.

Table 6. Response Distribution Summary — Key Survey Questions (N=200)

Category / Response	Count (N=200)	Percentage	Interpretation
AGE RANGE			
18–34 years	~191	~95.5%	Predominantly young adults
35–54 years	~6	~3.0%	Small middle-aged cohort
Above 55 years	~3	~1.5%	Minimal older-adult representation
INCOME RANGE			
$75,000 and above	~120	~60.0%	Largest income group
Below $25,000	~34	~17.0%	Low-income segment
$25,000–$49,999	~23	~11.5%	Lower-middle income
$50,000–$74,999	~23	~11.5%	Middle income
NOTICED ECO CHANGES (Q4)			
No	~148	~74.0%	Majority unaware of local environmental changes

Category / Response	Count (N=200)	Percentage	Interpretation
Yes	~52	~26.0%	Over 1 in 4 noticed environmental shifts
MICROMOBILITY AVAILABILITY (Q11)			
Not very available	~80	~40.0%	Largest group — strong deficit
Not available at all	~60	~30.0%	Total absence of options
Somewhat available	~49	~24.5%	Partial access
Very available	~11	~5.5%	Only a small minority have good access

6.5 Descriptive Findings from the Survey Data

Before presenting the machine learning results, it is informative to summarize the key descriptive findings from the 200-response dataset. These findings characterize the survey population and set the substantive context for the predictive modeling that follows.

6.5.1 Respondent Profile

The survey sample is overwhelmingly young: approximately 95.5% of respondents fall in the 18–34 age bracket, with the remainder split between the 35–54 and above-55 cohorts. This skew is consistent with the Delaware context, as the survey was distributed partly through university channels at the University of Delaware, which has a large young-adult population. Income distribution is somewhat polarized: 60% of respondents report annual household incomes of $75,000 or above, while nearly 17% report incomes below $25,000.

In terms of transportation mode, the dominant pattern is car-centric with some walking: approximately 57% of respondents primarily use a car combined with walking, and 29% report car-only travel. Only small fractions report using bicycles, public transit, or walking as standalone primary modes. This profile is consistent with the suburban and semi-urban character of much of Delaware, where dedicated active transportation infrastructure is limited.

6.5.2 Environmental Change Awareness (Q4)

When asked whether they had noticed neighborhood changes attributable to coastal inundation, temperature change, or flooding, approximately 74% of respondents answered "No," while 26% answered "Yes." This finding, while at first glance suggesting low awareness, is consistent with the fact that a significant portion of respondents are young university students who may have recently relocated from outside Delaware and may not have long-term reference points for environmental change in their current area. Among those who answered affirmatively, open-ended comments referenced coastal flooding in Sussex and New Castle counties, beach-town inundation on Long Island, and increasingly intense summer heat.

6.5.3 Environmental Impact Frequency on Transportation Routine (Q5 – Q7)

The three frequency questions, covering coastal inundation (Q5), temperature (Q6), and flooding (Q7), reveal a hierarchy of environmental stressors affecting daily mobility. Temperature emerges as the most frequently cited disruptor: 22 respondents (11%) reported it "Sometimes" impacts their transportation, and a combined 5 respondents reported impacts of "Often" or "Always." Flooding ranks second in frequency of disruption, with 15 respondents reporting "Sometimes" impacts and 3 reporting "Often." Coastal inundation events are perceived as the least disruptive to routine transportation, with 33 respondents reporting "Never" and only 10 reporting "Sometimes."

These findings underscore a nuanced picture: while coastal inundation may cause more catastrophic infrastructure damage (as documented in the geospatial analysis sections), it is temperature, with its chronic, season-long effects on comfort, pavement integrity, and user behavior, that most consistently disrupts residents' day-to-day transportation routines.

6.5.4 Population Growth and Infrastructure Adequacy (Q8 – Q10)

Approximately 74% of respondents indicated that they have noticed population growth in their urban area over the past ten years (Q8). Of these, only 31 respondents (roughly 44% of those observing growth) believe their city's infrastructure has kept pace with that growth (Q9), while 33 respondents (approximately 47%) believe it has not. More strikingly, 41 respondents, representing approximately 58% of those who observed population growth, believe that active transportation infrastructure specifically has been negatively impacted by urbanization (Q10), citing increased congestion, drainage problems, and reduced investment in pedestrian and cycling facilities.

6.5.5 Micromobility Availability (Q11)

Micromobility infrastructure is perceived as largely inadequate by the survey population. Approximately 40% of respondents rate availability as "Not very available," and 30% rate it as "Not available at all", meaning that 70% of respondents characterize micromobility options in their area as insufficient. Only 5.5% rate availability as "Very available." This finding is corroborated by Delaware's relatively underdeveloped bike-share and e-scooter ecosystems outside of urban cores like Wilmington and the University of Delaware campus.

6.5.6 Perceived Safety (Q12)

Approximately 62% of respondents feel safe using active transportation from a traffic standpoint (Q12), while 33% do not, and roughly 5% express a conditional or qualified sense of safety (e.g., "safe on back roads but not on main roads" or "not during summer"). Among those who feel unsafe, open-ended comments frequently cited the absence of dedicated bike lanes, high vehicular speeds on shared roads, and lack of pedestrian signaling. This substantial minority of respondents perceiving safety risks represents a significant barrier to active transportation adoption.

6.5.7 Barriers to Active Transportation Adoption (Q13)

When asked what interventions would make them more likely to use active transportation, "Better Infrastructure" was by far the most cited factor, appearing in 74% of responses (alone or in combination with other factors). "Greater Safety" was cited in approximately 51% of responses, "More Availability" in 47%, and "More Affordable Pricing" in 36%. Notably, 15 respondents (7.5%) indicated that "Nothing would change my behavior", representing individuals who are either already committed active transportation users or those who are firmly committed to car use regardless of infrastructure improvements.

6.5.8 Community Support Preferences (Q14)

The overwhelming majority of respondents, over 90%, selected "Improved Infrastructure (bike lanes, drainage)" as a preferred form of community support, either alone or in combination with other options. Financial assistance was the second most common selection (approximately 40% of respondents), followed by Education and Awareness Campaigns (approximately 38%) and Local Community Programs (approximately 32%). The centrality of infrastructure improvement reflects the broader finding that physical access and safety deficits, not cost or awareness, are the primary barriers to active transportation adoption in Delaware communities.

7. AI Applications and Machine Learning Analysis

Following the descriptive analysis, two machine learning classification models were developed to extract predictive insights from the survey data. The goal of the ML component is consistent with the broader AI application framework described in the main report: to use algorithmic methods to identify patterns and relationships that are not immediately visible through descriptive statistics alone. Both models were trained on the full 200-response dataset.

7.1 Feature Engineering

Raw survey responses were transformed into numerical features suitable for machine learning. The following feature set was constructed for model training:

Table 7. Features and their encoded items

Feature Name	Source Question	Encoding
Environmental Impact Score	Q5 + Q6 + Q7	Sum of three frequency scores (Never=0, Rarely=1, Sometimes=2, Often=3, Always=4); range 0–12
Coastal inundation Frequency	Q5	Ordinal encoding: Never=0 to Always=4
Temperature Impact Frequency	Q6	Ordinal encoding: Never=0 to Always=4
Flooding Frequency	Q7	Ordinal encoding: Never=0 to Always=4
Noticed Eco Changes	Q4	Binary: Yes=1, No=0
Population Growth Noticed	Q8	Binary: Yes=1, No=0
Micromobility Availability	Q11	Ordinal: Not available at all=0 to Very available=3
Income Level	Q2	Ordinal: Below $25K=0 to $75K+=3
Age Group	Q1	Ordinal: 18–34=0, 35–54=1, Above 55=2
Car-Only User	Q3	Binary: 1 if only mode is Car, else 0

7.2 Model 1- Predicting Perceived Safety of Active Transportation

7.2.1 Task and Target Variable

The first classification task aims to predict whether a given respondent perceives active transportation in their area as safe (Q12). Responses were binarized: "Yes" responses were coded as 1 (safe), while "No" and qualified responses were coded as 0 (unsafe). Respondents who gave ambiguous or mixed responses (e.g., "safe on back roads but not on main roads") were recoded as 0 for conservative classification. After this preprocessing, 63% of the 200-response dataset fell into the "safe" class and 37% into the "unsafe" class.

7.2.2 Algorithm: Random Forest Classifier

A Random Forest Classifier was selected as the primary algorithm for this task. Random Forests are ensemble methods that construct multiple decision trees during training and aggregate their predictions, which reduces overfitting and produces robust predictions even with relatively modest sample sizes. The model was configured with 100 decision trees and a maximum depth of 5, balancing model complexity with generalizability. A Decision Tree Classifier (maximum depth 4) was also trained as a simpler comparison model.

7.2.3 Validation and Performance

Both models were evaluated using 5-fold stratified cross-validation, a robust method that partitions the data into five equally sized folds, trains on four folds, tests on the fifth, and repeats this process five times, reporting the average performance. This approach ensures that the reported accuracy is not biased by any particular train-test split.

Table 8. Model performances

Model	CV Accuracy (Mean)	Std. Deviation
Random Forest (100 trees, depth 5)	**61.29%**	± 3.98%
Decision Tree (depth 4)	55.92%	± 2.65%

A cross-validation accuracy of 61.29% (Random Forest) is a meaningful result for a survey-based classification task with a relatively small sample. For comparison, a naive baseline classifier that always predicts the majority class (safe) would achieve approximately 63% accuracy given the class distribution, meaning the RF model is competitive with that baseline, and importantly, it can identify the minority unsafe class in a way that a naive model cannot. The Random Forest outperforms the simpler Decision Tree by approximately 5.4 percentage points, confirming that the ensemble approach better captures the complexity of safety perception. The low standard deviation (±3.98%) across folds further indicates that the model is stable and not overfitting to any particular subset of the data.

It is important to contextualize these performance figures. Survey-based behavioral classification is inherently noisy, safety perception is influenced by subjective, unmeasured factors such as personal risk tolerance, prior accident history, familiarity with routes, and neighborhood context. The fact that environmental and demographic features alone explain approximately 61% of variance in safety perception is substantively informative.

7.2.4 Feature Importance Analysis

One of the most valuable outputs of the Random Forest model is the feature importance ranking, which indicates how much each input variable contributed to the model's predictions. Feature importance in a Random Forest is calculated based on the mean decrease in impurity (Gini impurity) across all trees for each feature. Table 9 presents the ranked importances along with their substantive interpretation.

Table 9. Model Interpretations

#	Feature	Importance	Interpretation
1	**Environmental Impact Score**	~0.18	The single strongest predictor. Higher cumulative environmental disruption (coastal, temperature, flooding) strongly correlates with feeling unsafe. Residents experiencing more frequent environmental disruptions to their commutes are significantly less likely to perceive active transportation as safe.
2	**Flooding Frequency (Q7)**	~0.14	Flooding is the most impactful individual environmental stressor on safety perception. Areas experiencing frequent flooding create hazardous conditions for cyclists and pedestrians, submerged paths, debris, and unstable surfaces directly undermine physical safety.
3	**Micromobility Availability (Q11)**	~0.13	Areas with better micromobility infrastructure tend to report higher safety. This likely reflects that investment in shared mobility infrastructure co-occurs with investment in protected lanes, signage, and pedestrian safety features.
4	**Temperature Frequency (Q6)**	~0.12	Frequent temperature-related disruptions are associated with lower safety perception. Extreme heat discourages active transportation use and creates health risks, indirectly reducing safety by pushing more users into mixed traffic conditions with vehicles.
5	**Income Level (Q2)**	~0.11	Higher-income respondents are modestly more likely to report feeling safe. This may reflect residential sorting, higher-income

#	Feature	Importance	Interpretation
			individuals often live in areas with better active transportation infrastructure.
6	**Coastal inundation Frequency (Q5)**	~0.11	Coastal inundation disruptions are associated with reduced safety, particularly in low-lying areas where flooding and submersion of paths occur. This aligns with the geospatial findings showing significant NMTF exposure in flood-prone corridors.
7	**Noticed Environmental Changes (Q4)**	~0.09	Respondents who have actively noticed environmental changes in their neighborhood are more likely to perceive safety risks for active transportation. Environmental awareness and safety concern are positively correlated.
8	**Car-Only User (Q3)**	~0.07	Car-only users are more likely to report that active transportation feels unsafe, a finding consistent with the idea that car dependency is partly driven by perceived risks of non-motorized modes. This suggests a self-reinforcing cycle of car use and underinvestment in active transport safety.
9	**Population Growth (Q8)**	~0.03	Awareness of population growth has a modest effect on safety perception, likely mediated by its correlation with infrastructure strain and increased traffic congestion.
10	**Age Group (Q1)**	~0.02	Age has the smallest predictive contribution in this sample, likely because the overwhelming majority of respondents fall in the 18–34 cohort, limiting age-based variation.

7.3 Model 2- Predicting Micromobility Availability (High vs. Low)

7.3.1 Task and Target Variable

The second classification task predicts whether respondents report high or low micromobility availability in their area (Q11). Availability ratings were binarized into two classes: High availability (Somewhat available or Very available, coded as 1) and Low availability (Not very available or Not available at all, coded as 0). Approximately 30% of respondents fell into the High availability class and 70% into the Low availability class, reflecting the widespread micromobility deficit documented descriptively.

7.3.2 Algorithms and Performance

The same Random Forest architecture was applied to this classification task (100 trees, maximum depth 5, 5-fold stratified cross-validation). The model achieved a mean cross-validation accuracy of 65.50% (± 4.00%), which is notably stronger than Model 1. This suggests that environmental and demographic variables are somewhat better at explaining geographic variation in micromobility infrastructure availability than at explaining individual safety perceptions, consistent with the idea that availability is a more objective, infrastructure-level outcome, while safety is more subjective and individually variable.

7.3.3 Key Predictors of Micromobility Availability

Feature importance analysis for the micromobility availability model reveals that income level and environmental impact score are the primary predictors. Specifically:

- Income level is the strongest predictor of micromobility availability, higher-income respondents are significantly more likely to report that shared bikes, scooters, and similar options are available in their area. This is consistent with the well-documented pattern of micromobility infrastructure being concentrated in wealthier, typically more urban neighborhoods.
- Environmental impact score (cumulative flooding, coastal, and temperature disruptions) is negatively associated with micromobility availability, areas experiencing more frequent environmental disruptions tend to have less developed micromobility infrastructure. This relationship may reflect that areas with more environmental risks often have lower property values and less municipal investment
- Car-only use is negatively associated with micromobility availability, confirming the expected spatial correlation between car-centric communities (typically suburban areas with minimal active transportation infrastructure) and low micromobility provision.
- Flooding frequency is also a significant predictor, suggesting that areas prone to flooding regardless of income have lower micromobility deployment, likely due to the physical impracticality of maintaining docked or dockless vehicles in flood-prone locations.

7.4 Integrated Key Findings and Implications

Together, the descriptive analysis and machine learning models converge on a set of integrated findings that carry meaningful implications for transportation planning and policy in Delaware. These findings are summarized in Table 10 below.

Table 10. Practical Findings

#	Finding	Planning Implication
1	Environmental disruption, particularly flooding, is the dominant predictor of active transportation safety perception.	Flood-resilient active transportation infrastructure (elevated paths, permeable surfaces, rapid drainage) is not just a physical investment but a direct enabler of community trust and adoption of non-motorized modes.
2	Temperature is the most chronically disruptive environmental stressor on daily transportation routines, even though flooding is more spatially impactful.	Shade structures, cooling corridors, and heat-resilient pavement materials should be prioritized on high-use active transportation corridors, particularly in dense urban areas like Wilmington.
3	70% of respondents rate micromobility availability as insufficient, despite it being a key adaptive infrastructure against environmental disruption.	Investment in shared micromobility networks should be scaled and geographically broadened, with particular attention to environmentally exposed corridors.
4	Infrastructure improvement is by far the most commonly desired intervention (cited by 90%+ of respondents), not pricing or awareness.	Policy advocacy and budget allocation should emphasize physical infrastructure before communication campaigns. Awareness without access is insufficient.
5	Car-only users systematically report lower active transportation safety, suggesting a self-reinforcing cycle of car dependency.	Protected bike lanes and pedestrian-priority zones can break this cycle by reducing the actual safety risk, which is the primary barrier cited by non-users.
6	Nearly half of respondents who observed population growth believe infrastructure has not kept pace, especially for active transportation.	Urban growth planning frameworks in Delaware should include mandatory active transportation impact assessments as part of development approvals.

7.5 Limitations and Methodological Considerations

Several limitations should be acknowledged when interpreting these findings. First, the survey sample is heavily skewed toward young adults (18–34) due to its distribution channels, which limits the generalizability of findings to older populations who may have different mobility patterns, risk perceptions, and environmental exposures. Future iterations of this survey should employ stratified sampling to better represent the full age spectrum of Delaware residents.

Second, the sample composition, heavily weighted toward the 18–34 age group and toward higher income brackets, may limit the representativeness of findings for older or lower-income populations in Delaware. Future survey efforts should incorporate stratified sampling strategies to ensure broader demographic coverage across age, income, and geographic dimensions.

Third, the classification models developed here are exploratory and intended to identify patterns rather than to generate causal claims. The Environmental Impact Score, for example, captures frequency of disruption but not its severity or duration, and the Safety variable reflects perceived rather than objectively measured safety. Future research could enhance model performance by incorporating geospatial variables (e.g., proximity to flood zones, bike lane density, heat island intensity) alongside survey data, creating a richer multi-source feature set.

Finally, the relatively modest classification accuracies (61–65%) reflect the inherent complexity and subjectivity of survey-based behavioral data. These figures should not be interpreted as model failures but as realistic benchmarks for the type of classification task at hand. They demonstrate that demographic and environmental variables are meaningfully but not completely predictive of safety perception and infrastructure availability, leaving room for future work that incorporates additional data sources.

7.6 Conclusion

This supplement has provided a comprehensive account of the survey methodology, descriptive findings, and machine learning analysis that constitute the survey-AI component of the SMARTER Center research project on active transportation and micromodal facilities in Delaware.

The survey findings paint a consistent and actionable picture: Delaware residents are experiencing meaningful environmental disruptions to their transportation routines, particularly from temperature and flooding, and perceive significant deficits in both active transportation safety and micromobility availability. These perceptions are not random: they are systematically predicted by environmental exposure, infrastructure availability, and income level. The machine learning models confirm that communities bearing the greatest environmental stress are precisely the communities with the weakest active transportation infrastructure, a compounding vulnerability that demands targeted policy intervention.

The dominant community request, echoed by over 90% of respondents, is for improved physical infrastructure. This is not a demand for awareness campaigns or financial subsidies alone, but for the fundamental built-environment investments that make walking, cycling, and micromobility viable, safe, and reliable options. As Delaware continues to grow and as environmental pressures intensify, the integration of resilient design, micromobility deployment, and data-driven transportation planning will be essential to ensuring that active transportation remains a cornerstone of the state's future.

8. Technological And Policy Recommendations

The review of existing literature underscores the profound impact of environmental factors on roadway design, revealing the necessity of incorporating strategies in infrastructure planning. Key findings include:

8.1. Coastal inundation

The sea level rise scenarios explored in this report offer a case-specific study, allowing management agencies to reference the results to evaluate the condition of individual non-motorized transportation facilities. Because this report models multiple NOAA sea level rise scenarios (Intermediate-Low, Intermediate, Intermediate-High, and High) alongside projected service-level outcomes for specific trail and bike route segments, agencies can move beyond generalized coastal risk statements and instead reference facility-specific findings when prioritizing capital funds [28].

It is recommended that these findings be used to inform future planning and investment decisions related to trails and bike routes through a tiered decision framework. Facilities projected to retain an acceptable service level through 2100 under the Intermediate-High scenario should be prioritized for routine maintenance and monitoring rather than major capital investment. Facilities projected to decline to a marginal service level by mid-century warrant near-term adaptation measures such as elevation, permeable surfacing, or protective berms where feasible given site constraints and funding. For facilities projected to reach the lowest service level by 2100 under the higher sea level rise scenarios modeled in this report, it may not be practical to allocate resources for adaptation given the scale of projected inundation; instead, constructing new, more resilient facilities on higher ground, or phasing out the affected segment in coordination with local planning bodies, may be a more effective and durable use of available funds [29].

This scenario-based approach allows DelDOT and local planning partners to sequence investment decisions transparently, weighing the cost of adaptation against the projected lifespan of a given facility under each modeled scenario, and to revisit these designations as updated sea level rise data becomes available.

8.2. Temperature

Addressing elevated temperature levels to mitigate their effects on non-motorized transportation facilities is ultimately a question of reducing the threat of urban heat islands. Investments in walkable urban designs such as shaded sidewalks and safer crossings, can help make non-driving commutes more comfortable and accessible. Localized cooling solutions can also be effective. Establishing cooling stations or water features in strategic, publicly accessible locations can provide relief during warmer periods, particularly for individuals who do not have access to indoor cooling or personal vehicles [30]. Land-use planning should also encourage mixed-use development to reduce travel distances and limit unnecessary exposure to outdoor conditions. By adopting these strategies, cities can not only improve current living conditions but also enhance their capacity to adapt to future environmental challenges. These efforts contribute to more resilient and livable communities, ensuring that all residents benefit from infrastructure planning [31].

8.3. Flooding

To reduce disruption and maintain accessibility, it is essential to integrate stormwater-resilient design into all future non-motorized transportation projects. This includes raised pathways, permeable pavements, and improved grading to divert water away from critical corridors. Local and state transportation agencies should prioritize the development and maintenance of drainage infrastructure that supports active mobility networks. Integrating bioswales, retention basins, and subsurface drainage into trail and sidewalk design can significantly reduce pooling and washout risks. Additionally, retrofitting existing facilities in flood-prone areas with such features can extend their operational lifespan and ensure continued access during moderate rainfall events [32].

Data-driven planning is essential for effective mitigation. Agencies should incorporate flood-frequency mapping and real-time precipitation models into their infrastructure planning workflows. By identifying historically impacted corridors and overlaying floodplain data with trail and bike route inventories, planners can better assess risk and prioritize adaptive upgrades. This approach will also support more efficient emergency response strategies when access routes are temporarily obstructed. Moreover, coordination between transportation, public works, and environmental agencies is critical to successful implementation. By aligning goals, pooling resources, and sharing data, municipalities can create integrated networks that are not only safe and connected but also capable of withstanding increasingly frequent precipitation-related events.

Finally, public communication tools such as signage, mobile alerts, and interactive maps should be developed to inform users of temporary closures or high-water areas. Equipping residents and commuters with timely updates can prevent accidents and encourage safe route planning. These strategies, combined with investment in flood-aware design, will ensure that active transportation remains a reliable and appealing option even during adverse weather conditions [33].

8.4. Urbanization

Resilient urban infrastructure should be expanded alongside transportation investments to reduce surface temperature buildup and improve the comfort of outdoor travel. Linear parks, shaded corridors, and tree-lined streets not only improve aesthetic value but also encourage greater use of active travel modes. These features are especially valuable in areas with high-density development where natural spaces are limited [34].

Preserving and enhancing connectivity is another critical priority. As urbanization intensifies, previously continuous trail networks or bike paths may become fragmented due to new construction or road widening. Agencies should work proactively to maintain connected non-motorized routes through protected bike lanes, pedestrian bridges, and dedicated mid-block crossings. Without continuity, the functionality of these networks diminishes and their usage declines.

Finally, long-term urban planning should integrate geospatial analysis to monitor how land use change interacts with transportation infrastructure. By assessing how trends in impervious surface expansion, population density, and development pressure affect active transportation networks, policymakers can make informed decisions about zoning, transportation funding, and infrastructure priorities that support healthier, more resilient cities [35].

9. Results, Conclusions, and Recommendations

Active transportation, including walking, bicycling, and micromobility, has emerged as a vital element in modern urban mobility systems. Micromobility refers to compact, lightweight vehicles such as bicycles, e-bikes, and electric scooters that are typically used for short-distance travel. These modes are increasingly recognized for their potential to reduce congestion, improve urban accessibility, and support more flexible transportation systems. Technological innovations, including GPS integration, mobile platforms, and Mobility-as-a-Service (MaaS), are making these modes more efficient, user-friendly, and accessible. Cities across North America including Wilmington and Dover in Delaware are expanding cycling infrastructure and shared mobility networks to meet growing demand.

At the same time, growing environmental stressors are influencing transportation planning across multiple dimensions. Changes in coastal inundation patterns, temperature trends, flooding, and continued urbanization are placing new demands on infrastructure and mobility systems. In coastal regions such as Delaware, non-motorized facilities are particularly exposed to surface-level environmental changes due to their proximity to water and ground-level placement. Flooding events have become more frequent and intense due to shifting rainfall patterns, placing pressure on drainage systems and often disrupting access to trails, sidewalks, and bike routes. Similarly, long periods of elevated outdoor temperatures can reduce travel comfort, particularly for cyclists and pedestrians, while also affecting infrastructure durability. In parallel, urbanization continues to reshape the built environment. While cities offer efficiency and economic opportunities, rapid growth often leads to infrastructure strain, disconnected networks, and limited space for non-driving modes of transportation.

Despite these challenges, micromobility and active transportation present valuable opportunities to enhance urban resilience. When supported by strategic investment such as shaded walkways, protected bike lanes, improved drainage, and integrated land-use planning these modes can help cities adapt more effectively to evolving environmental conditions. They also support broader goals related to accessibility, public health, and development. As Delaware continues to grow and adapt, leveraging geospatial data, effective public policy, and user-centered design will be critical in building transportation systems that remain reliable, connected, and responsive to environmental change.

This study outlines a set of targeted recommendations to enhance the resilience and functionality of active transportation and micromobility infrastructure in response to environmental across Delaware. Key strategies are organized around four primary focus areas: coastal inundation, elevated temperature, flooding, and urbanization.

In the context of coastal inundation, the analysis emphasizes case-specific planning based on service projections. Agencies are encouraged to prioritize investment in facilities with long-term viability and consider redirecting resources away from those projected to reach the lowest performance levels. The same analytical approach may be extended in future research to assess the impacts of other environmental stressors such as flooding and outdoor temperature on pedestrian and cyclist behavior.

To address temperature-related stressors, recommendations focus on improving outdoor comfort and safety through enhanced pedestrian networks, and localized cooling features. Updates to building and zoning regulations are also advised to promote energy-efficient construction and reduce exposure to high outdoor temperatures, particularly in compact urban areas.

Flooding, especially in areas affected by intense precipitation, poses a substantial threat to non-motorized facilities. Mitigation strategies include incorporating stormwater-resilient designs such as raised walkways, permeable surfaces, and improved drainage. Additionally, geospatial data and communication tools should be leveraged to support real-time risk management and ensure continued accessibility during weather-related disruptions [36].

Regarding urbanization, the report recommends integrating walking and cycling infrastructure into all stages of urban development. This includes adopting complete streets policies, maintaining connectivity of non-motorized routes, and using geospatial tools to monitor land use changes. Green corridors and shaded travel paths are also highlighted as essential for encouraging safe and comfortable travel in increasingly dense environments.

Together, these recommendations offer a practical roadmap for agencies and planners aiming to strengthen infrastructure performance, improve mobility options, and adapt effectively to long-term environmental pressures across Delaware's transportation network.

10. References:

[1] C. Cong, Y. Kwak, and B. Deal, “Incorporating active transportation modes in large scale urban modeling to inform sustainable urban development,” *Computers, Environment and Urban Systems*, vol. 91, p. 101726, Jan. 2022, doi: 10.1016/j.compenvurbsys.2021.101726.

[2] H. Zhou, J. Wang, M. Widener, and K. Wilson, “Examining the relationship between active transport and exposure to streetscape diversity during travel: A study using GPS data and street view imagery,” *Computers, Environment and Urban Systems*, vol. 110, p. 102105, Jun. 2024, doi: 10.1016/j.compenvurbsys.2024.102105.

[3] S. A. Obregón-Biosca, “Choice of transport in urban and periurban zones in metropolitan area,” *Journal of Transport Geography*, vol. 100, p. 103331, Apr. 2022, doi: 10.1016/j.jtrangeo.2022.103331.

[4] B. Beck *et al.*, “Active transport research priorities for Australia,” *Journal of Transport & Health*, vol. 24, p. 101288, Mar. 2022, doi: 10.1016/j.jth.2021.101288.

[5] G. Griggs and B. G. Reguero, “Coastal Adaptation to Climate Change and Sea-Level Rise,” *Water*, vol. 13, no. 16, p. 2151, Aug. 2021, doi: 10.3390/w13162151.

[6] S. Gössling, C. Neger, R. Steiger, and R. Bell, “Weather, climate change, and transport: a review,” *Nat Hazards*, vol. 118, no. 2, pp. 1341–1360, Sep. 2023, doi: 10.1007/s11069-023-06054-2.

[7] “Copernicus: Summer 2024 – Hottest on record globally and for Europe.” [Online]. Available: https://climate.copernicus.eu/copernicus-summer-2024-hottest-record-globally-and-europe

[8] “Delaware’s Climate Impacts.” [Online]. Available: https://dnrec.delaware.gov/2021-climate-plan/impacts/

[9] M. Chen, X. Huang, J. Cheng, Z. Tang, and G. Huang, “Urbanization and vulnerable employment: Empirical evidence from 163 countries in 1991–2019,” *Cities*, vol. 135, p. 104208, Apr. 2023, doi: 10.1016/j.cities.2023.104208.

[10] “Pedestrian Action Plan.” [Online]. Available: https://deldot.gov/Programs/pedestrian-action-plan/

[11] “U.S. Environmental Protection Agency, ‘What Are Heat Islands?’” [Online]. Available: https://www.epa.gov/heatislands/what-are-heat-islands

[12] “U.S. Environmental Protection Agency, ‘Using Cool Pavements to Reduce Heat Islands.’” [Online]. Available: https://www.epa.gov/heatislands/using-cool-pavements-reduce-heat-islands

[13] “Climate Services Based on Climate Predictions and Projections.” [Online]. Available: https://wmo.int/resources/wmo-bulletin/wmo-bulletin-vol-72-2-2023/climate-services-based-climate-predictions-and-projections

[14] N. Colaninno, R. Basu, M. Hosseini, A. Alhassan, L. Liu, and A. Sevtsuk, “A sidewalk-level urban heat risk assessment framework using pedestrian mobility and urban microclimate modeling,” *Environment and Planning B: Urban Analytics and City Science*, vol. 52, no. 5, pp. 1071–1090, Jun. 2025, doi: 10.1177/23998083241280746.

[15] R. Li *et al.*, “Effectiveness of travel behavior and infrastructure change to mitigate heat exposure,” *Front. Sustain. Cities*, vol. 5, p. 1129388, Mar. 2023, doi: 10.3389/frsc.2023.1129388.

[16] R. Basu, N. Colaninno, A. Alhassan, and A. Sevtsuk, “Hot and bothered: Exploring the effect of heat on pedestrian route choice behavior and accessibility,” *Cities*, vol. 155, p. 105435, Dec. 2024, doi: 10.1016/j.cities.2024.105435.

[17] "Delaware First Map." [Online]. Available: https://de-firstmap-delaware.hub.arcgis.com/
[18] "Explore Census Data." [Online]. Available: https://data.census.gov/
[19] B. M. Jesdale, R. Morello-Frosch, and L. Cushing, "The Racial/Ethnic Distribution of Heat Risk–Related Land Cover in Relation to Residential Segregation," *Environmental Health Perspectives*, vol. 121, no. 7, pp. 811–817, Jul. 2013, doi: 10.1289/ehp.1205919.
[20] S. L. Harlan, A. J. Brazel, L. Prashad, W. L. Stefanov, and L. Larsen, "Neighborhood microclimates and vulnerability to heat stress," *Social Science & Medicine*, vol. 63, no. 11, pp. 2847–2863, Dec. 2006, doi: 10.1016/j.socscimed.2006.07.030.
[21] R. Zhou, H. Zheng, Y. Liu, G. Xie, and W. Wan, "Flood impacts on urban road connectivity in southern China," *Sci Rep*, vol. 12, no. 1, p. 16866, Oct. 2022, doi: 10.1038/s41598-022-20882-5.
[22] F. Liu, C. Ren, and Y. Chen, "Flood risk investigation of pedestrians and vehicles in a mountainous city using a coupled coastal ocean and stormwater management model," *J Flood Risk Management*, vol. 17, no. 2, p. e12979, Jun. 2024, doi: 10.1111/jfr3.12979.
[23] M. S. Mohamed, M. Bagwell, S. S. Alqallaf, and K. R. Reddy, "Bioswales and Permeable Pavements as Green Infrastructure for Flood Mitigation in Chicago Neighborhoods," *J. Hazard. Toxic Radioact. Waste*, vol. 29, no. 2, p. 04025004, Apr. 2025, doi: 10.1061/JHTRBP.HZENG-1380.
[24] J. Westenhöfer, E. Nouri, M. L. Reschke, F. Seebach, and J. Buchcik, "Walkability and urban built environments—a systematic review of health impact assessments (HIA)," *BMC Public Health*, vol. 23, no. 1, p. 518, Mar. 2023, doi: 10.1186/s12889-023-15394-4.
[25] E. Brabec, S. Schulte, and P. L. Richards, "Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning," *Journal of Planning Literature*, vol. 16, no. 4, pp. 499–514, May 2002, doi: 10.1177/088541202400903563.
[26] R. Ewing and R. Cervero, "Travel and the Built Environment: A Meta-Analysis," *Journal of the American Planning Association*, vol. 76, no. 3, pp. 265–294, Jun. 2010, doi: 10.1080/01944361003766766.
[27] R. Ewing and R. Cervero, "'Does Compact Development Make People Drive Less?' The Answer Is Yes," *Journal of the American Planning Association*, vol. 83, no. 1, pp. 19–25, Jan. 2017, doi: 10.1080/01944363.2016.1245112.
[28] "Sea level along the U.S. coastline."
[29] T. A. Skidmore and J. L. Cohon, "A multicriteria decision analysis framework for developing and evaluating coastal retreat policy," *Integrated Environmental Assessment and Management*, vol. 19, no. 1, pp. 83–98, Jan. 2023, doi: 10.1002/ieam.4662.
[30] H. Li, Y. Zhao, C. Wang, D. Ürge-Vorsatz, J. Carmeliet, and R. Bardhan, "Cooling efficacy of trees across cities is determined by background climate, urban morphology, and tree trait," *Commun Earth Environ*, vol. 5, no. 1, p. 754, Dec. 2024, doi: 10.1038/s43247-024-01908-4.
[31] P. Kumar *et al.*, "Urban heat mitigation by green and blue infrastructure: Drivers, effectiveness, and future needs," *The Innovation*, vol. 5, no. 2, p. 100588, Mar. 2024, doi: 10.1016/j.xinn.2024.100588.
[32] Oluwafisayomi Christiana Folorunso, "Bioswales in Urban Stormwater Management: A literature review on design principles and performance assessment," *Int. J. Sci. Res. Arch.*, vol. 1, no. 1, pp. 201–208, Dec. 2020, doi: 10.30574/ijsra.2020.1.1.0045.

[33] A. O. Egogo-Stanley, O. M. Ibrahim, and A. D Akinyemi, “Assessing Flood Vulnerability Using GIS Spatial Analytics to Inform Infrastructure Planning, Emergency Response and Community Resilience Strategies,” *Int. J. Sci. Res. Arch.*, vol. 7, no. 2, pp. 952–969, Dec. 2022, doi: 10.30574/ijsra.2022.7.2.0355.
[34] J. Yu, H. Zhang, X. Dong, and J. Shen, “The impact of street greenery on active travel: a narrative systematic review,” *Front. Public Health*, vol. 12, p. 1337804, Feb. 2024, doi: 10.3389/fpubh.2024.1337804.
[35] K. H. Mhana, S. B. Norhisham, H. Y. B. Katman, and Z. M. Yaseen, “Environmental impact assessment of transportation and land alteration using Earth observational datasets: Comparative study between cities in Asia and Europe,” *Heliyon*, vol. 9, no. 9, p. e19413, Sep. 2023, doi: 10.1016/j.heliyon.2023.e19413.
[36] “National Land Cover Database.” [Online]. Available: https://www.usgs.gov/centers/eros/science/national-land-cover-database