Austin, Texas

Next Generation

Transportation Asset Management Plan

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Glossary

Exposure - the degree to which a system is exposed to a given hazard

Risk - the positive or negative effect of uncertainty or variability upon agency objectives

Hazard - a potential occurrence of a natural/human-induced physical event that may cause damage

Uncertainty - limited information about past, present or future events

Vulnerability - a weakness in an asset's design, implementation, or operation that can be exploited

Acute shock – a disruption in an infrastructure system that is quick or localized

Chronic stressor - a disruption in an infrastructure system that is over a prolonged period

Adaptation – a modification in natural/human systems in response to actual/expected climatic stimuli

Mitigation - an intervention to reduce the emissions sources or enhance the sinks of greenhouse gases

Sustainability - meeting our needs without conciliating the ability of future generations to meet theirs

Greenhouse gas emissions - gases that trap heat in the atmosphere

Climate Change - a change in global or regional climate patterns

Resilience - the capacity to recover quickly and absorb stressors and shocks

Block-level - a census block; the smallest geographic unit used by the United States Census Bureau

Equity - the quality of being fair and impartial

Wildland-urban interface - area where human made structures are adjacent to areas prone to wildfire

Acronyms and Abbreviations

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
CAMPO	Capital Area Metropolitan Planning Organization
FEMA	Federal Emergency Management Agency
NOAA	National Oceanic and Atmospheric Administration
TAMP	Transportation Asset Management Plan
TxDOT	Texas Department of Transportation
TxWRAP	Texas Wildfire Risk Assessment Portal
USGS	United States Geological Survey
POC	People of Color
ACS	American Community Survey
MOU	Memorandums of Understanding
TSMO	Transportation Systems Management and Operations
GIS	Geographic Information System
GHG	Greenhouse gas emissions

Executive Summary

To promote sustainable and particularly equitable infrastructure growth, the City of Austin's transportation infrastructure requires continuous identification and monitoring to assess potential vulnerabilities. Through the assessment of acute shocks and chronic stressors that present high risks to the city, Austin can develop adaptation and mitigation strategies to enhance the transportation system's resilience for the next generation, a crucial process as climate change worsens and the population grows. The reduction and elimination of system vulnerabilities posed by severe weather hazards through specific asset implementation and design methods serve to protect the public of Austin, all of whom benefit from the transportation infrastructure. Requirements to begin conducting a vulnerability assessment for the City of Austin include the articulation of study objectives and scope followed by the collection and integration of data applicable to the infrastructure assets and climate trends. A systematic decision process that, through analysis of these integral components, identifies the most effective approaches to adaptation may properly combat vulnerabilities and help the City of Austin grow more resilient to threats. This document serves as the next generation Transportation Asset Management Plan (TAMP) for Austin, Texas, an addendum to the existing plan(s) to provide mitigation and adaptation strategies to increase transportation asset readiness and resilience for years to come.

The next generation TAMP serves to analyze the threats present to transportation assets and the populations who use them. This study focuses on the city corridors presented in the Imagine Austin city plan, a network of roadways vital to the city's mobility operations and growth concept. First, GIS data and Texas Department of Transportation (TxDOT) assessments were utilized to determine the status of transportations assets, including surface permeability and tree cover. Climate data were collected on wildfires, flooding, and the urban heat island effect and their threat levels to different geographic areas. Additionally, an equity analysis was conducted, comprised of income, housing, and other socioeconomic variables from the American Community Survey (ACS). The equity data were indexed and overlaid with the Imagine Austin corridors to determine inequity in transportation access.

The vulnerability assessment maps hazard risks from climate-related chronic stressors and acute shocks to the Imagine Austin Corridors. Infrastructure adaptation ideas and policy proposals are described in the report, ranging from short-term to long-term opportunities. Specific possible adaptation and mitigation measures include their advantages, their capability to address vulnerabilities, and the agencies responsible for their implementation. A flexible adaptive management prioritization strategy weighs each measure based on vulnerabilities addressed, user-experience improvement, economic and environmental impact, and overall feasibility of implementation. The vulnerability analysis, equity analysis, and adaptive management proposals work together to prioritize the right management solutions based on the needs of an area and community.

Introduction

Background

The City of Austin, Texas remains a pioneer in sustainability efforts throughout the energy, water, building construction, and transportation sectors. While improving the quantity and quality of transportation assets ranging from megaproject highways to bus stop waiting areas, the Austin metropolitan transportation network has struggled to maintain system resilience and performance throughout the entire region. In 2018, TxDOT's Austin District's highway system had almost 16,500 centerline miles of pavement, equal to approximately 36,000 lane-miles by road (*1*). Austin experiences over 60 million daily vehicle-miles traveled, with an additional 4,500,000 vehicle-miles by trucks (*1*). With especially vast and complex transportation infrastructure in place that serves more than 2.2 million people living within the 4,300 square miles of the Austin metropolitan area, special care must be taken to operate, maintain, and protect the infrastructure that allows the public to move throughout the city (*2*).

The resilience of the transportation infrastructure system is at risk from hazards that have increased in frequency and magnitude in the past years, known as either acute shocks or chronic stressors. Acute shocks, which disrupt infrastructure systems in a quick or localized manner, include wildfires and flooding within Austin. Chronic stressors tend to disrupt an infrastructure system over a prolonged period, such as the urban heat island effect and inequitable transportation access. These hazards degrade the infrastructure to the point of falling below the required performance level and thus fail to provide for the public's mobility needs. Despite various infrastructure asset management plans and strategies implemented by the city, there remain unaddressed or poorly mitigated vulnerabilities to the shocks and stressors. Populations deemed most vulnerable to wildfires, flooding, the urban heat island effect, and inequitable transportation access are generally households with lower incomes. Income inequality, exhibited by the 20.6% of Austin households with an annual income of less than $35,000, and historic redlining relegate populations to neighborhoods with insufficient infrastructure upkeep or directly in the path of extreme weather events (*2*). Special attention to these communities is required to grow the transportation system as a whole, avoiding leaving behind entire regions while advantaged populations receive next-generation infrastructure for other perceived benefits. Through an extensive vulnerability assessment that analyzes the resilience of specific transportation assets under wildfires, flooding, urban heat island, and inequity, adaptations can be developed and implemented to the benefit of all residents.

Motivation

The changing climate and growing population make taking drastic action to reduce the impacts of acute shocks and chronic stressors imperative. Because the inner city cannot accommodate the density of Austin's growing population (Figure 1), residents expand outwards, as indicated by the green regions. An approximate surge of 100 new residents per day paired with low population density signifies that many people are limited in access to various transportation modes and likely commute by personal vehicles more often (*3*). Thus, infrastructure failures in roadways or bridges will have an increased impact on the population. Considering that only 31% of surveyed Austin residents felt their transportation needs were met in 2012, it becomes even more essential to improve and maintain the infrastructure before acute shocks and chronic stressors lower performance levels even more (*3*). Climate change presents another significant challenge to the transportation infrastructure in Austin, directly increasing the severity and frequency of wildfires, flooding, and the urban heat island effect. Adapting the system to resist the harmful effects and damage from hazards is only part of the solution. Mitigating Austin's direct contributions to worsening climate change through smart technologies and policies should be used in conjunction with adaptation to improve system resilience.

Acute shock: Flooding

Flooding, especially flash flooding, is a common hazard for the City of Austin, most often caused by excessive rainfall in the region. The extremely flat terrain and proximity to floodplains or riverine areas results in flood events that harshly strike the region. Additionally, flood magnitude trends upwards as climate change increases. Flooding has a multitude of impacts on the transportation infrastructure of Austin, including closing roadways, cutting off access to specific populations, and even the destruction of signal technology, signage, and other vital components. From 1996 to 2014, flooding in Austin caused approximately 100 million dollars of property damage alongside ten deaths and 50, statistics that are only expected to increase as populations move to the wildland-urban interface and other vulnerable areas (*4*). The limitations of transportation routes during flood events can halt parts of Austin's economy or reduce the quality of life and safety of users. Closures often extend past the initial shock, as entire areas may require repairs and rehabilitation of damaged assets. Infrastructure improvements have not been implemented throughout the metropolitan area, as many regions are more susceptible to the harsh effects of flooding than others. As described in the *Austin Hazard Mitigation Plan*, new populations who must live further from the city center are disproportionately impacted by the lack of sufficient infrastructure in new land development, especially in less urban and under resourced areas (*4*). Adaptation techniques to resist floods encroaching on transportation assets and inflicting critical damage must be developed so all residents of Austin can stay mobile regardless of their location.

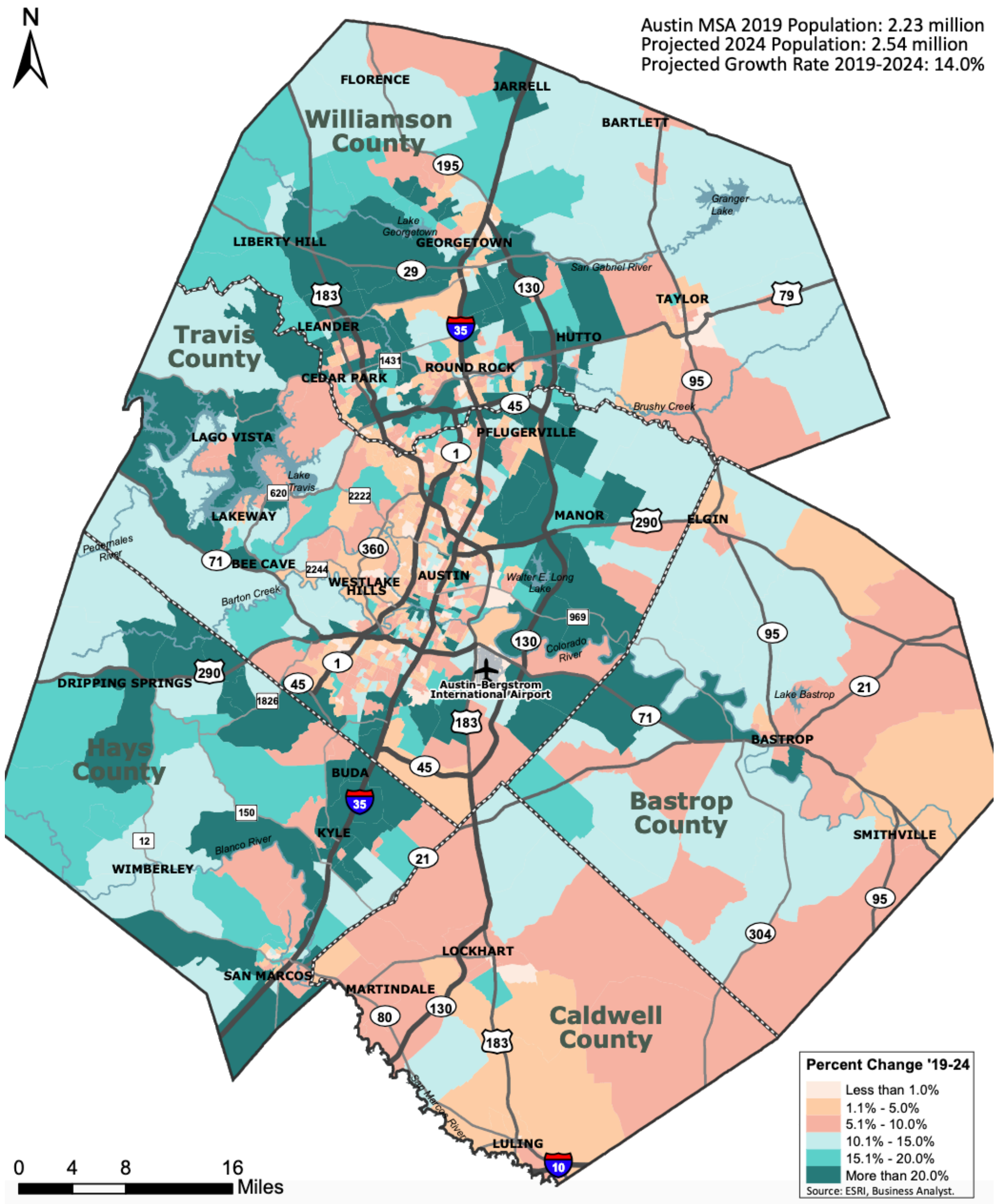


Figure 1 Projected Population Growth in Austin from 2019-2024 (Source: Austin Chamber).

Acute Shock: Wildfire Risk

The City of Austin has experienced wildfires that devastated increasing extents of residential areas and undeveloped land over the past years. Considered to be number five of the top 15 metropolitan areas at risk of wildfires, Austin is extremely vulnerable to wildfire destruction (*5*). Wildfires in 2011 destroyed 53 homes and burned 7,000 acres of land, emphasizing the need for wildfire-resistant emergency service and evacuation routes (*6*). If roadways become congested by people evacuating on routes that are not within a dangerous range of the wildfire, the heavy traffic flow may be too large for the transportation network to properly handle efficiently. The access to emergency services would also be limited, with plenty of regions unable to safely accommodate the required vehicles due to weaker transportation infrastructure farther from the city center. This is only exacerbated by the fact that wildfire events have much more potential to occur in suburban neighborhoods housing vulnerable minority populations according to the *Community Wildfire Protection Plan* (*7*). Climate change will increase temperatures and the likelihood that fires burns longer, emphasizing the need for adaptation to match the increasing frequency of the wildfires. Besides temporary limitations to mobility access, wildfires have and will directly damage transportation assets. Through the destruction of pavement, guard rail and post deterioration, or closure by falling trees, wildfires can have more permanent effects that endanger the lives of the public while also reducing the transportation system's ability to meet performance requirements. Efforts must be taken to not only diminish the number of regions that lack access to transportation during wildfires but also resist damage to specific assets in areas with high wildfire risk (Figure 2).

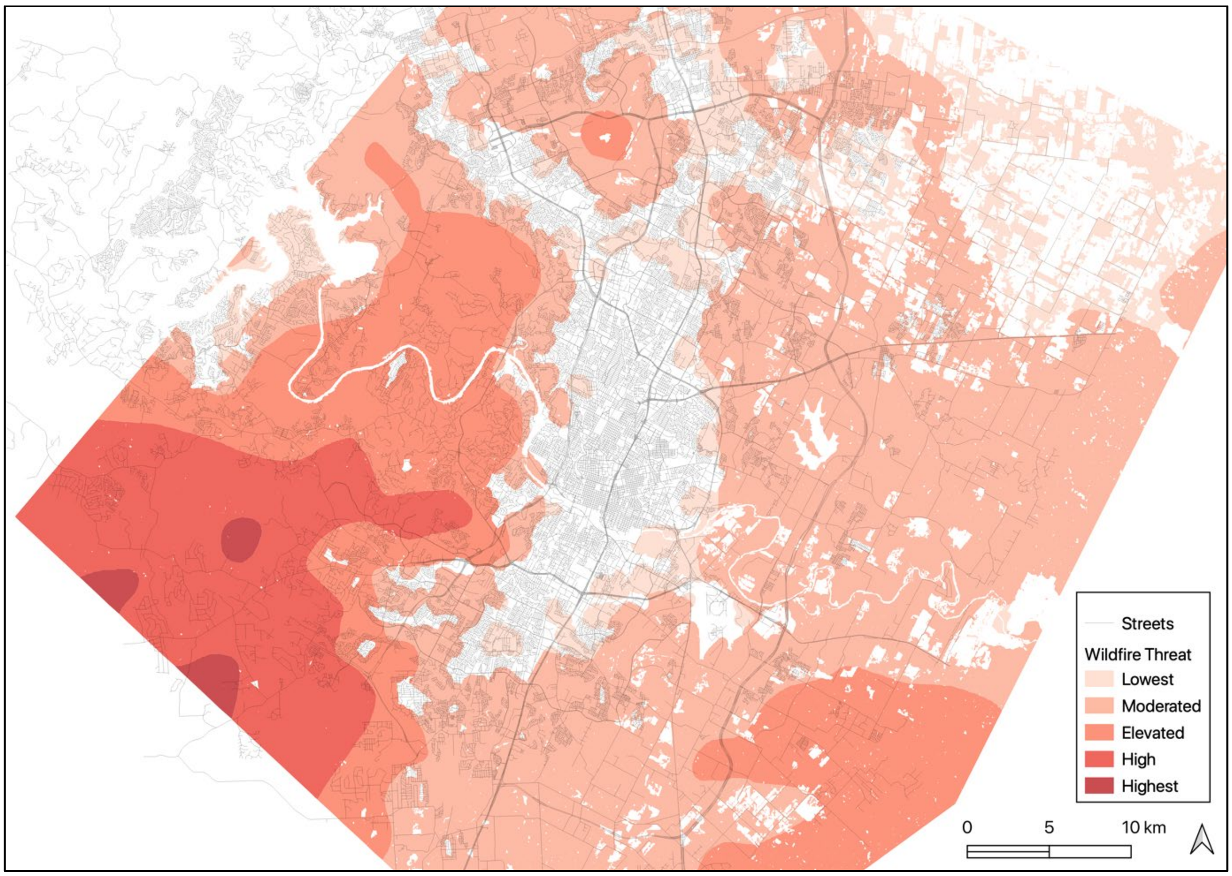


Figure 2 Austin Wildfire Risk (Source: Austin Wildfire Threat Map)

Chronic Stressor: Inequitable Access to Transportation

As a chronic stressor, inequitable access to transportation causes both social and economic degradation in affected Austin communities. City planning and development has, in the past and present, isolated communities from one another and reduced the efficiency of mobility for members of those communities. A primary example includes the I-35 interstate highway, constructed in between western white populations and eastern Hispanic and Black populations (*3*). The physical separation serves to degrade social resiliency through the furthering of racial division and the creation of "sides" in the city. Communities with higher proportions of minorities are physically separated from others, which yields a secondary effect of transportation implementation, repair, and rehabilitation being completed less often. Austin's population is comprised of 8% African American or Black citizens and 33% Hispanic citizens, a significant proportion of whom are disproportionately affected by weaker transportation infrastructure management and access (*2*). The neglect of the transportation needs of these communities is seen in extended delays and repairs, fewer mass transit access points, and under designed roads. Inequitable asset management practices throughout the region often penalize members of marginalized communities in their ability to attend work or school, helping maintain income inequality throughout the city (Figure 3). A comprehensive update to the transportation asset planning strategy that considers social divisions before implementation would alleviate only part of the problem; it is imperative that marginalized communities not only receive infrastructure access point improvements but also that transportation assets within marginalized communities continue to be monitored and adapted with consideration for anti-displacement strategies.

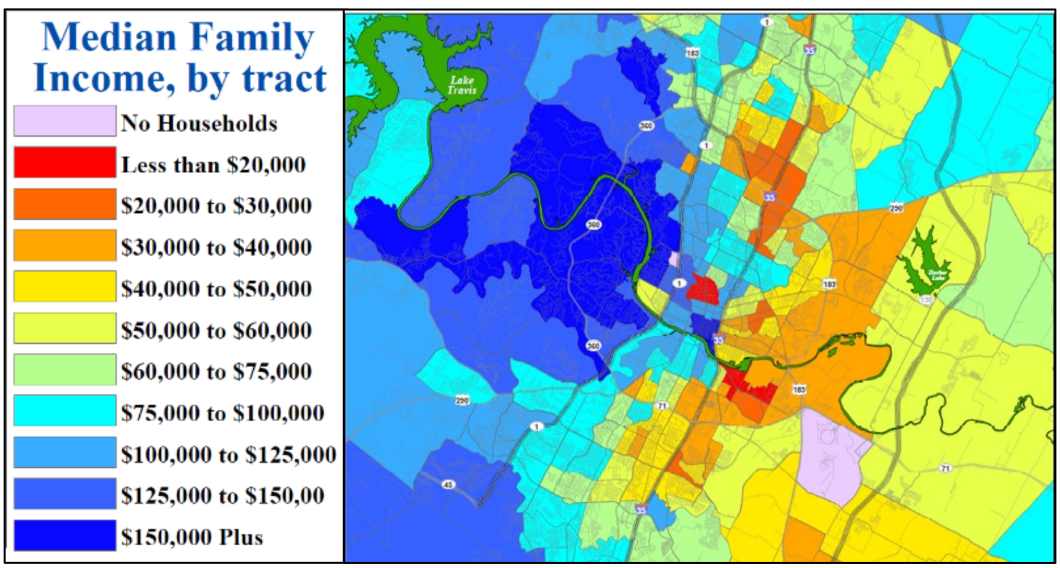


Figure 3 Median Family Income in central metropolitan Austin. Data Source: American Community Survey, 2010-14, 5-year composite dataset, Table B19113, census tracts. US Census Bureau.

Chronic Stressor: Urban Heat Island

The urban heat island is characterized by temperatures significantly higher than the normal ambient air temperature. This effect results from a developed urban location containing densely packed artificial surfaces, such as pavement and buildings, with little natural surfaces, grass, or trees, trapping heat within the built environment and preventing it from dissipating as needed. In a city such as Austin with an already hot climate, heat dissipation is required for the system's health. With increasing land coverage by new roadways, parking lots, and other transportation assets, the urban heat island effect only worsens. The urban heat island effect is commonplace within the most developed parts of Austin, which contain higher buildings separated by narrow rights-of-way (Figure 4). The damage caused by high heat is two-fold, diminishing the health of the population and damaging transportation infrastructure. Thus, the devastating effects of heat-related illnesses like heat strokes and respiratory issues will be harsher for those not using a personal vehicle to commute or otherwise travel. It is therefore noteworthy that members of lower-income communities walk and take the bus more often as a primary mode of transportation, regardless of the weather (*8*). Secondly, extremely high temperatures from the heat island effect can damage roads and reduce performance, including the melting and cracking of pavement (*9*). High heat also stresses transit vehicle air conditioners, the failure of which will decommission the vehicle until it can be fixed and disrupt services (*10*). The planning and development of city-wide transportation projects need to address both community health and transportation asset performance to prevent urban areas from trapping heat.

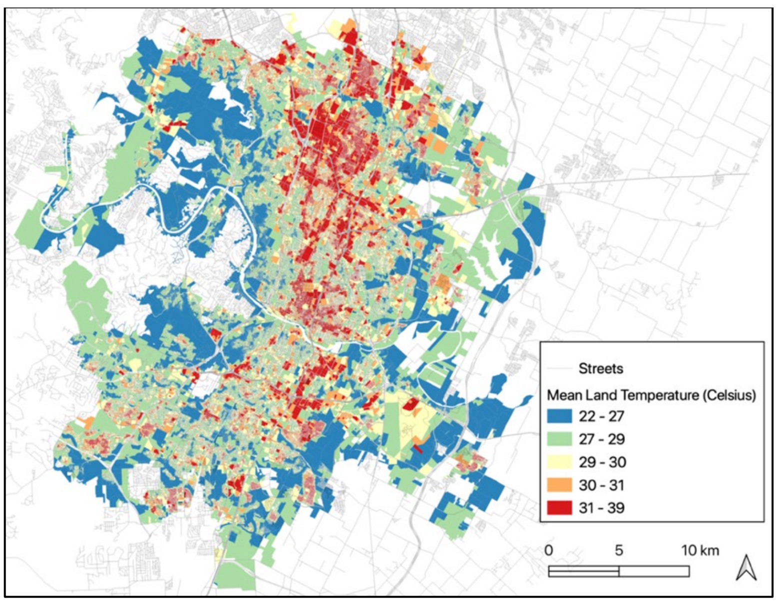


Figure 4 Example of the Urban Heat Island Effect for downtown Austin (Source: Landsat).

The acute shocks of wildfires and flooding and the chronic stressors of inequitable city-wide access and the urban heat island effect are not independent of one another and their potential threats to the transportation infrastructure and the population cannot be fully separated independently. However, visualizing them independently and analyzing them together integrates the immediate problems and solutions for each threat. Potential solutions that adapt to and mitigate multiple shocks and stressors, depending on the needs of the area and infrastructure, yield beneficial results while under financial and scheduling constraints. While directly reducing the damage to assets and their performance, adaptation can only account for the foreseeable future's hazards. Adaptation may be conducted through protective improvements to existing transit networks or implementation of legislation that mandates equitable and long-lasting transportation assets. Because of adaptations limitations, mitigation to reduce Austin's contribution to climate change is equally vital. Through providing multimodal transportation infrastructure, access for all communities, and a higher degree of system efficiency, emissions from congested traffic and personal vehicle use will decrease. The circular relationship between adaptation and mitigation techniques has the potential to develop Austin sustainably without reducing the performance of existing infrastructure. Ultimately, vulnerability assessments enable asset design and management modification, smart technology implementation, and collaboration between city departments to create next-generation infrastructure based in adaptation and mitigation.

Gaps and Opportunities

Austin's City Council adopted *Imagine Austin* in 2012, launching the development of multiple plans to address its action items and laying the groundwork for Austin to plan mitigation and adaptation measures across sectors (*11*). *Imagine Austin* is a long-term vision that is meant to reflect the values of the community and the aspirations of the City of Austin. To further solidify Austin's commitment to resiliency, Mayor Steve Adler signed the Global Covenant of Mayors in 2015 and joined the C40 Cities Climate Leadership Group (*11*). In the same year, to emphasize their commitment to equity, the City of Austin launched the "Spirit of East Austin Initiative" and created an Equity Office in 2016 tasked with advancing equity across all city projects and operations (*11*). Most recently, Austin participated in the White House's 2016 Smart City Challenge, which provided the opportunity to better understand how smart technologies can augment the city's infrastructure. As a direct result of these events, Austin's City Council has a vast array of plans and reports that highlight various hazards, mobility issues, inequity, and the city's vision, which are outlined in Table 10 in the Appendix.

The *Austin Smart City Plan* serves as the basis of smart solutions and sustainable growth for the City of Austin and has been mimicked in the form of corridors for analysis in the vulnerability assessment (3). The smart city plan emphasizes reducing Austin's carbon emissions though fails to present adaptation strategies for the hazards of wildfire and flooding for much of the region. There are two City of Austin plans that directly focus on the acute shocks. The *Austin Hazard Mitigation Plan* considers flooding as an acute shock to expanding populations in newly developed land yet neglects to mention wildfire threat or delve deeply into the precise relationship between a growing population and hazard frequency (4). In contrast, the *Austin-Travis County Community Wildfire Protection Plan* naturally only focuses on wildfires, though similarly failing to consider the population sprawl alongside wildfire severity (6). Both flooding and wildfires are appropriately analyzed for frequency and vulnerable infrastructure and community impact in *Toward a Climate-Resilient Austin*, yet the scope of the study disregards the urban heat island effect entirely (*12*). The danger of failing to analyze climate-related hazards for the entirety of the region and all appropriate communities lies in incomplete infrastructure management and only serves to weaken the resilience of the overall system. Additionally, as seen in the *Austin Strategic Direction 2023* plan, considering hazards separately from one another fails to address circumstances where a community may be highly vulnerable to both (*13*). Gaps in these plans' analyses are generally from analyzing hazards independently, failing to consider all vulnerable regions, or sometimes failing to analyze a hazard all together.

Additional plans helped shape the vulnerability assessment of this study through parameters, objectives, and methods of analysis. The vague data collection methods and broadly targeted communities seen in the vulnerability assessment conducted in the *Austin Strategic Mobility Plan* left opportunities to expand on regional analysis, in addition to implementing exact data collection methods using GIS and other data sources (*14*). The incomplete analysis of roadways was once again a gap in the *Climate Resilience Action Plan for City Assets and Operations*, which only addressed main arterial roads, as opposed to a variety of roadway types and locations (*15*). Overall, the vast majority of the studied infrastructure asset management plans fail to highlight the detrimental effects of inequitable transportation access alongside climate-related hazards. Instead, chronic stressors are often left out of the discussion of acute shocks' impacts on communities entirely or are considered entirely separate issues. The Austin Transportation Asset Management Plan serves to directly address the acute shocks of wildfire and flooding with chronic stressors of the urban heat island effect and transportation inequity alongside one another. Through conducting both a vulnerability and inequity assessment, climate hazards of wildfire and flooding can be considered for the most at-risk populations as opposed to the whole city. The issues of inequity and climate change effects often intermingle, and the most vulnerable communities must have proper adaptation strategies implemented to resist lasting damage.

However, this Austin Transportation Asset Management Plan is unable to address a variety of gaps within previous plans, due to insufficient data or otherwise the scope defined for this study. The development of specific teams within government agencies to address hazards or otherwise manage vulnerable infrastructure served as a goal of the *Climate Resilience Action Plan for City Assets and Operations* (*15*). Due to the potential impact of adaptive management through team development being difficult to estimate, this solution will be somewhat neglected in this asset management plan. Additionally, this plan will only consider the transportation infrastructure of Austin under these hazards. Although the *Long-Range Capital Improvement Program Strategic Plan* leaves an opportunity to continue considering the interdependencies of infrastructure systems and responsible agencies under hazards, the scope of this study will be limited to transportation infrastructure (*11*). In a similar sense, many of these previously mentioned plans emphasize the importance of partnerships between departments and the collaboration for an overall positive impact upon the vulnerable infrastructure. Within this study, adaptations against these hazards will primarily rely upon technology, construction methods, response to hazards, and other policy changes. Thus, the relationships between departments will be undefined within this study, due to its mention in previous plans and intricate political networks that may be difficult to reorder through this asset management plan. Table 10 (Appendix) shows which acute shocks and chronic stressors were addressed in each of the City of Austin's plans, highlighting gaps in past analyses.

Objectives and Study Scope

The next-generation Austin TAMP presents vulnerability analysis, equity analysis, and adaptive management prioritization methods on a narrowed scope of the Imagine Austin Corridors. The Imagine Austin Corridors, outlined in *Imagine Austin*'s growth concepts, span different regions of the city and are therefore good candidates to test analysis methodologies on that could be expanded to the rest of the city in a later iteration (*16*). The study analyzes the effects of wildfire, flooding, the urban heat island effect, and inequitable transportation access. This report seeks to combine all potential threats in the vulnerability assessment so that practical adaptations may be developed which address the problem under feasibilities of budget, schedule, and technological capability. The plan is developed utilizing multiple previous infrastructure asset management and climate resilience plans as a benchmark to build in previously discussed gaps and opportunities and directly addressed within the vulnerability and inequity assessment.

There are two objectives for this next-generation asset management plan, based on prior infrastructure asset management and sustainability plans: (1) conduct a vulnerability assessment of the road network and (2) equity analysis of transit network along the road network. The vulnerability assessment examines how flood risk, wildfires, and extreme temperatures affect the road network. The equity analysis examines the relationship between inequity and public transit. The analyses align with the City of Austin's efforts to increase resiliency, connectivity, and equity within the Imagine Austin corridors, (Figure 5).

Vulnerability Assessment

This section highlights the chosen assets and the relevant climate data aquired, followed by the analysis methods and results. Figure 5 depicts the corridor segments included in the assessment. These segments vary in length, travel mode, and vulnerabilities outlined in Table 1 using vulnerability indicators from *Central Texas Extreme Weather and Climate Change Vulnerability Assessment of Regional Transportation Infrastructure* (*11*). The results of the vulnerability analysis for this paper appear in Table 3.

Table 1 Imagine Austin Corridors, length, modes, and vulnerabilities

ID	Corridor Street Name	Length (m)	Travel Mode	Potential Vulnerabilities
1	Howard Lane/Gregg	13,933	Car, bike	Flooding, wildfire
2	Parmer Lane	25,661	Car, bike	Flooding, wildfire
3	Jollyville Road	6,000	Car, bike, bus	Flooding, wildfire
4	Anderson Lane	3,502	Car, bus	Flooding
5	51st Street / Airport / 53rd Street	7,642	Car, bike, bus	Flooding
6	35th/38th	2,013	Car, bike, bus	Flooding
7	MLK	13,989	Car, bus	Flooding, wildfire
8	Riverside Drive	8,490	Car, bus	Flooding, wildfire
9	Stassney Lane	6,856	Car, bike, bus	Flooding, wildfire
10	William Cannon Drive	16,032	Car, bike, bus	Flooding, wildfire
11	Slaughter Lane	20,657	Car, bike, bus	Flooding, wildfire
12	East Cesar Chavez	4,482	Car, bus	Flooding
13	East 7th St	4,529	Car, bus	Flooding
14	5th/6th Streets/Lake Austin Blvd	6,085	Car, bike, bus	Flooding
15	Loyola Lane	12,992	Car, bike, bus	Flooding, wildfire
16	Braker Lane/Blue Goose	16,838	Car, bike, bus	Flooding, wildfire
17	Rundberg Lane/Ferguson	8,997	Car	Flooding, wildfire
18	Burnet Road	9,573	Car, bus	Flooding
19	Lamar Boulevard	25,806	Car, bus	Flooding
20	Cameron Road/Dessau	12,918	Car, bike, bus	Flooding, wildfire
21	Manor/Springdale/Cameron	10,495	Car, bike, bus	Flooding, wildfire
22	Pleasant Valley	18,114	Car, bike, bus	Flooding, wildfire
23	South Congress	11,285	Car, bike, bus	Flooding, wildfire
24	South First	14,583	Car, bus	Flooding, wildfire
25	Springdale	7,185	Car, bike, bus	Flooding, wildfire
26	Airport Blvd	10,608	Car, bus	Flooding, wildfire
27	Wells Branch Parkway	5,365	Car, bus	Flooding, wildfire
28	11th	539	Car, bike, bus	Flooding
29	12th	1,273	Car, bike, bus	Flooding
30	Wells Branch Parkway East	9,000	Car, bike	Flooding, wildfire
31	Harris Branch Parkway	8,171	Car, bike	Flooding, wildfire
32	Arterial A	5,817	Car	Flooding, wildfire
33	Rundberg Connector	948	Car	Flooding, wildfire
34	Tuscany Way North	2,482	Car, bus	Flooding, wildfire
35	Guadalupe	2,638	Car, bus	Flooding

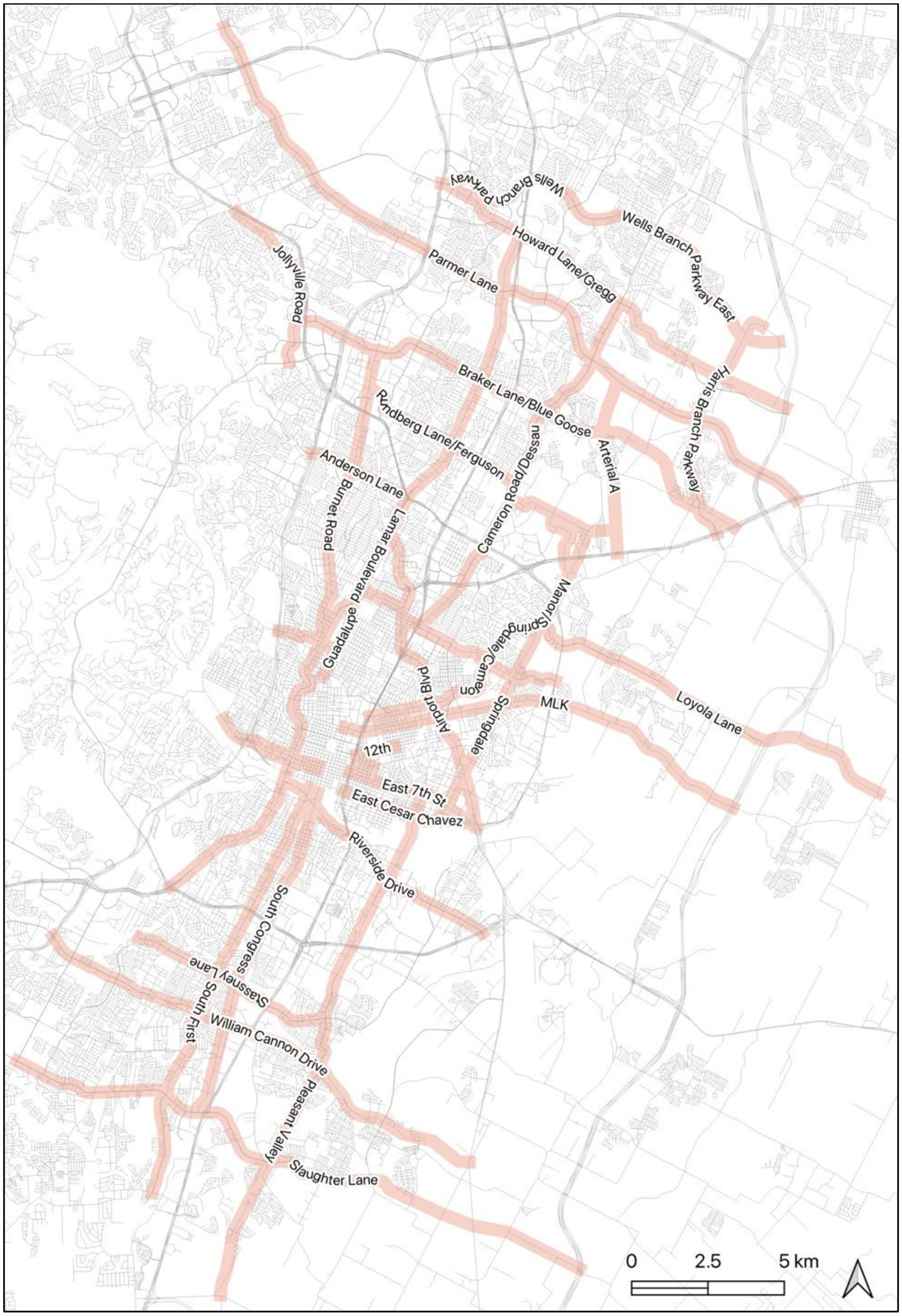


Figure 5 Imagine Austin Corridors.

The vulnerability assessment was conducted based on the stressors and shocks of flooding, wildfire, and the urban heat island effect. Scores and weights were assigned to each indicator based on a wide variety of available data (Table 2). In all indices, a higher score indicates higher vulnerability to that hazard. For example, a corridor with very low permeability (25%) will get a higher score (3) and thus raise its overall flooding vulnerability index. All assessments consider a 40-foot buffer around road centerlines to approximate an 80-foot right of way, capturing the right-of-way without manually choosing the correct distance for each corridor. Due to the poor accuracy of the Imagine Austin Corridor shapefile, the values reflected in the current state of the model may not be as accurate as desired but are satisfactory for proof of concept (See appendix Figure 17).

Each corridor's flood exposure is assessed by measuring the permeable surface area of the buffer and the number of storm drains in that buffer per corridor-mile. Pervious surface data is from the City of Austin GIS Portal and the storm drain data required special request from the kind people at the City of Austin Department of Watershed Management. According to the FHWA's Urban Drainage Design Manual, stormwater inlets should be placed at least upgrade of intersections, if not more regularly based on site-specific conditions (*17*). As Austin's median block length is 377 ft according to GIS analysis of Austin's road centerlines, the minimum standard would be met with two inlets every 377 ft, or 28 inlets every mile. The Urban Drainage Design Manual provides more specific detail about proper inlet placement, but integrating additional factors would require elevation data and geographically specific rainfall data, which were unavailable in an understandable format Because of the lack of precipitation data, the analysis considers a uniform eight inches of rainfall for all corridors, the maximum 5-day precipitation in Austin for 2071-2100 from the ATMOS Research & Consulting Group to assess climate change projection for the city of Austin (*18*).

The Texas Wildfire Risk Assessment Portal's (TxWRAP) wildfire data was obtained through their portal after receiving professional access (*19*). TxWRAP rates wildfire threat on a scale of 0-7, and the average threat level along each corridor calculates the corridor-wide wildfire threat level. To assess the urban heat island effect, tree canopy data was obtained from the City of Austin in raster form (*20*) and the Zonal Statistics tool was used to provide each corridor with the percentage of its 40-foot buffer covered by trees. Using the United States Geographic Survey's (USGS) Landsat data prepared by Mayer et al. (*21*) surface temperatures were averaged along each corridor's buffer. Temperature thresholds are based on the viability for asphalt conditions. For all variables, the area considered is 40 feet from the centerline of the Imagine Austin Corridors. The 40-foot buffer was chosen to capture the right-of-way without manually choosing the correct distance for each corridor. Due to the poor accuracy of the Imagine Austin Corridor shapefile, the values reflected in the current state of the model may not be as accurate as desired but are satisfactory for proof of concept.

As displayed in through Figure 9, the Imagine Austin corridors tend towards high vulnerability for flooding and urban heat effect and low vulnerability to wildfire. Because wildfire tends to be a greater issue in the wildland-urban interface, it is not surprising that the Imagine Austin corridors, located predominantly within the city proper, have lower wildfire risk levels than corridors further out from the city (Figure 2). Even though the corridors all fall in areas of 0-3 risk on a scale of 0-7, Figure 9 illustrates the increased risk levels moving out from the downtown by splitting corridors according to their risk level.

Corridors further out from the city center are more vulnerable to flooding (Figure 6), and because precipitation data is uniform across the system and all corridors received a "4" for permeability (0-25% of ROW permeable), the differences are due to frequency of inlets. These corridors also tend to be longer, and using the null hypothesis that corridor length and inlets-per-mile are not related and a desired confidence level of 99%, single regression between corridor length and inlets-per-mile yields a t-value less than the critical value (-2.89<-2.73), and we safely reject the null hypothesis. The estimate for corridor length is -0.001, so we can say with significance that longer Imagine Austin Corridors tend to have fewer inlets per mile. This is not a very strong relationship even though it is significant (R^2=0.2). Corridors with lower flood vulnerability tend to be closer to downtown and thus may likely have more intersections, so it is a possible source of error that the metric uses a city-wide average instead of counting each corridor's intersections.

All corridors are highly vulnerable to the high temperatures of the urban heat island (Figure 7). Only two corridors, Arterial A and Rundberg Connector, have tree coverage above 25% and receive scores of "3" for canopy coverage, which weights them enough to be the only corridors with a vulnerability index of 2, the lowest in the group. No corridors had average temperatures over 35 C, so corridors with low canopy coverage weight more towards higher vulnerability. This shift is also affected by the difference the scales, as a 4 in tree coverage pulls the vulnerability index by more than a 3 in land temperature (their respective top scores) (Table 2).

While Arterial A and Rundberg Connector are the least vulnerable to the urban heat island, their tree canopies may be partially responsible for making them the most vulnerable to wildfire (threat level 2) of all the corridors (Table 3). A similar regression analysis can be done on percent tree canopy coverage and wildfire vulnerability, which indicates a significant relationship, though the narrow range of canopy coverage and wildfire levels in the sample renders this analysis only slightly stronger than the intuitive relationship between trees and fire. Parmer Lane, Braker Lane/Blue Goose, Airport Blvd, and Wells Branch Parkway are the most vulnerable to all three hazards, each scoring 3.75 for flood, 3 for urban heat island, and 1 for wildfire (Table 3). As stated earlier, they do not have the highest average wildfire vulnerability in the system, but they do have the highest indices in flooding and urban heat island, and would be very good candidates for adaptive and mitigating measures addressing all three hazards.

Table 2 Exposure Indicators for Vulnerability Analysis

Stressor	Indicator	Data Source	Indicator Value	Score	Weight	Vulnerability Index
Flooding	Amount of pervious surface	Austin GIS Portal	100% 75% 50% 25% 0%	0.5 1 2 3 4	25%	Flooding Index (range: 0.5 - 4)
	Maximum 5-day precipitation	Katherine Hayoe Report on Climate projections	0-2 inches 2-4 inches 4-8 inches 8-10 inches 10-12 inches	0.5 1 2 3 4	25%	
	Stormwater Infrastructure	Austin Stormwater Management	≥35 inlets per mile ≥28 inlets per mile ≥21 inlets per mile ≥14 inlets per mile <14 inlets per mile	0.5 1 2 3 4	50%	

Stressor	Indicator	Data Source	Indicator Value	Score	Weight	Vulnerability Index
Wildfire	Wildfire Threat	Texas Wildfire Risk Assessment Portal (TxWRAP)	0 1 (low) 2 (low/moderate) 3 (moderate) 4 (moderate/high) 5 (high) 6 (high/very high) 7 (very high)	0 1 2 3 4 5 6 7	100%	Wildfire Index (range: 0 - 7)
Urban Heat Island	Land temperature	USGS Landsat	Low (25 – 30 C) Medium (30 – 35 C) High (>35 C)	1 2 3	50%	UHI Index (range: 0.5 - 4)
	Tree Canopy	Austin GIS Portal	100% 75% 50% 25% 0%	0.5 1 2 3 4	50%	

Table 3 Imagine Austin Corridors Vulnerability Indices

ID	Corridor Street Name	Travel Mode	Flooding Vulnerability	Urban Heat Island Vulnerability	Wildfire Vulnerability
1	Howard Lane/Gregg	Car, bike	3.75	3	0
2	Parmer Lane	Car, bike	3.75	3	1
3	Jollyville Road	Car, bike, bus	3.75	3	0
4	Anderson Lane	Car, bus	2.25	3	0
5	51st Street / Airport / 53rd Street	Car, bike, bus	2.75	3	1
6	35th/38th	Car, bike, bus	2	3	0
7	MLK	Car, bus	3.25	2.5	1
8	Riverside Drive	Car, bus	2.25	3	1
9	Stassney Lane	Car, bike, bus	2.75	3	1
10	William Cannon Drive	Car, bike, bus	3.75	2.5	1
11	Slaughter Lane	Car, bike, bus	3.75	2.5	1
12	East Cesar Chavez	Car, bus	2	3	1
13	East 7th St	Car, bus	2	3	1
14	5th/6th Streets/Lake Austin Blvd	Car, bike, bus	2	3	1
15	Loyola Lane	Car, bike, bus	3.75	2.5	1

16	Braker Lane/Blue Goose	Car, bike, bus	3.75	3	1
17	Rundberg Lane/Ferguson	Car	3.25	3	1
18	Burnet Road	Car, bus	3.25	3	0
19	Lamar Boulevard	Car, bus	2.75	3	1
20	Cameron Road/Dessau	Car, bike, bus	2.75	3	1
21	Manor/Springdale/Cameron	Car, bike, bus	2.75	3	1
22	Pleasant Valley	Car, bike, bus	3.75	2.5	1
23	South Congress	Car, bike, bus	3.25	3	1
24	South First	Car, bus	2.75	2.5	1
25	Springdale	Car, bike, bus	2.25	2.5	1
26	Airport Blvd	Car, bus	3.75	3	1
27	Wells Branch Parkway	Car, bus	3.75	3	1
28	11th	Car, bike, bus	2	3	0
29	12th	Car, bike, bus	2.25	3	0
30	Wells Branch Parkway East	Car, bike	3.75	2.5	1
31	Harris Branch Parkway	Car, bike	3.75	2.5	1
32	Arterial A	Car	3.75	2	2
33	Rundberg Connector	Car	3.75	2	2
34	Tuscany Way North	Car, bus	2.75	3	1
35	Guadalupe	Car, bus	2	3	0

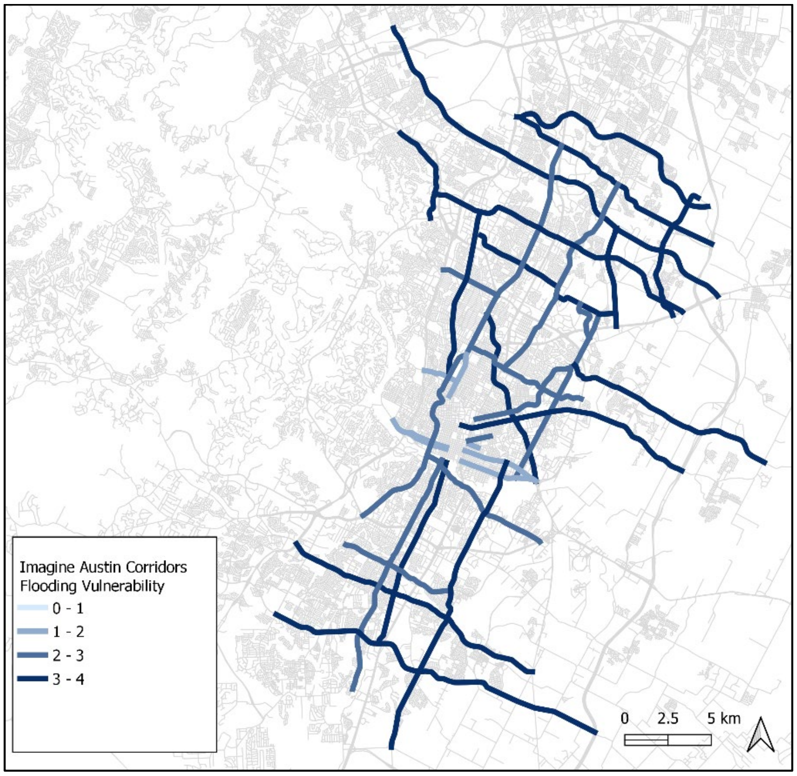


Figure 6 Imagine Austin Corridors by Vulnerability to Flooding

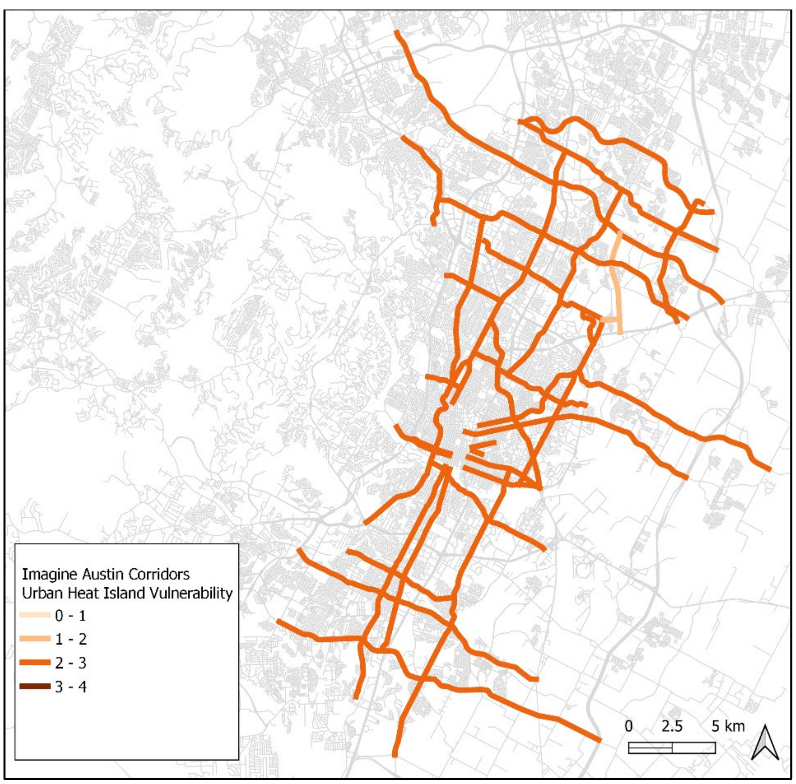


Figure 7 Imagine Austin Corridors by Vulnerability to the Urban Heat Island Effect

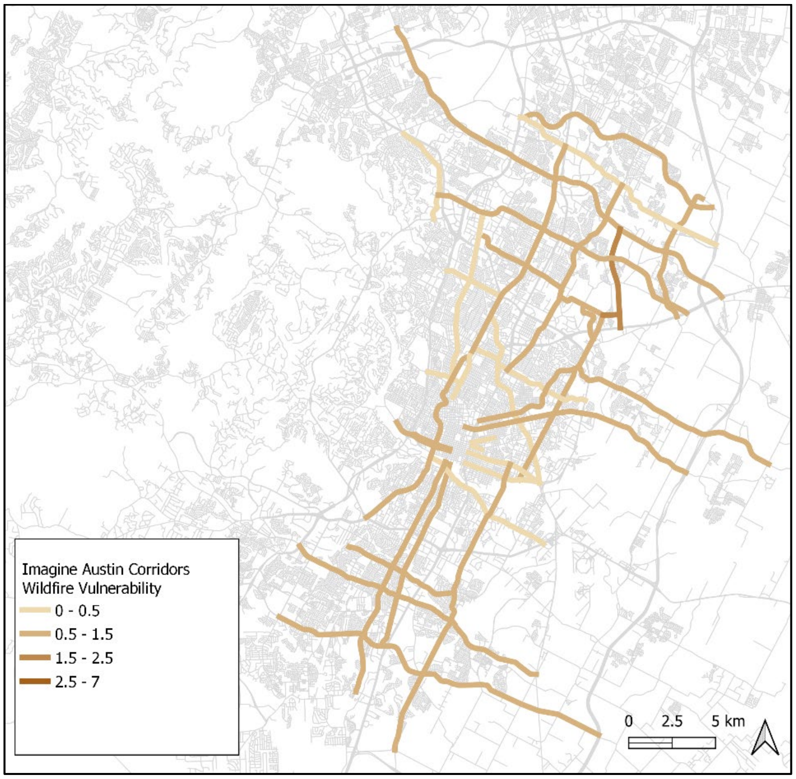


Figure 8 Imagine Austin Corridors by Vulnerability to Wildfire

Figure 9 Sections of Wildfire Vulnerability within Imagine Austin Corridors

Equity Analysis

The equity analysis examines the relationship between inequity and the Capital Metro bus lines in Austin. For the last 20 years, the City of Austin and Capital Metro have made great efforts to develop an equitable and accessible transit system; however, large discrepancies remain (*22*), (*23*). The objective of this analysis is to assess how physically and economically accessible Capital Metro's bus system is within the newly introduced Imagine Austin Corridors through determining the level of bus coverage (Figure 10) and measuring the accessibility of bus services to Austin's vulnerable communities (Figure 11, Figure 12).

Inequity and Public Transit System

Table 4 shows the data used to come up with the exposure indicators. The City of Austin's open data portal (*20*) provided public transit coverage information for the corridors. To examine inequity in public transit access, it is necessary to focus on households that are economically dependent on the service. For this reason, households below the federal poverty line data were obtained from the American Community Survey (ACS). Given Austin's history of racial segregation (*24*), transit access for communities of color is an important determinant of system equity. The percentage of residents of color in different neighborhoods was cross referenced with bus lines (*25*) to determine the level of service provided for people of color (POC). Given Austin's history of racial segregation (*24*), the question of access to transit for communities of color is an important determinant of equity. Data about the percentage of people of color in different neighborhoods was cross referenced with bus lines (*25*) in order to determine the level of service provided for people of color (POC). Finally, as access is also determined by economic accessibility, the analysis considers the cost of transportation and the percentage of households for whom transportation costs could exceed 5% of household income. Although transportation costs should not normally exceed 15% of a household's income, 5% becomes too costly for households below the Federal poverty line (*26*). Table 4 shows the scores attributed to levels of bus coverage, with 0 being the least amount of coverage and 4 total coverage.

Figure 10 illustrates the corridors served by Austin's two bus types: the local service, which mainly connects neighborhoods within Austin proper and the commuter service that extends to the outskirts of the city (*25*). Although most of the corridors are covered by a bus service, certain communities to the north-east, east, and south-east of Austin have no public transit access. It is apparent, however, that the western neighborhoods are well served by bus services. While the Imagine Austin corridors transect all levels of income and demographics, which shows effort from the City to be more inclusive and accessible to everyone in their corridor improvements, overlaying the corridors' transit coverage and socioeconomic variables shows disparities in Austin's transit accessibility (*27*).

Table 4 Public Transit Coverage Scores

Indicator	Data Source	Indicator Value	Score
Public transit coverage	City of Austin open data portal	100% 75% 50% 25% 0%	0.5 1 2 3 4

Table 5 Public transit coverage for Imagine Austin corridors

ID	Corridor Name	Corridor Length (m)	Bus Route Length (m)	Coverage in public transit (%)	Score
1	Howard Lane/Gregg	13,933	2,039	14.6	4
2	Parmer Lane	25,661	4,778	18.6	4
3	Jollyville Road	6,000	4,409	73.5	2
4	Anderson Lane	3,502	2,752	78.6	1
5	51st Street / Airport / 53rd Street	7,642	3,803	49.8	3
6	35th/38th	2,013	2,013	100.0	0.5
7	MLK	13,989	9,407	67.2	2
8	Riverside Drive	8,490	7,416	87.3	1
9	Stassney Lane	6,856	6,856	100.0	0.5
10	William Cannon Drive	16,032	10,811	67.4	2
11	Slaughter Lane	20,657	10,625	51.4	3
12	East Cesar Chavez	4,482	4,482	100.0	0.5
13	East 7th St	4,529	4,529	100.0	0.5
14	5th/6th Streets/Lake Austin Blvd	6,085	6,085	100.0	0.5
15	Loyola Lane	12,992	6,452	49.7	3
16	Braker Lane/Blue Goose	16,838	10,223	60.7	2
17	Rundberg Lane/Ferguson	8,997	0	0.0	4
18	Burnet Road	9,573	9,573	100.0	0.5
19	Lamar Boulevard	25,806	25,806	100.0	0.5
20	Cameron Road/Dessau	12,918	6,864	53.1	2
21	Manor/Springdale/Cameron	10,495	9,600	91.5	1
22	Pleasant Valley	18,114	7,558	41.7	3
23	South Congress	11,285	10,901	96.6	1
24	South First	14,583	14,583	100.0	0.5
25	Springdale	7,185	5,382	74.9	3
26	Airport Blvd	10,608	10,608	100.0	0.5
27	Wells Branch Parkway	5,365	5,365	100.0	0.5
28	11th	539	0	0.0	4
29	12th	1,273	1,273	100.0	0.5
30	Wells Branch Parkway East	9,000	9,000	100.0	0.5
31	Harris Branch Parkway	8,171	0	0.0	4
32	Arterial A	5,817	0	0.0	4
33	Rundberg Connector	948	0	0.0	4
34	Tuscany Way North	2,482	1,590	64.1	2
35	Guadalupe	2,638	2,638	100.0	0.5

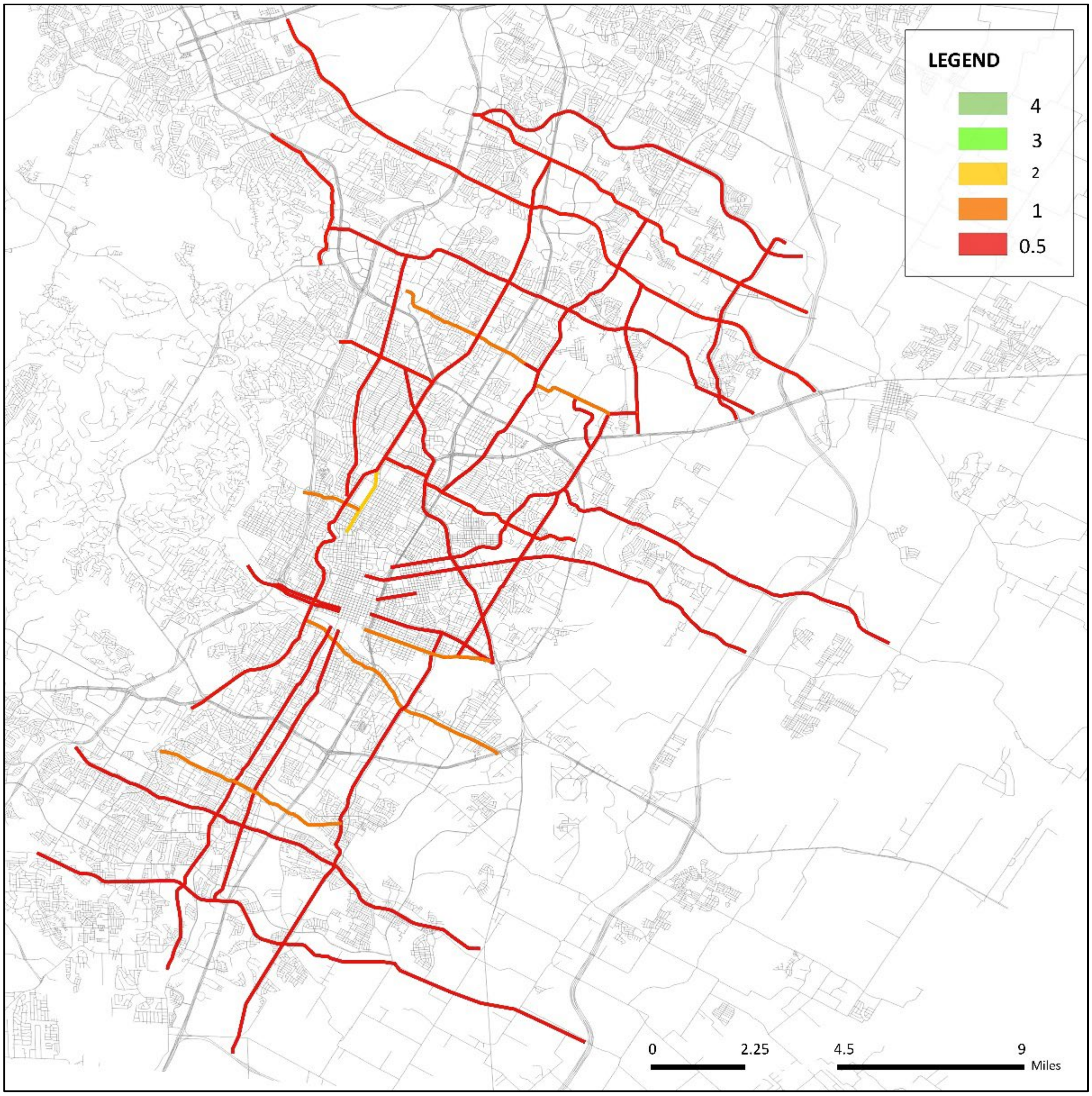


Figure 10 Coverage of Imagine Austin Corridors in public transit

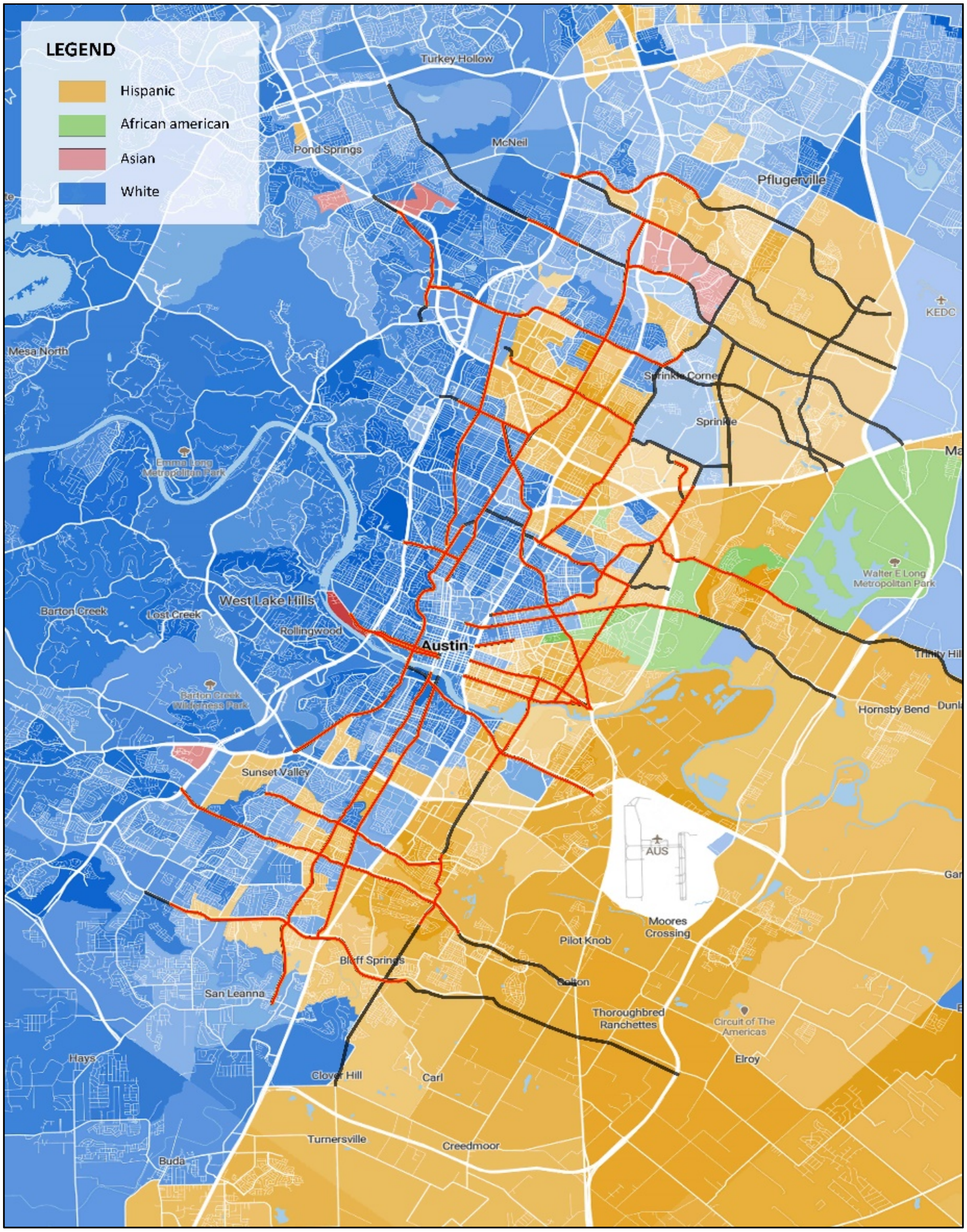


Figure 11 Public transit access for block groups by majority race (Source: Best Neighborhood)

Figure 11 shows a clear divide between white households and communities of color. Historically, this divide has been enforced by the I-35 and redlining (*28*) and continues to be palpable in today's public policies (*29*). The map shows a high concentration of communities of color in the northern, eastern, and south-eastern parts of the cities, largely overlapping with the sections of the Imagine Austin corridors that do not intersect with public transit. Austin's race map shows a clear divide between white households and communities of color. Historically, this divide has been enforced by the I-35 (*28*) and continues to be palpable in today's public policies (*29*). The map shows a high concentration of communities of color in the northern, eastern, and south-eastern parts of the cities, the same parts where the Imagine Austin corridors do not specifically intersect with public transit.

Comparing vulnerable households' physical proximity to transit and transportation affordability is integral to measuring transit access and equity. Mapping block groups with the highest concentration of households under the federal poverty line (*30*) (Figure 12) shows the proximity of transit critical communities. The analysis is limited to bus coverage of the Imagine Austin corridors, but a similar process applied to the entire system could show the physical distance between transit and vulnerable households.

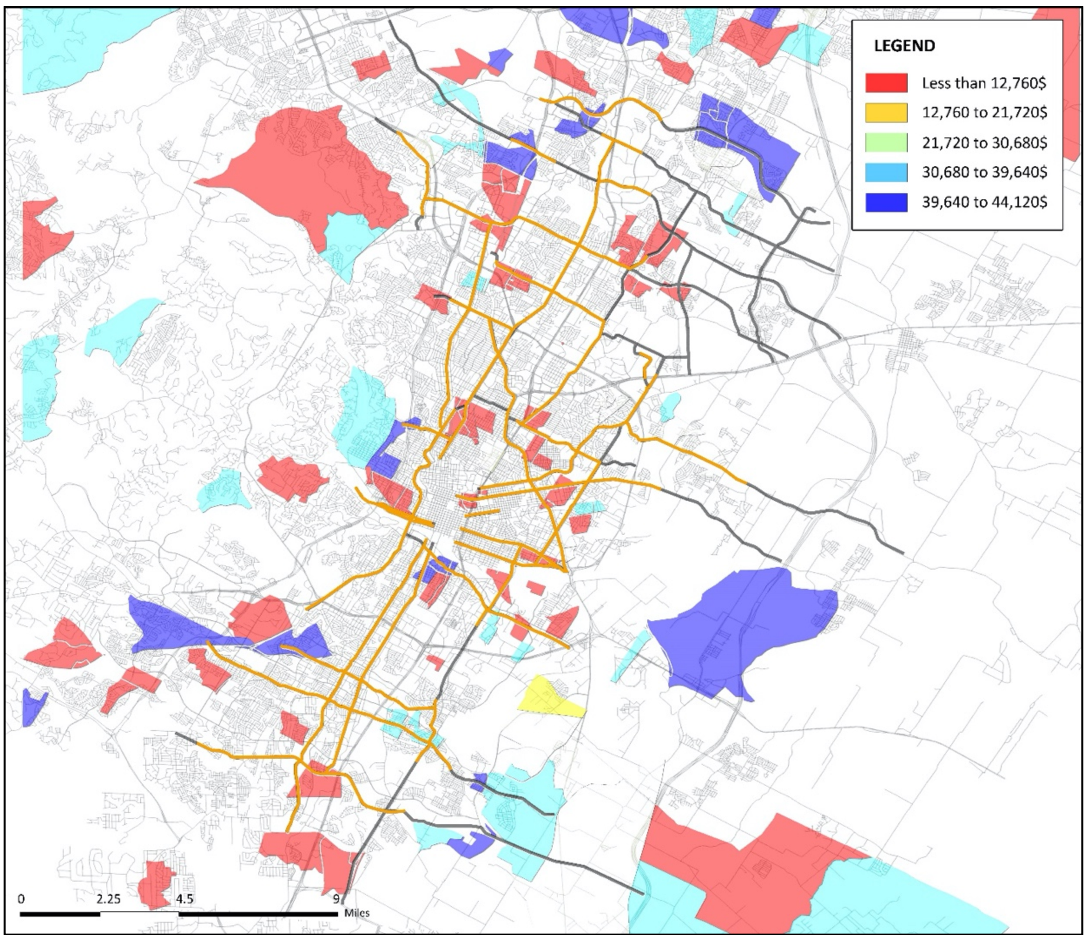


Figure 12 Public transit accessibility level of households below the federal poverty line within the Imagine Austin corridors (Source: American Community Survey).

The highest concentrations of households under the federal poverty line are not exclusive to certain neighborhoods in Austin. Figure 12 shows that geographic location largely determines whether access to public transit is possible. In central Austin, for instance, all the recorded low-income households make less than $12,760 a year and are situated within walking distance from public transit. The farther these households are from central Austin, the less physical transit access they have, a growing issue confronting Austin's population growth, as shown in Figure 1.

Physical proximity to public transit is based on the distance an individual is willing to walk, generally regarded as 500 meters to access public transit (*31*). The distance changes from urban to rural settings, where people are more willing to walk, to reach 1,000 meters in an urban setting (*32*). However, it is highly recommended to place bus stops and transit lines 500 meters from communities for patrons with limited mobility. By measuring the distance between transit-accessible corridors and high concentrations of vulnerable households, restricting the scope to only the Imagine Austin corridors renders 80% of the corridors more than 1,000 m away and physically inaccessible (Figure 13). The study should be repeated with the entire CapitalMetro (or at least MetroBus) system to reach a generalizable result.

Although physical proximity is important, equitable access to public transit cannot be measured solely by the distance walked to a bus stop. Economic variable should also be considered to determine how accessible bus services are for vulnerable households and communities of color. Even though certain vulnerable households are geographically near corridors with public transit, whether they can truly afford it remains integral to their access. For a household with an average of five people and an income less than $44,000, the cost of transportation can become hefty. Table 6 details the cost of public transit for five income brackets under the Federal poverty line. A threshold of 5% per person is considered acceptable, while any costs beyond that become too expensive to withstand for the household (*26*). Table 6 shows that the commuter service is currently too costly for all the examined income groups. With a $3.50 fare (*33*), this specific bus service is not realistically accessible by Austin's low-income households. For the local service bus, the cost exceeds 5% of income for all households with an income of less than $21,720. Figure 14 shows, in red, all the Imagine Austin corridors with financially inaccessible public transit for economically vulnerable households and a table of values can be found in Appendix Table 11. The city of Austin has made great efforts towards racial and economic inclusion, yet many households still find themselves unable to access a reliable public transit.

Table 6 Transportation costs for households below the Federal poverty line

Median household income	Local service	Commuter service
Less than 12,760$	11.8	33.2
12,760 to 21,720$	7.0	19.5
21,720 to 30,680$	4.9	13.8
30,680 to 39,640$	3.8	10.7
39,640 to 44,120$	3.4	9.6

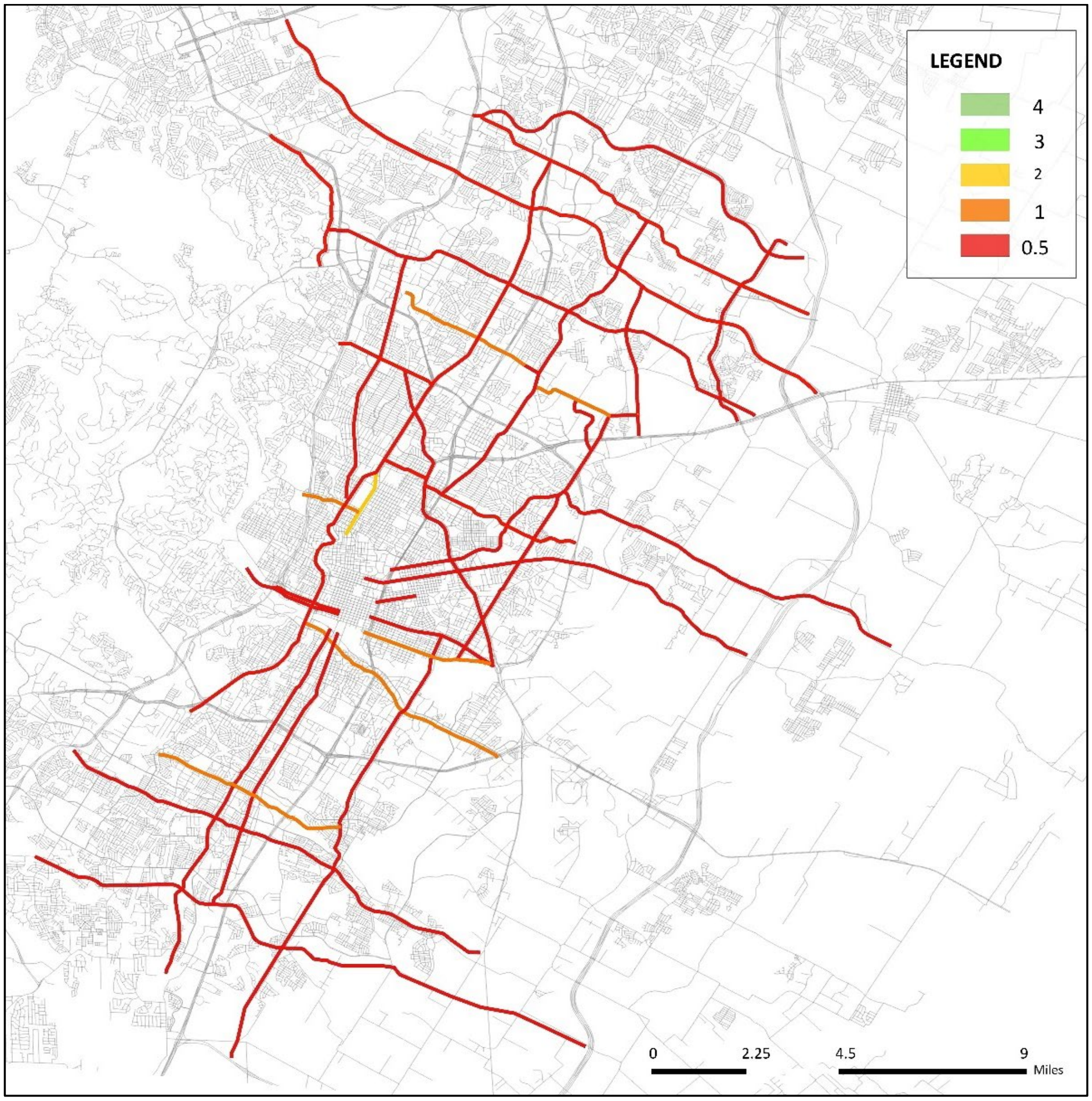


Figure 13 Corridors with bus lines more than a 1000m away from vulnerable households

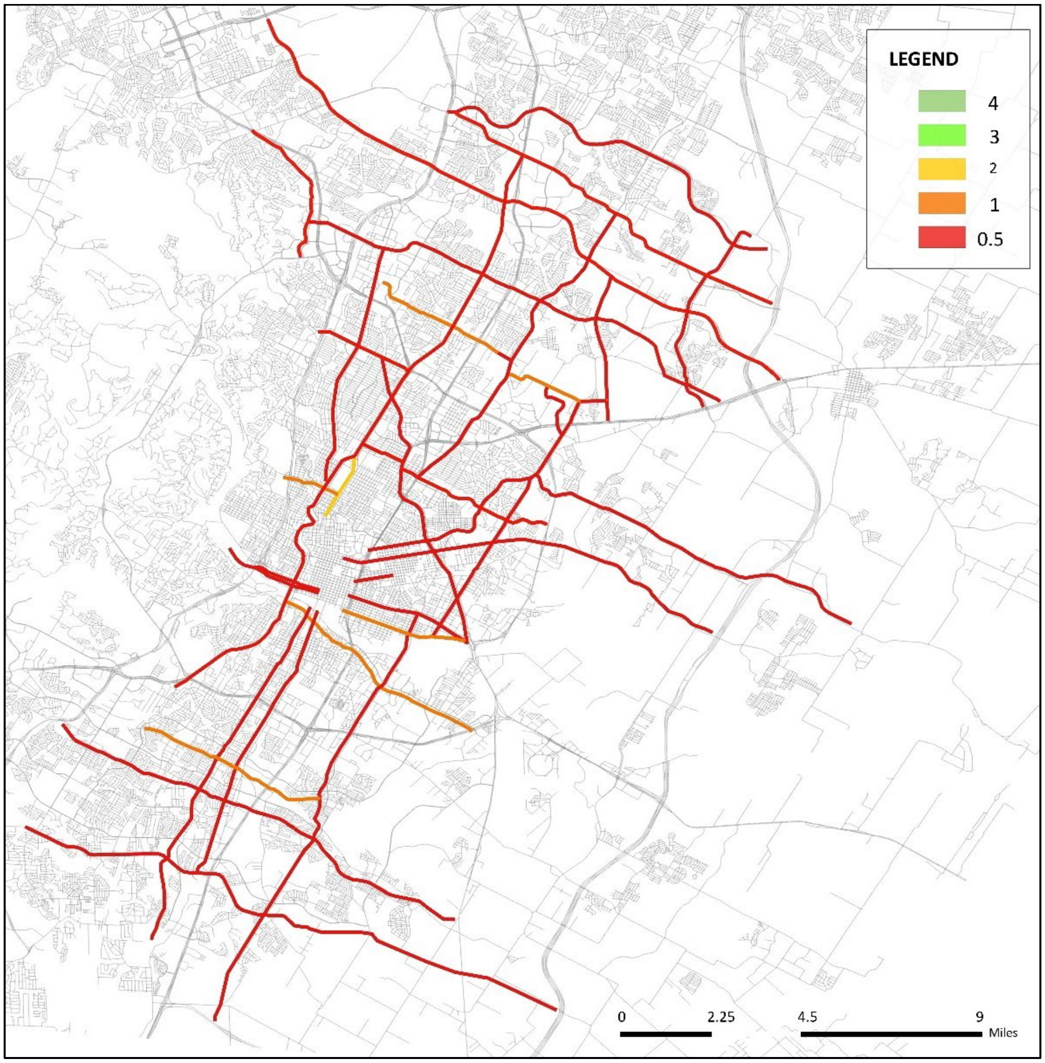


Figure 14 Corridors with bus services that are too expensive for vulnerable households

Identify and Prioritize Adaptation Options

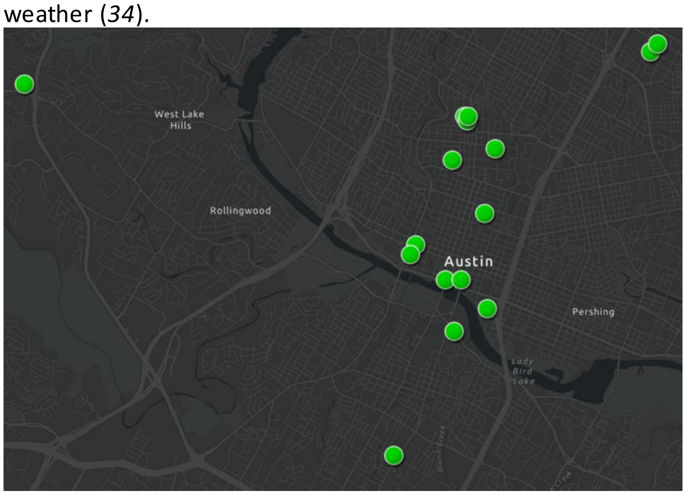
It is important to consider a diverse range of adaptation strategies to ensure that possible solutions can address the vulnerabilities within the target area. Adaptation strategy types include (1) built infrastructure measures, including infrastructure construction , permanent or temporary infrastructure relocation, development of climate-resilient design standards and retrofits, and green infrastructure; and (2) adaptive management strategies, which track hazards, impacts, costs, and the effectiveness of adaptations and post-disaster response to inform adaptation categories. Disciplined tracking of climate or weather impacts serves as an interim adaptation strategy to help develop a quantitative basis for investments and/or reimbursements. The identified adaptation options are prioritized based on a time-frame prioritization strategy depending on the urgency of adoption and the period of implementation.

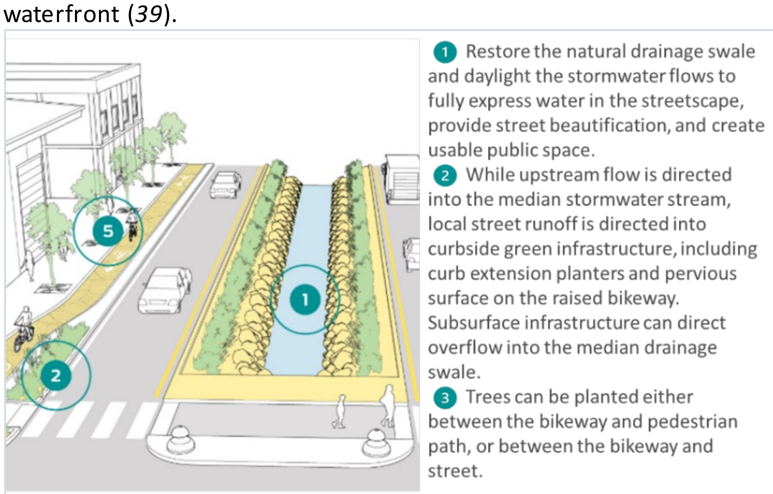
Built Infrastructure Measures

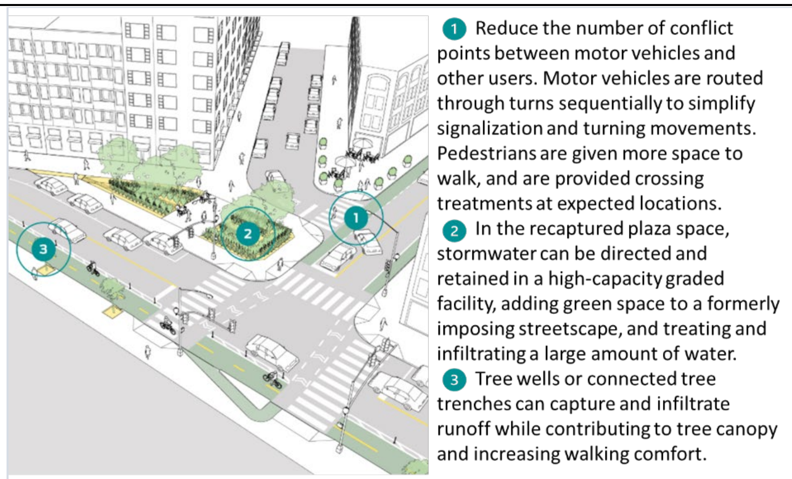
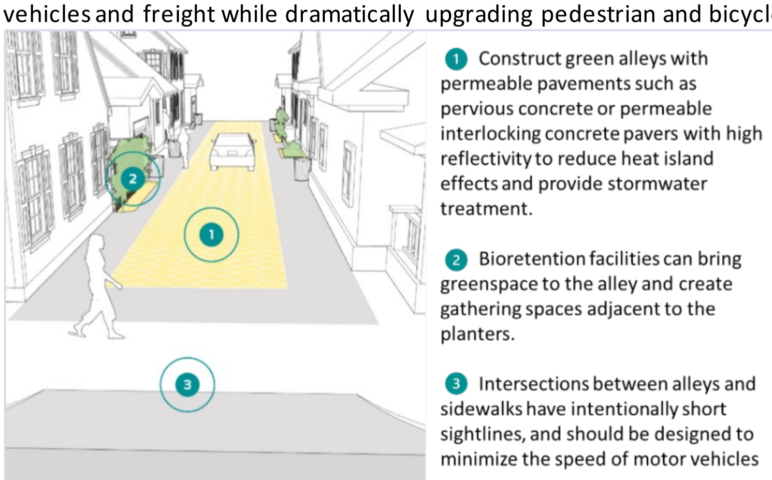
To incorporate the vulnerability assessment results into adaptation strategies, options are phased into three-time frames: short-term, medium-term, and long-term. Short-term adaptation options include building green roofs or cool roofs, cool pavement, and rain gardens; the medium-term adaptation options include building storm water greenways, reclaiming intersections, and green alleys; while the long-term option is the relocation of major facilities currently in flood zones. Table 7 highlights the short, medium, and long-term options and how they address the stressors and shocks of flooding, wildfire, urban heat island, and inequity in transportation.

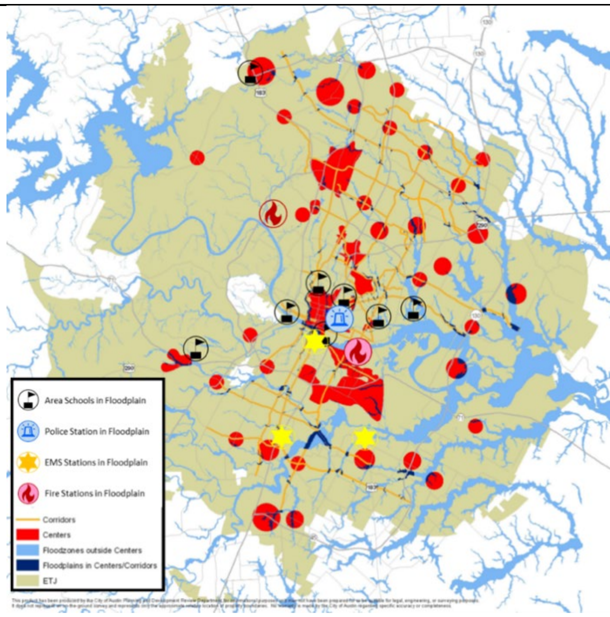
The short-term and medium-term adaptation options directly address acute shocks and the urban heat island effect. They would also create an indirect positive externality on transportation equity. Low-income communities living in hazard areas with high exposure to flooding and wildfires are also the most vulnerable to heat-related illnesses due to poor housing conditions, including lack of air conditioning and small living spaces, and inadequate resources to find alternative shelter during a heatwave. Therefore, the phased adaptation options in Table 7 would make some progress to addressing system inequities.

Table 7 Built infrastructure adaptation options

Adaptation Options	Description	Stressor/Shock Addressed			
		Flooding	Wildfire	Urban Heat Island	Inequity
Short-term: Enhance existing infrastructure					
Green Roof / Cool Roof	Green (vegetated) roofs add value to structures, providing insulation, green space, a sanctuary for wildlife, a place for ecological education and food production. Green roofs can reduce stormwater runoff. Cool roofs (coated in a reflective material to eliminate heat buildup) can remain approximately 50° to 60°F cooler than traditional materials during peak summer weather (*34*).  Figure 15 Green Roof Inventory Map (Source: Green Roofs in Austin)	o	o	o	

	The city of Austin created an inventory of green roofs in August 2011 that has been regularly updated on the website. Millions of square feet of roof space could be utilized in the Central Business District for green/cool roofs, supporting and improving quality of life, the natural environment, sustainability, and unique community character (*35*)				
Cool Pavement	The term “cool pavement” denotes materials and construction techniques selected to reduce the absorption, retention, and emittance of solar heat. Cool pavement has the following benefits (*36*): o Reduces the heat island effect o helps to lower air temperatures, improve air quality, and quality of life during the heat of summer o Keeps surfaces more comfortable to the touch o Promotes cooling, through increased air filtration and evaporation. o Porous/permeable paving reduces stormwater runoff and the need for stormwater retention. o Reduces heat released back into the air at night. Temperatures get hotter in the city than in rural areas because the built environment (highways, buildings, parking lots, etc.) absorbs and retains far more heat than the natural environment. As Austin becomes more built up, this “heat island effect” intensifies. Not only does the whole urban core gets hotter, but specific hot spots – like a blacktop parking lot – can become intolerable (*37*). New and renovated corridors can utilize cool pavement to prevent generating urban heat, as well as to provide more comfortable places for residents.	o	o	o	
Rain garden	A rain garden is a low area that absorbs and filters rainwater runoff from roofs, sidewalks, and driveways. Rain runs off the hard surfaces, collects in the shallow depression, and slowly soaks into the soil. They are usually planted with colorful native plants and grasses (*38*).	o	o	o	
Medium-term: Build new infrastructure					
Storm Water Greenway	Cities around the world are restoring urban streams that had previously been decked or canalized, often with a roadway on top. Streets-to-streams projects are transformative: opportunities to implement high-performance water quality management practices while creating inviting and active public spaces. These spaces can become destinations in themselves, giving people in cities access to a new kind of waterfront (*39*).  *(Source: NACTO)*	o	o	o	
Reclaimed Intersection	Complex or multi-legged intersections are common in non-grid street networks, or where two grids at different orientations come together. Multi-legged intersections can be reconfigured to improve access for people walking and bicycling while capturing large amounts of surface area to gather and infiltrate runoff (*40*).	o	o	o	

	 *(Source: NACTO)*				
Green Alley	Urban alleys, often ignored or considered dirty or unsafe, can be designed to play an integral role in street networks, provide service access, and recapture space for the public realm. Integrating green stormwater infrastructure into alleys transforms negative spaces into community assets that also serve mobility functions, improving the ease of access for service vehicles and freight while dramatically upgrading pedestrian and bicycle accessibility (*41*).  *(Source: NACTO)*	o	o	o	
Long-term: Relocate existing infrastructure					
Locating major facilities outside the flood zones	The City of Austin planning area has experienced high growth, resulting in greater flood losses due to extensive development in this area. During periods of heavy rainfall, homes, businesses, and other critical facilities located in the floodplain remain at risk of flash flooding due to the generally flat terrain of Travis County. During flood events, lower-income communities are the most affected by the abnormal operations and service delivery as they often lack an alternative way of transportation. In the long-term, the relocation of critical facilities outside the floodplain may be necessary to ensure sustainable and equitable service delivery for the entire community.	o			o

	 Figure 16 Central Austin and critical facilities vulnerable to flooding The City of Austin critical facilities located in the floodplain (*Figure 16*) include Travis County State Jail, Noel Grisham Middle, The Griffin School, Regents School of Austin, Ace Academy, Fire station/EMS Station #24, EMS Station #28, EMS Headquarters, Fire Station #107, Fire Station #31, Austin Fire Department Wellness, and Police Headquarters (*4*).				

Adaptive management

An adaptative management plan suggests options regarding personnel, resources, equipment siting, asset condition, vegetation, traffic, and public transportation. In this plan, each option is framed into short-term, medium-term, and long-term schedules and the implementing department is identified to clarify responsibilities throughout the process.

Table 8 Adaptive management adaptation options

Adaptation management	Response with Time Frames	Implementing Department
Increased frequency of extreme events may require **additional personnel** to monitor, control, report, and respond to events.	**Short-term:** Train existing personnel on the potential impacts of climate change and how this may affect their roles and responsibilities. **Medium-term:** Increase the availability of contract staff to assist during extreme events. Develop memorandums of understanding (MOUs) with other agencies for equipment and staff sharing during extreme weather events. **Long-term:** Hire additional staff to keep pace with increasing transportation systems management and operations (TSMO), maintenance, and emergency management needs.	TSMO, Maintenance, Emergency Management
Extreme events and long-term climate changes can affect **resource requirements**. For example, temperature increases can grow annual pavement maintenance costs.	**Short-term:** Increase cost tracking to respond to specific extreme weather events. Establish a "rainy-day" fund for unexpectedly bad years. **Medium-term**: Revise the budgeting process and protocols to account for recent trends that may diverge from the historical baseline.	Maintenance

	Long-term: Work with meteorologists and climatologists to develop a process for taking anticipated future events into account while budgeting and planning.	
Siting equipment in areas that will be impacted by flooding or other climatic events may damage the infrastructure.	**Short-term**: Consider Federal Emergency Management Agency (FEMA) flood zone maps (after confirming the relevant local maps are up to date), National Oceanic and Atmospheric Administration (NOAA) climate maps, or other similarly informative maps when siting and designing sites for equipment. **Medium-term:** Include consideration of future stressors (e.g., accelerated sea-level rise) when making decisions about siting equipment. Consider changes (e.g., increasing freeboard requirements) to accommodate more intense rainfall events. **Long-term:** Shift investments to mobile data sources (e.g., citizen reporters, snow patrol reporting, mobile probes), which are less likely to end up in harm's way.	TSMO, Maintenance
Climate stressors can lead to increased **asset deterioration**, requiring more frequent inspections (which can be expensive and time-consuming).	**Short-term:** Track impacts of weather events to identify "hot-spots" that may require an increased rate of inspection. **Long-term**: Use detailed, downscaled climate models to determine portions of the state (or region) that are anticipated to have greater shifts in climate. Dedicate increased inspection resources to those areas.	Maintenance
Increased rain (in some parts of the country) paired with increased temperatures can lead to accelerated **vegetation growth and death**. The dry fuel that remains poses **wildfire hazards**.	**Short-term**: Increase vegetation control within the existing right-of-way. **Medium-term:** Plant more drought-tolerant vegetation that is less likely to provide fuel for wildfires.	Maintenance
Flooding or other extreme weather events may cause long-term **disruptions to traffic** (that run counter to the current understanding of demand-supply relationships in a system).	**Medium-term**: Develop a plan for traffic maintenance during weather events of various intensities (including non-severe, recurrent weather). In some cases, this may require significant detours and wide-area communications to support adequate traveler information. Develop plans for culvert clearing and other maintenance or asset management activities. **Long-term:** Create after-event reports that assess what worked and what did not. Revise plans based on lessons learned.	TSMO, Maintenance
Mitigate inequitable access to transit for vulnerable communities.	**Short-term**: Adjust transportation fares for households below the poverty threshold or appropriately decided income level. Examples include the TAP program from MetroTransit in the Twin Cities, Minnesota. **Medium-term:** Plan for bus line extensions within vulnerable neighborhoods. **Long-term:** Introduce public transit lines to all Imagine Austin corridors.	TSMO, Public transportation agency

Adaptation strategy prioritization

Built infrastructure prioritization includes four criteria. 'Address vulnerability' measures whether the options address the shocks and stressors identified from the vulnerability assessment. The 'User' variable checks whether the suggested options can improve the user's quality of life by supporting public transportation or improving the pedestrian environment. The 'Impact' variable prioritizes options that can maximize the economic benefits and minimize the environmental costs. Lastly, 'Feasibility' characterizes options by how much technological and personnel inputs they require, as well as how many stakeholders and agencies require consultation.

While the evaluation metrics are a useful tool for informing the decision-making process, they should not the basis for decision making. It is critical to reflect the input of the staff who work on these programs daily, the officials who understand the needs of the community, and the community members themselves.

Table 9 Built infrastructure prioritization metrics

		Address Vulnerability				User		Impact		Feasibility	
		Flooding	Wildfires	UHI	Inequity	Improve pedestrian environment	Supports public transportation	Minimize impact on environmental resources	Maximize the economic benefits	Involve fewer stakeholders	Requires less technology and personnel input
Short-term	Green Roof/ Cool Roof	x	x	x				x			x
	Cool Pavement	x	x	x		x		x		x	x
	Rain Garden	x	x	x		x		x		x	x
Medium-term	Storm Water Greenway	x	x	x		x		x		x	
	Reclaimed Intersection	x	x	x		x	x	x	x	x	
	Green Alley	x	x	x		x	x	x	x	x	
Long-term	Relocation	x	x		x				x		

Incorporating Assessment Results in Decision Making

Resilience is a vital decision-making factor in the transportation planning of Austin. The *CAMPO 2040 Regional Transportation Plan* addresses the impacts of extreme weather on the transportation system to minimize exposure and reduce risk to climatic hazards (*10*). To improve the decision-making process, it is crucial to integrate assessment results at each stage. The four decision-making stages include: regional vision and goals, long range transportation plan, project evaluation and prioritization, and project development.

Regional Vision and Goals. At this stage it is necessary to establish goals and performance measures related to resilience (e.g. system reliability, sustainability, and reduced delays). This should also include an investment plan that outlines how to achieve the objectives laid out in the vulnerability assessment.

Long Range Transportation Plan. It is critical to use assessment results to identify strategies and investment scenarios during development of statewide and metropolitan long-range transportation plans. The CAMPO in Austin has integrated its vulnerability assessment results into its *2040 Regional Transportation Plan*, which identifies five extreme weather events: floods, droughts, extreme heat, wildfires, and frozen precipitation (*10*). However, it lacks and assessment that analyzes the interdependencies within and across infrastructure systems and climatic hazards. There is an opportunity to integrate an equity analysis as vulnerable communities are the most exposed to stressors. Lastly, it is recommended to use the assessment results to create multiple investment scenarios to proactively increase the transportation system's climate resiliency. The plan should include an objective to increase the multimodal transportation system's security and resiliency, with an associated performance measure on adaptation, not only on mitigation.

Project Evaluation and Prioritization. Climate change adaptability can be achieved when resilience is used as a factor for project prioritization. The result from the vulnerability assessment can delineate locations where communities are the most exposed to acute shocks and chronic stressors. The results from the assessment can be further utilized to screen new project plans. Lastly, the responsible agency should prioritize the projects that serve the communities most at risk.

Project Development. The assessment result can be fully utilized in the project development process by helping project planners to identify vulnerability issues and adaptation solutions early in the project planning process. The project planner should reflect the voices of the communities identified as the most vulnerable to shocks and stressors from the assessment.

Conclusion

Austin's rapid growth is accompanied by pressing challenges that deteriorate its communities, infrastructure, and development. The fourth industrial revolution wherein smart technologies are used to connect people and infrastructure in ways that were not previously possible can lift vulnerable populations from poverty (*42*). This is possible with smart transit that is more accessible and connects communities in new and dynamic ways (*43*). In becoming a truly smart city, Austin must tackle acute shocks and chronic stresses in ways newly available due to technology adoption and community partnership. It is clear that the City of Austin is aware of and committed to mitigation and adaptation measures that will enable them to become more resilient. Yet, it is also clear that the city may need to establish a new framework and institutions to achieve this. The interdependency of infrastructure systems and the complexities of climate change impacts requires a "new and more integrative level of sophistication in infrastructure conceptualization, design, and management" (*44*). This can be facilitated by the incorporation of smart technologies into infrastructure systems which can allow for precise and accurate measurements throughout the lifespan (*45*). Smart technology adoption can be streamlined and integrated across departments and the city through shared data, inter-departmental partnerships, and effective communication. This will enable a robust operation and management system that can highlight vulnerabilities in real-time, which is crucial as unpredictable climatic hazards become more frequent and extreme.

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Appendix

Limitations

When conducting the buffer analysis, it came to light that there may be some errors in the original data, as shown in *Figure 17*. The corridor shapefile did not always precisely follow the roadways, so the buffer may not accurately overlap with other GIS layers. This should only pose small errors in the results and can be remedied by redrawing the corridors.

Figure 17 Example of a Limitation with the GIS Buffer

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Supplementary Tables

Table 10 Reports and Plans addressing floods, wildfires, urban heat island effect, population growth, and inequity.

Year	Plan	Acute Shock		Chronic Stressor			Notes
		Floods	Wildfires	Urban Heat Island	Population Growth	Inequity	
2014	Toward a Climate Resilient Austin	x	x		x	x	Lack of data focuses largely on a conceptual framework of climate change mitigation
2014	Climate Change Projections for Austin						General predictions of temperature and precipitation
2015	Austin Community Climate Plan	x	x	x	x	x	Limited analysis of inequity
2015	Central Texas Extreme Weather and Climate Change Vulnerability Assessment of Regional Transportation Infrastructure	x	x	x	x	x	Detailed risks and hazards but not solutions
2016	Live from Austin, Texas: The Smart City Challenge			x	x	x	Acute shocks are neglected
2016	Austin Hazard Mitigation Plan	x	x		x	x	Limited analysis of population growth
2016	Watershed Protection Master Plan	x			x		No reference to smart technologies
2018	Austin Strategic Direction 2023				x	x	Acute shocks are neglected
2018	Climate Resilience Action Plan for City Assets and Operations	x	x				Superficial assessment of vulnerabilities
2018	Imagine Austin Comprehensive Plan	x		x	x	x	Wildfire is not addressed
2019	Texas Asset Management Transportation Plan	x			x		Flooding is mostly addressed in terms of hurricanes
2019	Wildfire preparedness audit report		x			x	Does not account for population growth in the wildland-urban interface.
2019	Long-Range Capital Improvement Program Strategic Plan	x			x	x	Lack of details on how smart technology can be invested in and advanced in capital projects.
2019	Austin Strategic Mobility Plan	x			x	x	Vague targets and indicators

Table 11 Percentage of vulnerable households along Imagine Austin corridors for whom transportation costs more than 5% of income

ID	Corridor Name	Households covered by public transit (%)	Score
1	Howard Lane/Gregg	0.0	-
2	Parmer Lane	0.0	-
3	Jollyville Road	0.0	-
4	Anderson Lane	0.0	-
5	51st Street / Airport / 53rd Street	18.7	4
6	35th/38th	18.1	4
7	MLK	15.8	4
8	Riverside Drive	9.9	4
9	Stassney Lane	0.0	-
10	William Cannon Drive	0.0	-
11	Slaughter Lane	9.1	4
12	East Cesar Chavez	21.4	4
13	East 7th St	42.4	3
14	5th/6th Streets/Lake Austin Blvd	16.2	4
15	Loyola Lane	0.0	-
16	Braker Lane/Blue Goose	17.3	4
17	Rundberg Lane/Ferguson	22.1	4
18	Burnet Road	0.0	-
19	Lamar Boulevard	2.7	4
20	Cameron Road/Dessau	12.3	4
21	Manor/Springdale/Cameron	4.2	4
22	Pleasant Valley	6.5	4
23	South Congress	4.1	4
24	South First	5.8	4
25	Springdale	7.8	4
26	Airport Blvd	6.7	4
27	Wells Branch Parkway	0.0	-
28	11th	0.0	-
29	12th	0.0	-
30	Wells Branch Parkway East	0.0	-
31	Harris Branch Parkway	0.0	-
32	Arterial A	0.0	-
33	Rundberg Connector	0.0	-
34	Tuscany Way North	0.0	-
35	Guadalupe	65.2	2