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A multi-criteria approach to building resilient neighborhoods through green space investments in Sacramento

Luis E. Montes
University of San Francisco, lemontes33@gmail.com

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Luis Montes

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Luis Montes [Date]	Stephanie A. Siehr [Date]

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Abstract

The consequences of climate change and urbanization have increased heat, air pollution, and flood risks in urban areas. Green spaces—parks, trees, trails, and gardens—are multifunctional solutions that help communities adapt to these various climate vulnerabilities, promoting urban resiliency through the socio-ecological service they provide. Yet, low-income communities and neighborhoods of color are often deprived of these services. As a result, this study utilizes a multi-criteria analysis to assess a variety of social, climate, and green space indicators in North and South Sacramento, two racially diverse and historically marginalized communities, to recommend more robust green space implementation strategies. Priority areas are identified along the northeastern and eastern edge of North Sacramento and within the central area and eastern boundary of South Sacramento, concluding that both communities could benefit from the additional park and tree investments to meet the area's unique climate needs. Recommendations to maximize green space benefits include: 1) considering multifunctionality in all green space implementation projects 2) further assessing priority areas to identify appropriate locations for future green spaces 3) effectively and equitably engaging with community stakeholders 4) utilizing GIS to better integrate both social equity and climate data 5) consider environmental justice concerns and basic needs of the communities 6) designing green spaces to meet the unique climate and social needs of the areas. These recommendations will serve as a model to direct City of Sacramento decision-makers and planners to consider social and ecological variables in future green space projects in North and South Sacramento.

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1.0 Introduction

Green spaces are multifunctional solutions that effectively integrate ecological functions to support urban life. There are several terms that define green spaces (i.e., green infrastructure, urban forest, urban greening), described as vegetation—trees, trails, parks, and gardens—which provide both cultural and ecosystem services that impact human well-being, as well as help cities adapt to climate impacts (Nesbitt, Lorien et al. 2017). Green spaces promote public health for all life stages: reducing infant mortality, supporting expecting mothers throughout their pregnancy, and promoting physical activity in children through late adulthood (Nesbitt et al. 2017, Douglas et al. 2017). They are also effective climate mitigation and adaptation tools because they increase humidity and airflow, which offset the heat island effect experienced in cities (Mathey et al. 2011). The co-benefits green spaces offer are robust, as they address climate vulnerabilities while also influencing social justice issues, social cohesion, and economic growth in communities (Raymond et al. 2017). Overall, green spaces provide an integrated approach for improving the environmental and ecological quality of urban areas and can help meet important sustainability and resiliency goals for cities (Heidt and Neef 2008).

Still, climate hazards are anticipated to become more frequent and extreme, presenting numerous challenges for urban communities and city infrastructure (Revi et al. 2014). Cities host half the world's population and are epicenters of economic activity; by 2050, it is expected that two in three people will reside in urban areas (Hunter et al. 2019). This will translate to a 2.5-billion-person influx into cities by 2050 (McDonnell Mark and MacGregor-Fors Ian 2016). Increased urbanization and rapid migration have challenged policymakers and urban planners to develop effective solutions that address associated risks and anticipated climate impacts (Revi et al. 2014). Climate hazards such as extreme heat days, precipitation changes, sea-level rise, and wildfires challenge a city's economy, ecosystems, and public health (Safeguarding California Plan 2018). In response to these challenges, local and state governments are using green space to meet local climate action and statewide emergency goals that build more climate-resilient cities (Safeguarding California Plan 2018).

What makes a resilient city? According to the City Resilience Index by Arup (2017), city resilience is "the capacity of cities to function, so that the people living and working in cities – particularly the poor and vulnerable – survive and thrive no matter what stresses or shocks they encounter." The principle of city resilience continues to gain momentum in public discourse, research, and policy initiatives due to its flexible framework and bridging capabilities to include multiple stakeholders (Meerow and Newell 2019). Resiliency is the primary goal of climate adaptation strategies that aim to identify approaches that strengthen socio-economic systems to reduce vulnerabilities and moderate the harmful impacts of climate change (Ramyar 2017). Efforts to build resilient cities and better adapt to future climate risks are essential to address climate change and protect vulnerable populations who are often most susceptible to these impacts. Furthermore, city resiliency is a system-based approach, balancing both cultural and ecological factors alongside social networks so that in the face of a shock or disturbance, the usual function can be maintained or quickly returned to normal (Meerow and Newell 2017). As the severity of climate impacts continues to grow, providing local investments in green spaces will become increasingly important.

However, there are challenges to building resilient cities due to the natural complexity of urban systems. For example, an urban area reflects many interconnected and overlapping components (i.e., governance networks, networked material, urban infrastructure, and socio-economic dynamics) (Meerow and Newell 2019). Figure 1 highlights the complexities and multi-leveled dynamics which require stakeholder involvement to quantify tradeoffs and identify priority areas for planners and policymakers (Meerow and Newell 2019). While green spaces are just one component of urban infrastructure, they are essential links that provide numerous benefits to society.

An integrated system, like a city, requires equally integrated green spaces that incorporate both social factors (i.e., human health and well-being) with efforts to protect biodiversity and adapt to climate change. This method is more commonly known as a Nature-based solution intended to build resiliency through cost-effective approaches that provide social, economic, and environmental benefits (Raymond et al. 2017). A nature-based solution is multi-sector oriented and assesses important biodiversity and climate factors and their relationship with social issues (Raymond et al. 2017). This aligns with the definition of urban resilience and green space implementation because both require social, cultural, and ecological factors in order to provide holistic solutions and avenues for stakeholder collaboration (Raymond et al. 2017, Meerow and Newell 2017).

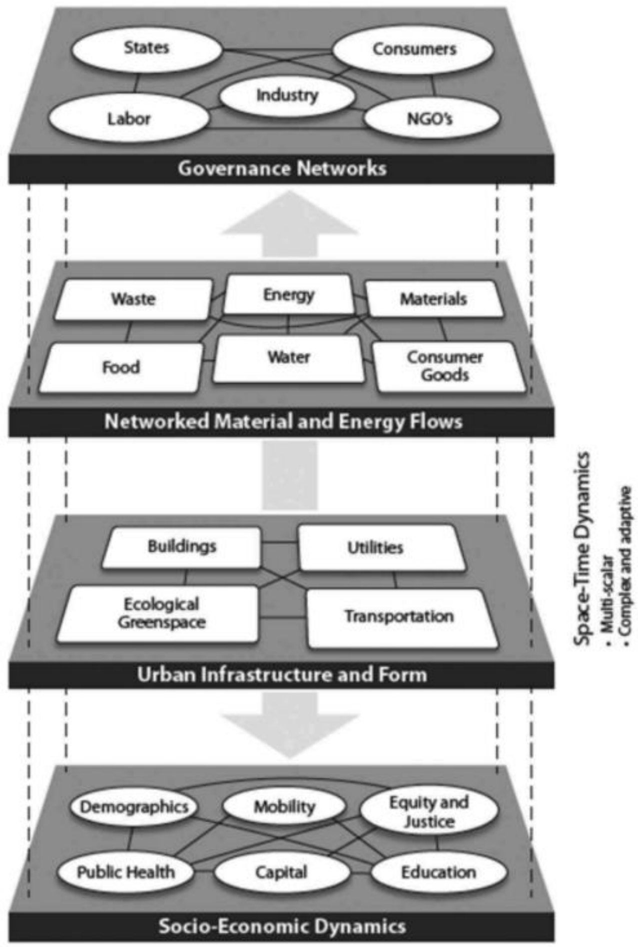

Figure 1: A conceptual model that depicts the complexity of urban systems (Meerow and Newell 2019)

Due to their integrated benefits, urban green spaces can be effective investments that uplift communities that have been historically marginalized due to income or race. Yet, their distribution across cities, environmental service delivery, and green space quality favor affluent and white communities (Rigolon et al. 2018, Liotta et al. 2020). Consequently, a deprivation of green spaces is experienced in disadvantaged black and brown neighborhoods with lower socioeconomic statuses, depriving them of the many benefits urban green spaces provide (Dai 2011). As the urban population and risk of climate disasters increase, green spaces should continue to be accessible to every city resident, especially those who have been historically ignored.

1.1 Motivation for research

Sacramento is not exempt from a history of racist laws and policies that have led to more segregated communities and disproportionate investments in those neighborhoods. An example that continues to impact Sacramento today is redlining. In the 1930s, Sacramento was unwelcoming to Black and brown communities in predominantly white residential areas (Hernandez 2009). As a result, Sacramento actively excluded Black and other non-white populations from predominately white neighborhoods, which impacted communities of color well beyond its abolishment after the 1968 Fair Housing Act (Hernandez 2009). There is a correlation between historically redlined areas and loan denials in 2004 among Black and brown homebuyers who were pushed to accept sub-prime loans with higher interest rates, reinforcing harmful economic and racial injustices (Hernandez 2009). Black communities continue to be negatively affected by policies and unfair disadvantages due to redlining. This highlights a need for increased community-based investments to restore and rebuild neighborhoods.

Green spaces can be an effective way to address some of the inequities that communities continue to experience. However, Sacramento's green space access and distribution is an area of improvement, as many historically marginalized communities continue to lack equitable access. According to The Trust for Public Land, Sacramento residents in communities of color have 48% less access to park space per person than the city median and 63% less than those in white neighborhoods, as shown in Figure 2 (ParkScore - Sacramento 2018). Regarding socioeconomic status, Figure 3 shows that residents in low-income communities have less than 10% of park space per person than the city median and 31% less than communities in high-come areas (ParkScore - Sacramento 2018). Consequently, in the City of Sacramento, race and income appear to influence an individual’s access to high-quality parks. These numbers reflect a more extensive study that determined that cities with large Latino and Black populations experienced lower quality parks than cities with higher median incomes and lower percentages of non-Hispanic black and Latino residents (Rigolon et al. 2018). The City of Sacramento is racially diverse, yet, as we can see, there is an opportunity for restorative justice efforts in Sacramento to address the inequitable distribution of parks in the city.

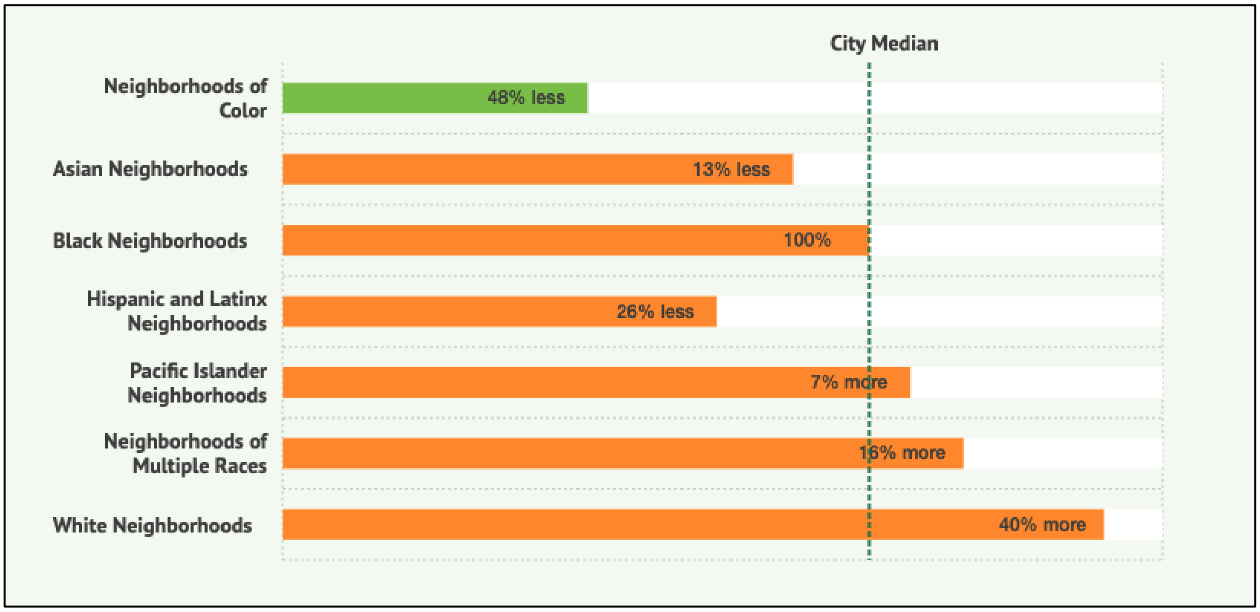

Figure 2: Park space access per person by race or ethnicity in Sacramento (ParkScore - Sacramento 2018)

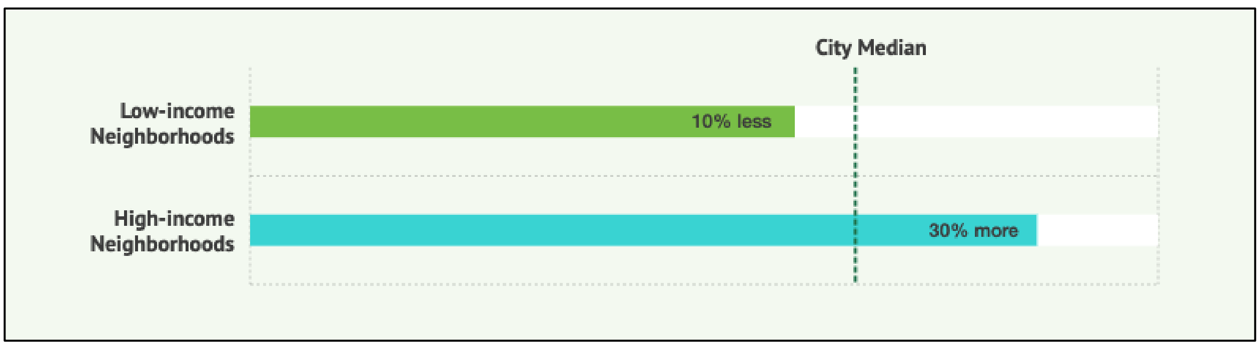

Figure 3: Park space access per person by income in Sacramento (ParkScore - Sacramento 2018)

1.1.1 Physical and phycological benefits

Urban green spaces are fundamental components of cities because they promote physical, mental, and social health and well-being (Nesbitt et al. 2017). They provide a sense of community for residents and an opportunity to develop community social ties that promote cohesion (Douglas et al. 2017). Furthermore, urban green spaces help individuals connect with nature, leading to healthy behaviors that benefit prenatal development (i.e., reducing maternal stress, noise, exposure to pollutants, and temperatures) and support individuals well into late adulthood (Douglas et al. 2017). Consequently, urban green spaces have gained popularity as a solution due to their connection with urban planning and the ability to provide environmental services that support healthy lifestyles (Douglas et al. 2017, Meerow and Newell 2019).

Green spaces like parks and trails increase access to nature and encourage more physical activity, leading to healthier decisions and outcomes for users (Hunter et al. 2019). This is increasingly important as more children are impacted by Nature-deficit disorder due to reduced time spent outdoors (Douglas et al. 2017). The physical health benefits of urban green spaces (i.e., trees, parks, trails) are significant for children and are well defined. A study on low-income households in New York City confirmed that access to green spaces led to reduced obesity levels and more opportunities for physical activity, correlating with an 11-19% reduced risk of obesity (Douglas et al. 2017). However, the benefits are not limited to children. Green spaces also positively influence physical health in adults and senior citizens. Access to green infrastructure and space is linked to improving cardiovascular outcomes and reducing the risk of stroke and heart disease-related mortality (Douglas et al. 2017). Higher survival rates were noted among senior citizens who reported living near tree-lined roads, and a 6% reduction in mortality was observed in areas with higher greenness concentrations (Douglas et al. 2017).

There is also clear evidence linking access to green infrastructure and nature with improved psychological health. Increased physical activity associated with green spaces is positively correlated with mental health benefits (Nesbitt et al. 2017). More so, the presence of a tree or exposure to nature helps improve emotional health, manage stress, and promote mental wellness (Nesbitt et al. 2017). In children, there were observed improvements in hyperactivity and attention-deficient disorders. For example, children diagnosed with ADHD who went on a walk in a park were better able to concentrate than children who walked along downtown streets (Nesbitt et al. 2017). Limited access to green infrastructure can also lead to higher levels of depression or increased use of anti-depressant medication compared to areas with large amounts of green space (Nesbitt, L. and Meitner 2016).

1.1.2 Green space inequities

Green spaces are crucial for historically marginalized communities as green investments have the greatest marginal benefits in communities that need them most (Nesbitt and Meitner 2016, Nesbitt et al. 2017). This means that parks, trees, trails, and gardens provide the most significant benefits (i.e., reduced mortality and better health outcomes) in low-income areas or communities of color that already experience disproportionate health burdens (Nesbitt et al. 2017). However, it is important to note that the benefits of urban green spaces are not evenly distributed as race and socioeconomic status often determine the quality or accessibility of green spaces (Rigolon et al. 2018). Green spaces are more prevalent in white neighborhoods with high median household incomes than in communities of color or low-income status (Dai 2011, Rigolon et al. 2018). Furthermore, in cities where green investments are being made, they are often without prioritizing those most vulnerable or the immediate needs of residents. A study of green space distribution in Detroit used GIS and feedback from stakeholders to identify priority areas in need of urban greening, only to reveal that current and planned projects did not effectively address local climate vulnerabilities or the concerns made by stakeholders (Meerow and Newell 2017). This highlights a real problem as green space implementation should reflect the immediate needs of urban areas and the risk they are expected to experience.

The findings presented by Rigolon et al. (2018) assess how race and socioeconomic status might influence a city's overall ParkScore, a score that determines the quality of a city's park system in the top 99 most populated cities in America. The research compares social indicators (i.e., race and socioeconomic status) with park quality, accessibility, and distribution to recommend environmental justice-focused advocacy and highlight the importance of parks as a green investment (Rigolon et al. 2018). They find that more work needs to be done nationally to ensure equitable access and distribution of green spaces. Cities with predominantly high Latino or Black populations experienced the lowest Parkscores compared to cities with larger white populations. This emphasizes that, across the nation, investments and provisions of green spaces are not happening in low-income areas or communities of color (Rigolon et al. 2018). Meanwhile, cities with fewer Black and Latino populations and higher median incomes had the highest ParkScores and more park facilities and green spaces per acre (Rigolon et al. 2018).

City-specific case studies support Rigolon et al. (2018) findings. For instance, Black neighborhoods in Atlanta experienced the greatest disparities in the city, with a 50% reduction in access to green spaces than in white neighborhoods (Dai 2011). Furthermore, in the same study, accessibility was a problem for areas with high Black populations as they significantly lacked green space within a 25-min radius (Dai 2011). This is an issue as ParkScore recommends parks be a 10-min walking distance from every home (ParkScore - Sacramento 2018). Portland saw similar results, as areas that were more educated (i.e., some secondary or post-secondary education), wealthier, and white saw the highest level of urban forest cover (Nesbitt and Meitner 2016). As a result, the City of Portland has outlined a tree planting program in their Urban Forest Action Plan, which prioritizes neighborhoods of color and low-income communities; however, the success of this program was not noted (Nesbitt and Meitner 2016).

1.2 Research questions and objectives

This study aims to identify strategies that incorporate multifunctional components into green spaces to build more climate-resilient communities in areas that need it most. The scope of the study is in two locations, the North Sacramento and South Sacramento community, which will be defined later. This study encourages policymakers and urban planners to incorporate a multifunctional approach to green space implementation. One that considers social and environmental factors to build climate resiliency in historically marginalized communities, often deprived of green spaces. Census information, distribution of green space, and climate vulnerabilities will be reviewed to identify priority areas and support recommendations for future green space implementation in North and South Sacramento. Indicators to identify priority areas include park coverage, tree canopy cover, heat vulnerability, flood risk, and air quality. This study will review how these indicators connect with social indicators like socioeconomic status and race to advocate for investments in specific areas.

Below is my research question and sub-questions that outline the intentions for this project:

How can green space investments better incorporate multifunctional approaches to address socio-ecological vulnerabilities in historically marginalized communities?

Sub-Question 1

- How can green spaces be effective investments that create resilient cities?
  - Objective: Investigate green spaces and their ability to support local efforts to mitigate and adapt to climate hazards.

Sub-Question 2

- What is the importance of green spaces in communities of color or low socioeconomic status in Sacramento?
    - Objective: Highlight green space disproportionalities and investigate how they can be investments for historically marginalized communities.

Sub-Question 3

- What recommendations can be made to identify priority areas that promote the equitable implementation of green spaces in North and South Sacramento?
    - Objective: Make general recommendations that will serve as a tool to promote climate resiliency in marginalized communities.

2.0 Literature review: green spaces and resiliency

Several peer-reviewed research articles about green space distribution, application, and effectiveness were studied to support the direction of this study. The following section synthesizes the literature reviewed to provide context to the multifunctional climate benefits green spaces offer. The following section will focus on three climate benefits: the vital function green spaces have in adapting to extreme heat, air pollution, and flood risk. It is necessary to highlight these in order to support the methods, findings, and recommendations made later.

2.1 Multifunctionality

A local park provides a diverse range of services, like tall trees to provide shade, pervious surfaces to reduce flood risk, and vegetation to intersect pollutants while supporting residents' cultural needs. They are multi-functional in that they are a single strategy that provides solutions to multiple issues while also positively influencing people who have access to them. Green spaces improve the quality of life for residents within communities, providing several ecological, social, and economic services that influence how urban areas operate. Figure 4 highlights these interactions and the robust benefits green spaces can provide to urban residents. A wide range of ecosystem functions is observed, as green spaces can promote biodiversity, reduce run-off, filter pollutants, improve evapotranspiration, and reduce heat storage in buildings (Heidt and Neef 2008, Mathey et al. 2011). Therefore, they are important planning tools for helping communities mitigate future risks and build resilience in marginalized areas that need it most. (Heidt and Neef 2008) .

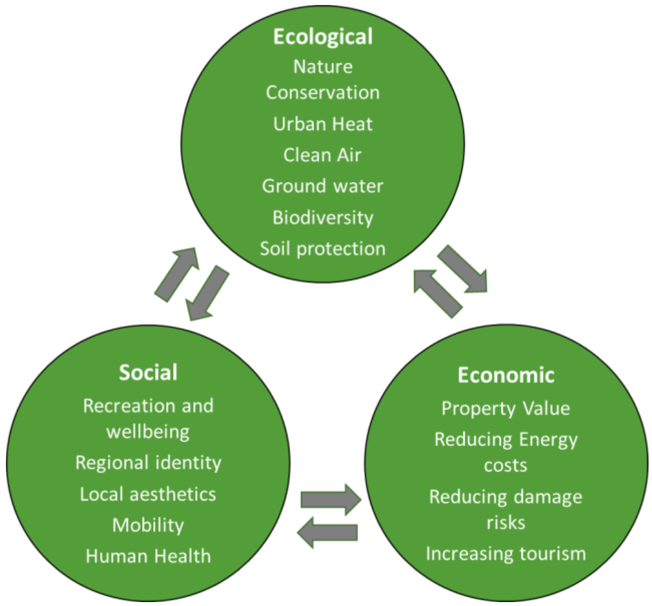

Figure 4: Urban green space influences social, economic, and ecological functions and their interactions with one another (Heidt and Neef 2008).

Green spaces provide an opportunity to connect cultural and social components with ecological services. Socially, green spaces provide a space for engagement that promotes diversity and social cohesion among various ethnic and cultural backgrounds (Hansen et al. 2019). Ecologically, they promote biodiversity and a diverse set of ecological functions and services to the surrounding community (Lovell and Taylor 2013, Hansen et al. 2019). This combination provides decision-makers and planners with a tool and opportunity to include multifunctional green space solutions that incorporate various strategies and provide numerous benefits.

In terms of building a resilient city, the concept of multifunctionality is an important adaptive strategy that supports public health and the well-being of a neighborhood (Lovell and Taylor 2013). For example, if planned correctly, a multifunctional green space can provide many services (i.e., reduce urban heat, absorb solar radiation, mitigate flood risk, redirect rainwater, sequester carbon, and reduce greenhouse gases) (Lovell and Taylor 2013). All very different functions under one solution. However, to effectively account for diverse groups and better yield equitable solutions, it is critical to incorporate diverse perspectives through community engagement (Anguelovski et al. 2016). Local involvement is essential for identifying problems and implementing successful green intervention solutions (Lovell and Taylor 2013).

Assessing for multifunctionality is important because it addresses the complex interactions between society and the environment. To successfully implement a green space project, it is essential to identify necessary trade-offs for the surrounding community (Meerow and Newell 2019). Historically, green space implementation has had a narrow focus, often only accounting for stormwater and flood abatement and ignoring other ecological services (Lovell and Taylor 2013, Kremer et al. 2016, Meerow and Newell 2017). While adapting to flood risks is necessary, a single focus does not yield equitable results and could provide an uneven distribution of ecological services that hinder future resilience efforts. For example, a multicriteria analysis of green space distribution of various scenarios in New York City showed that using stormwater absorption led to the least amount of variation compared to other scenarios, which evenly accounted for other ecological services (i.e., carbon storage, heat regulation, air, and pollution removal) (Kremer et al. 2016). The same was true for a Los Angeles study that compared two green space implementation scenarios; (1) park implementation focused solely on flood management and (2) park implementation to foster culture, community resiliency, and increased access to parks. The Los Angeles study found that park inequities persisted in marginalized communities when flood mitigation was the only priority (Meerow and Newell 2019).

The multifunctionality of green spaces is purposefully defined broadly. It is simply outlined as providing various ecosystem services that deliver multiple functions (i.e., economic, social, and ecological) (Hansen et al. 2019). It is important to note that multifunctionality is not limited to the adaption and mitigation of climate risks outlined in this paper and can also account for other ecosystem services like biomass or food production, increased habitat diversity, fire management, movement of species, or even additional recreational activities (McDonnell Mark and MacGregor-Fors Ian 2016, Hansen et al. 2019). Yet, regardless of the indicators used to determine trade-offs, a multifunctional approach integrates environmental and social indicators to develop robust solutions. The following sections will explore the multifunctional assets green spaces provide in their ability to offset climate hazards. While a green space has many environmental functions and assets, this study will predominately explore extreme heat adaptation, air quality mitigation, and flood management.

2.1.1 Adaptation to extreme heat

A critical climate hazard that urban areas must prepare for is extreme heat. Cities are more susceptible to the urban heat island effect, leading to hotter, dryer, and less wind than rural areas (Larsen 2015). Urban areas contain dark or dense building materials (i.e., grey infrastructure, buildings, concrete); this restricts airflow and absorbs additional solar radiation, creating warmer microclimates (Mathey et al. 2011). Furthermore, the collective impact of increased global greenhouse gases only amplifies extreme urban heat and associated health risks in vulnerable communities (Mathey et al. 2011, Larsen 2015, Makido et al. 2019). As a response, green spaces and their vegetation are considered necessary solutions for decision-makers who are grappling with ways to reduce heat vulnerability. Commonly, green spaces are effective at helping communities adapt to heat waves due to their natural cooling and air circulation effects (Heidt and Neef 2008). For example, an increase in plants, shrubs, hedges, and trees found in green spaces can increase albedo, which affects a surface's ability to reflect solar radiation leading to cooler temperatures (Makido et al. 2019). Green spaces also reduce temperatures through shade and evapotranspiration provided by trees and other tall vegetation structures. These reduce local hot spots and better regulate moisture content than unshaded areas (Zölch et al. 2016). Additionally, unshaded or unvegetated areas will take additional time to cool and are the warmest areas of a city at night (Heidt and Neef 2008).

A green space's ability to reduce temperatures is well documented through case studies in urban areas that highlight their cooling capabilities. Chen et al. (2022) reviewed 60 urban parks in Wuhan, China, a megacity experiencing rapid urbanization and hot summers, and found that 54 of the 60 parks reviewed had positive effects on cooling. The reviewed parks all varied in size and shape, but overall, they had a significant impact on reducing temperatures, with 77.7% of park areas considered cold spots and only 3% delineated as hot spots (Chen et al. 2022). Important findings also highlighted that green space configuration, landscape composition, and the incorporation of blue infrastructure can complement a city's ability to meet cooling demands (Zölch et al. 2016, Chen et al. 2022). Additionally, a study on Portland, Oregon, whose climate resembles that of Sacramento, reviewed several scenarios on green infrastructure treatments to identify the best approach for the region. It determined that a combined approach, including trees, grass, and green roofs, had the most significant cooling potential and cited an average decrease of over 3 degrees Celsius for optimal configurations (Makido et al. 2019). This confirms the findings of Chen et al. (2022), that land-use cover and green space arrangement will determine the effectiveness of urban cooling (Makido et al. 2019). Finally, it was further determined that removing vegetation in a no-green scenario could increase temperatures up to 6.9 degrees Celsius, highlighting the importance of preserving green space in urban areas (Larsen 2015, Makido et al. 2019).

The literature reviews a range of green spaces, including green facades, green roofs, trees, woodlands, and urban forests, and their ability to mitigate extreme heat effectively. Across the research, configuration and type of green space yielded different results and could be arranged to address a city's unique needs. For example, an assessment of the microclimate along a street corridor in Murch, Germany, determined that tree planting has the most potential for mitigating thermal comfort during high temperatures; green walls or facades also saw reductions in temperatures; yet, green cover saw the least drop in temperatures due to their inability to provide shade (Zölch et al. 2016). It is important not to underestimate the power a tree can have in reducing overall neighborhood temperatures; a study that reviewed the configuration of tree placement in a Phoenix neighborhood noted that the most effective strategy for lowering temperatures by 1.5 degrees Celsius was placing one tree or two trees at equal distances in front yards, ensuring to avoid canopy overlap for increased circulation (Zhao et al. 2018). Even more impressive was that cooling benefits were noticed across the entire neighborhood (Zhao et al. 2018). Due to these benefits, studies recommend that future construction projects incentivize or even require the use of green elements in new development projects due to their shared benefits (Larsen 2015).

Still, some concerns and areas require further analysis in the literature. First, extreme heat is related to pollutant vulnerability; a study of the ten hottest days in Richmond, Virginia, in 2019 noted a correlation with higher PM2.5 concentrations near the urban core (Andre M. Eanes et al. 2020). The study further indicated that high temperatures and pollution levels were more commonly observed in lower-income areas with lower life expectancies than in wealthier neighborhoods (Andre M. Eanes et al. 2020). This highlights the disproportionate impacts noticed in vulnerable areas and the amplified effects of multiple climate risks on public health.

However, because each urban area is unique, it is still unclear how to best apply the findings in the literature to address issues in other cities. For example, while there is a consensus that green space configuration and vegetation influence overall cooling, more information on specific land-cover arrangements must be further reviewed (Makido et al. 2019). Makido et al. (2019) encourage future research to focus on the impacts of medium canopy neighborhoods since they are experiencing the most growth in population and contain many residents. This same research also flagged a critical issue, as cities continue to develop green space solutions, they are also concurrently experiencing increased urbanization; as a result, more research on how a city can cope with increased population densities while also maintaining pre-developmental temperatures and preserving green spaces will be critical (Makido et al. 2019).

2.1.2 Air quality protection

Air quality management is a challenge for maintaining public health in urban areas and ensuring that clean air is accessible to those most vulnerable. Cities often see five to 25 times higher levels of air pollution (i.e., sulfur dioxide, carbon dioxide, aerosols, ozone, lead) than rural areas outside of city limits (Heidt and Neef 2008). Furthermore, climate change is anticipated to worsen urban air quality, which is concerning since air quality in urban areas is already compromised due to transportation, industrial, and residential sources (Revi et al. 2014). This is problematic for residents as high levels of air pollution also influence extreme heat because an increase in particles in the air also leads to increased heat-trapping in urban areas (Heidt and Neef 2008).

The most harmful pollutants are particulate matter (PM) and ground-level ozone, which lead to respiratory issues even in healthy individuals and more severe health problems among those more vulnerable to exposure (i.e., those with heart disease or lung disease, asthma, pregnant women, children) (SMAQMD 2017). PM includes smoke from fires, metals, soot, dust, and sulfates, whose potential for health issues is linked to particle size. Smaller particles classified as PM2.5 are the most dangerous because they can be inhaled deeper into the lungs (SMAQMD 2017). Ground-level ozone is also harmful because it is an irritant that can constrict airways and make it difficult for one's respiratory system to provide oxygen (SMAQMD 2017).

Green spaces present cities with a potential solution for air management districts to mitigate and reduce the negative impacts of air pollutants like PM and ozone. Research shows that plants and trees in green spaces interact with PM and provide three functions that influence pollution levels. The first is the most researched, deposition, which is the process of particles being trapped on the surface or within the leaf structure (Chen, Ming et al. 2019, Diener and Mudu 2021). Deposition is important because it can permanently or temporarily reduce exposure to PM and can effectively pull pollutants generated from roadside traffic (Diener and Mudu 2021). The second is dispersion, which, through a plant's physical structure, changes PM course and velocity (Chen et al. 2019, Diener and Mudu 2021). This can reduce PM levels by creating a physical barrier which can decrease PM exposure in communities near highly polluted areas (Chen et al. 2019). For both deposition and dispersion, spatial configuration of green spaces and leaf composition play an essential role as a dense tree canopy can hinder ventilation and further trap PM (Chen et al. 2019, Diener and Mudu 2021). Diener and Mudu (2021) also explore another function defined as modification, or the altering of PM properties and composition, which could modify the size and toxicity of a particle. The process can be chemical, microbial, or selective, depending on PM structure and leaf configuration (Diener and Mudu 2021).

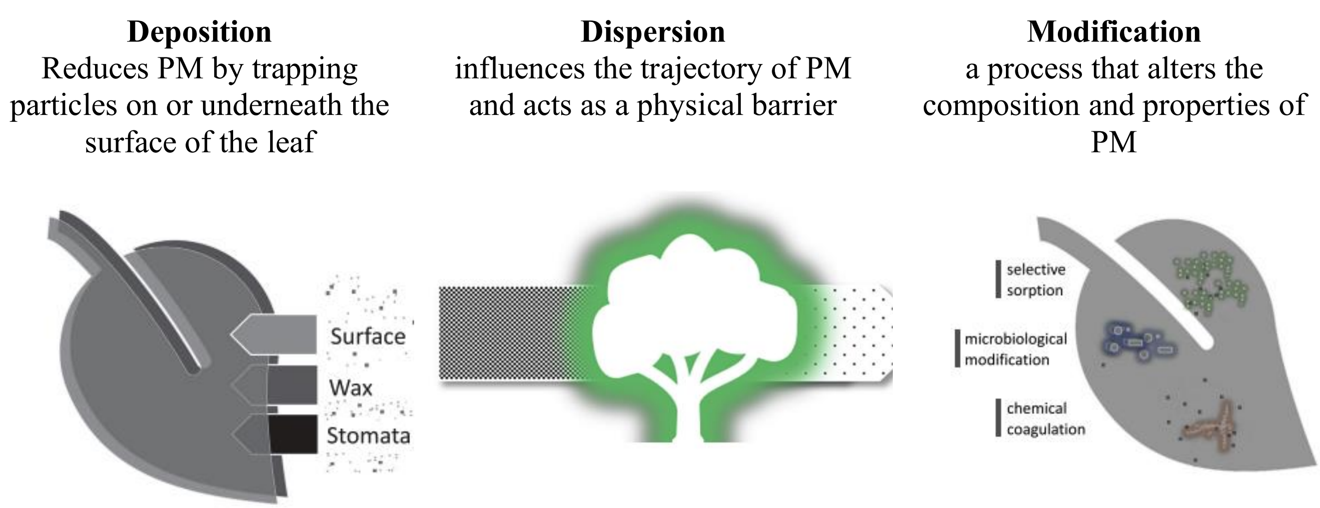

Figure 5: Visual representation of the three functions trees and plants provide when interacting with particulate matter (PM) (Chen et al. 2019, Diener and Mudu 2021)

However, it is important to note that PM reduction through green space implementation is complex and reliant on several other factors like plant species, vegetation characteristics, local meteorology, quality of green spaces and deposition velocity (Chen et al. 2019, Tomson et al. 2021). As a result, different types of vegetation will interact with PM uniquely, and some provide different solutions than others. Chen at al. (2019) performed a study that reviewed PM2.5 data from five cities in China and found that trees are better capable of reducing and removing PM2.5 than grass. Furthermore, in the same study, the size and age of the tree also played a factor, as healthy large trees were 60 times more effective at removing pollution than smaller and younger trees (Chen et al. 2019). The configuration of trees is also important; in a street canyon with buildings on both sides of a street, it is recommended that 25-33% of vegetation be present to see reductions in PM levels; however, wind direction and airflow patterns may require increased vegetation, up to 50% for some case (Tomson et al. 2021). Green walls and hedges also provide a different solution and mitigate air quality by acting as a barrier and intercepting local emissions sources (Tomson et al. 2021). Again, the configuration is important as optimum results were observed among green walls and hedges that were less permeable and taller; moreover, fragmented hedges led to a 3-19% increase in PM2.5 concentrations (Tomson et al. 2021).

Finally, while most of the literature focused on particulate matter like PM2.5, a Sacramento County-specific study from 1998 assessed the region's ability to reduce ozone, PM10, nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) as well as estimated cost saved. While the study results are outdated due to 1990 pollutant concentrations being used and significant changes in tree canopy over time, its findings on reduced concentrations due to tree cover are very relevant to the research presented in this study. Of the four pollutants reviewed, it was determined that Sacramento's urban forest was successful in removing 1,457 metric tons of total pollutants; furthermore, using the Sacramento Metropolitan Air Quality Management District 1993 cost controls, this translated to a monetary value of $28.7 million, not accounting for inflation (Scott et al. 1998). The highest cost savings came from ozone removal (57%), and the second was from PM10 reduction (27%), both very harmful pollutants for public health. From here, Scott et al. (1998) calculated $1,500 in savings per hectacre a year, which is about a $5 removal benefit per tree, given that about 6 million trees were estimated throughout the county at the time. This is significant as it quantifies uptake and provides a valuation system for trees and their ability to uptake pollution in urban areas with tree canopy cover.

Table 1: Pollutant uptake annual monetary values for different sectors in Sacramento County (in millions of U.S. Dollars) using 1993 SMAQMD cost controls (Scott et al. 1998)

Sector	Ozone	NO2	PM10	SO2	**Total**
City	$3.333	$0.937	$1.476	$0.090	**$5.836**
Suburban	$5.878	$1.595	$2.508	$0.163	**$10.144**
Rural	$7.707	$1.476	$3.949	$0.287	**$12.782**
Study areas: Sacramento County	**$16.281**	**$4.008**	**$7.933**	**$0.541**	**$28.763**

2.1.3 Water and flood management

Urban flood and water management are under additional stress due to increased urbanization, hindering climate resiliency efforts. The combined impacts of extreme weather events due to climate change and the increase of impervious surfaces to accommodate urban growth present significant issues for cities (Chan et al. 2018). As a result, cities are experiencing limitations in retention capacity for heavy storms and an inability to recharge groundwater supply for later use (Chan et al. 2018). The impacts of climate change will only exacerbate these issues (Dong et al. 2017, Chan et al. 2018, Meerow and Newell 2019). A study in Kunming, China, was able to quantify the collective impact of urban flooding and climate change by comparing both increased urbanization and rainfall under various scenarios. They determined that just a 20% increase in both urbanization and rainfall intensity due to climate change could reduce a system's resiliency by 24% (Dong et al. 2017). This is significant as flood management is interdependent on other essential city functions like electricity distribution, access to transportation, waste management, and sewage/water treatment, and a disruption could hinder social cohesion, public safety, and emergency response efforts (Kaźmierczak and Cavan 2011, Hoang and Fenner 2016).

Nonetheless, green spaces provide an essential function due to their pervious surface, which helps direct stormwater during heavy rains and promotes groundwater restoration (Chan et al. 2018). This is significant as green spaces are flexible solutions that can be modified to help a municipality meet flood management goals (Hoang and Fenner 2016, Dong et al. 2017, Chan et al. 2018). However, studies show that a decrease in green space is often correlated with increased poverty and vulnerability in high-density areas, making these areas more prone to surface flooding (Kaźmierczak and Cavan 2011).

In the literature, flood mitigation and adaption techniques have been referred to by a range of approaches which all contain green space solutions as an important component to the overall plan; the approaches include Blue-Green Cities, Sustainable Drainage Systems, Sponge Cities (Hoang and Fenner 2016, Dong et al. 2017, Chan et al. 2018). Each approach aims to temporarily store or control urban runoff, recycle and clean stormwater, or encourage traditional flood management infrastructure to be more climate-resilient (Hoang and Fenner 2016, Dong et al. 2017). Green space is an effective solution because they have a higher adaptive capacity than traditional grey infrastructure techniques that also provide beneficial services during non-flooding periods (Hoang and Fenner 2016, Dong et al. 2017). The ecosystem functions outside of flooding events are essential for general public health and management of other climate-related risks (Dong et al. 2017). Most importantly, its application and implementation can be customized to meet the unique flood and water management needs of a city, often varying by design, ranging from small neighborhood scales to large city-wide projects (Liu and Jensen 2018).

In the literature, green space can complement overall flood management approaches and support the functions of grey infrastructure like storage tanks (Hoang and Fenner 2016, Dong et al. 2017). A case study in Kunming, China, compared flood resilience strategy scenarios under a combined green and grey approach with a grey infrastructure only approach. The study determined that grey infrastructure provides a basic capacity for mitigating flood risks, yet green space can significantly increase the resiliency of a system to flooding (Dong et al. 2017). A 20% increase in green roofs and permeable surfaces through green spaces could improve the performance of a city's drainage system and lead to a 30-33% increase in overall system resilience (Dong et al. 2017). Furthermore, green spaces provide a more efficient alternative as the efficiency of grey infrastructure to promote flood resiliencies decreases as more are built; this is a result of concrete which negatively impacts permeability (Dong et al. 2017). Consequently, green spaces help meet high flood management demands and provide a flexible option for decision-makers (Dong et al. 2017).

The application of green spaces as a flood mitigation tool varies depending on location and management goals for a city. A study reviewed unique and flexible approaches across five municipalities (i.e., Singapore, Berlin, Melbourne, Philadelphia, and Tianjin) (Liu and Jensen 2018). In the study, green spaces were observed to promote a self-sufficient city water supply, manage stormwater discharge to improve the water quality of rivers, link green space irrigation to secondary, or reused water sources (Liu and Jensen 2018). Furthermore, there is also a diverse range of green space types that provide unique hydrological and ecosystem functions. The literature explored parks, public and private gardens, swales, green roofs, forested woodland, and wetlands as strategies to provide important ecosystem services and support urban flood management goals (Hoang and Fenner 2016, Chan et al. 2018). Areas where these green space techniques have been documented are in China's efforts to implement a "Sponge City" concept (Figure 6), which mimics natural water cycles to address water and flood risks. The goal aims to reuse and retain 80% of stormwater by 2030 through strategic planning that promotes green landscapes (Chan et al. 2018).

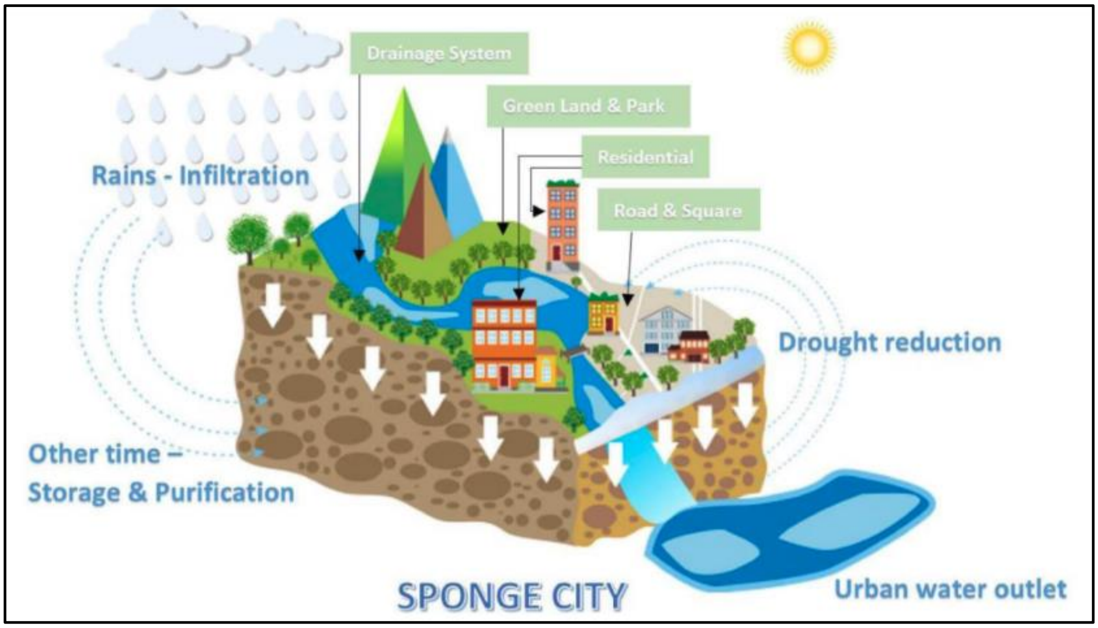

Figure 6: The role green spaces and parks have on the overall storage, purification, and infiltration of water to ensure resilience during droughts as well as extreme rain events (Chan et al. 2018)

Concerns are highlighted throughout the literature when viewing green space implementation through a water or flood management lens. For example, green space, soil, flood risk, and water are all managed by different agencies with different codes and practices (Chan et al. 2018). This presents a challenge for cities as flood management through green space implementation requires additional strategic planning from city departments, and the decentralization of agencies may hinder progress (Hoang and Fenner 2016). However, it is argued that this also presents an opportunity to bring together many of these siloed stakeholders and bridge gaps to address necessary flood management plans (Chan et al. 2018). Furthermore, a lack of knowledge or available resources on how green infrastructure can support flood management can be an issue. Water management often requires innovative solutions to conventional problems that are not always equally accessible to the stakeholders involved (Liu and Jensen 2018). Finally, environmental concerns were also raised as the accumulation of pollutants and debris around green spaces after flooding can present health risks to the surrounding community and damage native ecology (Hoang and Fenner 2016).

2.2 Summary

Extreme heat, Air pollution, and flooding are all expected to increase in the future, negatively impacting local ecosystems and economies. Areas that lack the necessary infrastructure and services to adapt to these changes will be most vulnerable (Revi et al. 2014). As the research shows, these areas are often communities of color and low socioeconomic status (Rigolon et al. 2018). It's important to note that while there is information on the function of green spaces and the benefits they provide, there is not enough information on recommendations to address social-spatial issues related to equity (i.e., race and socioeconomic status). Environmental justice and equity-focused research on this topic are relatively new as most equity-focused literature was published more recently. There is also a consensus regarding the areas deprived of green spaces and the vulnerabilities they will endure; however, more research needs to be conducted on their socio, political and environmental overlap and how to best deliver effective and equitable solutions.

As reviewed, green spaces are a viable solution for addressing many of the climate-related vulnerabilities urban areas are already experiencing due to the increased impacts of climate change. Their ability to address social and ecological issues in urban environments makes them robust and multi-scale approaches (Meerow and Newell 2017). However, it will be important not to oversimplify the social issues at hand when assessing urban climate resilience. Resiliency plans have often been critiqued due to their inability to create restorative changes and address the complexity of social concerns (Meerow and Newell 2017). There is an opportunity for adaptive justice through green space implementation, which could uplift historically marginalized communities while also meeting the basic needs of individuals (Ramyar 2017). As a result, this study will further advocate for multi-scaled green space approaches and compare them with important social indicators. The goal is to assess neighborhood resilience alongside multiple indicators to make well-rounded recommendations for action.

Table 2: Goals, approaches, principles, and functions reviewed regarding the implementation and effectiveness of green spaces

GOAL			
Urban Community Climate Resilience			
Approaches	Principles	Ecosystem Services	
		Environmental	Social
Green Space implementation (Parks, tree's, greenways, hedges, green walls, green facades)	• Multifunctional • Multi-scale planning • Community engagement • Equity and Environmental Justice • Stakeholder involvement • Social ecological • Conservation	• Air quality • Water and flood Management • Extreme Heat mitigation	• Improved public health • Mental and physical health • Economic Benefits • Community investment • Culture/Identity

3.0 Methods

3.1 Multi-Criteria Assessment

This research conducted a multi-criteria assessment for North and South Sacramento areas and compared tree cover and park distribution with climate vulnerabilities and risk. A multi-criteria approach was selected due to its capacity to include and integrate multiple economic, social, and ecological variables across numerous stakeholders, spatial locations, and social groups (Langemeyer et al. 2016). Furthermore, they are also effective at identifying links among complex issues, which can be used to influence not only policy decisions but also a community's wellbeing (Langemeyer et al. 2016). A set of climate hazard, ecological, and social indicators were identified to further advocate for green space investments as an adaptive solution to increase urban resilience.

Recognizing that green space is a broad term, this study focuses on park distribution and tree canopy cover as key indicators for green spaces. The Trust for Public Land's ParkScore Index and City of Sacramento data helps identify priority areas in need of green space once compared alongside climate risks and census data. Climate indicators in the study correlate with the three vulnerabilities presented in the literature review (i.e., heat vulnerability, air quality, and flood risk) to determine the level of risk and identify hotspots in the North and South Sacramento communities. These indicators will be compared alongside important race, ethnicity, and other socioeconomic information pulled from the 2020 census tract.

3.2 Area of Focus

The North and South Sacramento communities will be the focus of this research. Both neighborhoods are in the City of Sacramento, the Capitol of California, located along the American and Sacramento Rivers. According to the US Census Bureau, in 2020, Sacramento's population was 531,285, a 13.89% increase in population size since 2010 (Sacramento Census Bureau 2020). The city is expected to continue growing at a rate of 1.12% a year and has seen significant increases in Native Hawaiian/pacific islander, Asian, and Hispanic populations since 2010 (Sacramento Census Bureau 2020). This population increase aligns with the growth projections and highlights the urgency for action in mitigating and adapting to urbanization and associated climate risks. Additionally, Table 3 highlights the racial diversity throughout Sacramento, which has a smaller white population, significantly larger Asian and Latino or Hispanic population, and equivalent Black or African American populations to the United States average. Sacramento's increased diversity highlights the importance of equity and environmental justice approaches required to uplift historically marginalized communities.

Table 3: Census Data for Race and Hispanic origin for the City of Sacramento compared to the United States average (Sacramento Census Bureau 2020)

Race (%)	City of Sacramento (%)	United States Average (%)
White alone	46.3%	76.3%
Black or African American alone	13.2%	13.4%
American Indian and Alaska Native alone	0.7%	1.3%
Asian Alone	18.9%	5.9%
Native Hawaiian and Other Pacific Islander alone	1.7%	0.2%
Two or more races	7.4%	2.8%
Hispanic or Latino*	28.9%	18.5%
White alone, not Hispanic or Latino	32.4%	60.1%

* For the 2020 Census, Hispanics or Latinos may be of any race and are included in other applicable race categories as well (Sacramento Census Bureau 2020)

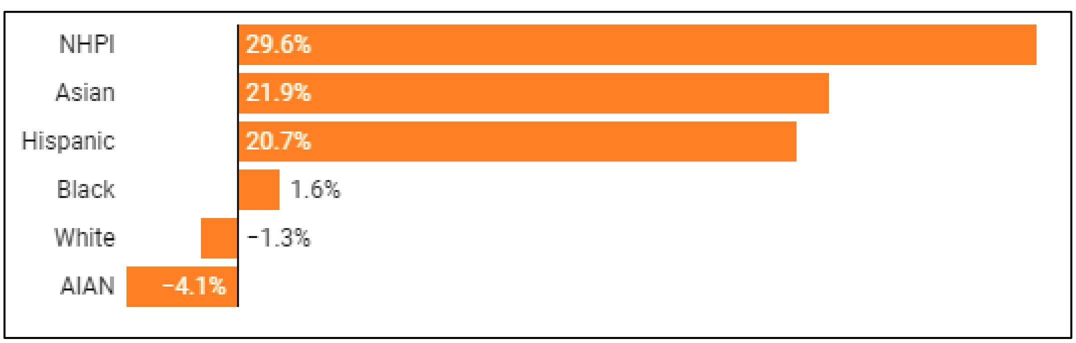

Figure 7: City of Sacramento population changes (%) for specific populations from 2010 to 2020 (Sacramento Census Bureau 2020).

North and South Sacramento have specific community plans that guide local development and investment decisions. Both locations were selected because they have diverse populations of people of color and mid-to-low socioeconomic statuses. These areas have also experienced a history of being marginalized and deprived of green space and public investments that could improve the livelihood of individuals who need it most. As urbanization and climate change continue to worsen, it is more important than ever to encourage efforts to mitigate and adapt to associated negative externalities. While investments must be made across many areas, this study will expand on the community plans for North and South Sacramento and advocate for green spaces as an approach that directly addresses both socio-ecological inequities and better prepares communities for expected climate risks.

The city's General Plan presents broad strategies and policies, while the community plans provide more focused details to improve neighborhood design, livability, economy, health, safety, and other aspects. The community plans for North and South Sacramento provide an in-depth explanation for future development and opportunities. Both plans were published in 2015 and are a product of the City of Sacramento's Planning Department that reflect long-range goals for community-scale investments (North Sacramento Community Plan 2015, South Area Community Plan 2015).

In South Sacramento, greenway buffers, green streets and walkways throughout neighborhoods, and additional green public spaces are highlighted as potential developments (South Area Community Plan 2015). In North Sacramento, green space is mentioned significantly less, only to restore and improve "opportunity areas" or areas in need of recreational or economic development (North Sacramento Community Plan 2015). In light of these plans, this study aims to further explore and advocate for these green space recommendations and analyze why additional green space investments are necessary from a climate risk and vulnerability perspective. The following sections will provide a brief description of North and South Sacramento to better understand the study area.

South Sacramento **North Sacramento**

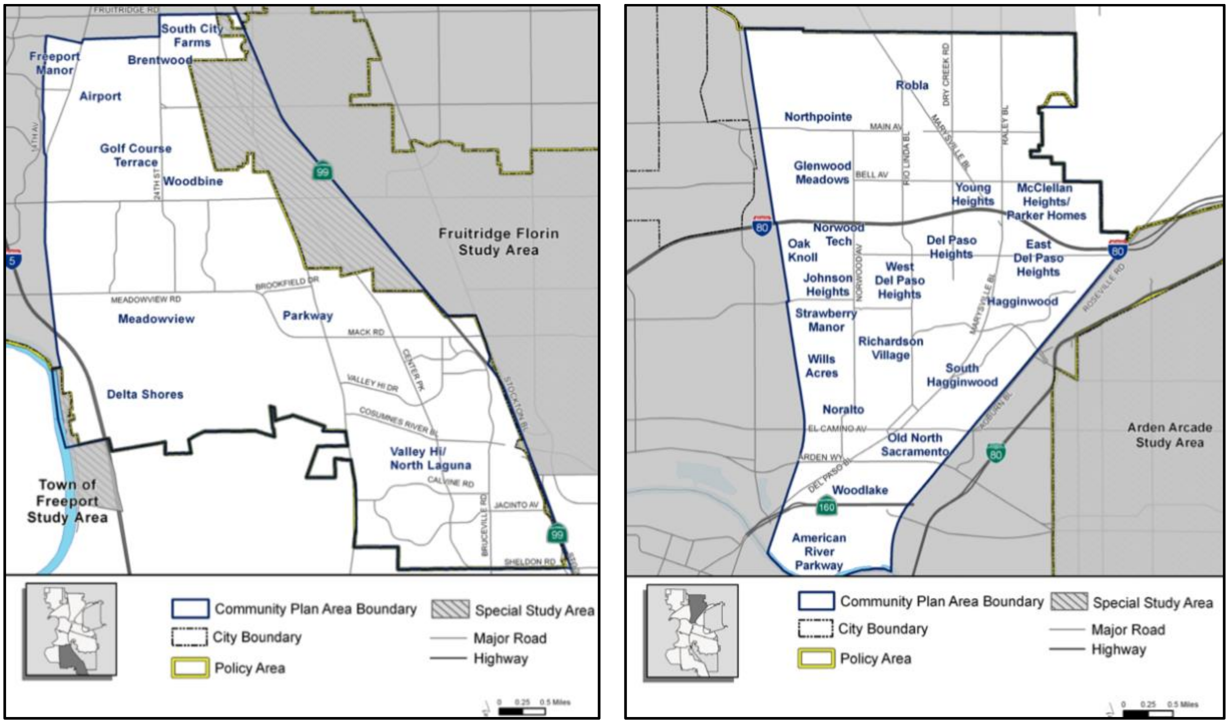

Figure 8: The two areas of focus for this study as shown in the community plan for North and South Sacramento (North Sacramento Community Plan 2015, South Area Community Plan 2015)

North Sacramento is located in the northeastern area of the City of Sacramento and is about 13 square miles or 8,380 acres (North Sacramento Community Plan 2015). Land use in this area is more diverse than in South Sacramento and includes light industrial, suburban residential, and office uses. The plan mentions vacant land availability but cites constraints due to their odd shape and the lack of infrastructure for development. The plan is different from South Sacramento as it does not provide key concerns, instead it presents community policies unique to the area to direct decision making. However, the only component related to greenspace intervention includes efforts to provide a green space buffer on both sides of the Magpie Creek that runs through the community. Opportunity areas in need of recreational and economic investments are also identified in an effort to improve subsections of the community, but very little is mentioned about green space implementation or improvements as an approach (North Sacramento Community Plan 2015). Subsequently, this study serves to consolidate and deliver valuable information that could guide future investments in green space in North Sacramento.

The South Sacramento area is the southernmost part of the City of Sacramento and encompasses about 24.5 square miles or 15,040 acres, much larger than North (South Area Community Plan 2015). Most land use is dedicated to single-family residential neighborhoods and employment options consisting of public sector, office work, and industrial jobs. Significant community issues identified in the plan include urban design and environmental and economic concerns, which are all relevant to green space implementation. Regarding urban design, the area is expected to experience overcrowding, lacks tree cover, and is deficient in neighborhood amenities and services (South Area Community Plan 2015). A need for redevelopment and unclear planning for residential and commercial areas is a component that also needs further development (South Area Community Plan 2015). Environmental concerns include the loss of the local Swanson's Hawk habitat and surrounding wetland, vulnerability to street flooding, and limited capacity of nearby drainage facilities (South Area Community Plan 2015). Results from this study will support the planned green space investments mentioned and advocate for more investments to uplift neighborhoods.

3.3 Social Indicators

This study collected data from the 2020 Census tract to identify indicators that reflect race and ethnicity, and socioeconomic status. Data was pulled from Census Reporter, which provides census tract-specific demographic, economic, social, housing, and family information (Census Reporter). These are relevant to green spaces because income, race, and ethnicity often influence green spaces' quality, access, and distribution (Rigolon et al. 2018). Census info is available to the general public to influence local decisions. However, it is important to note that the census tract is not perfect and has a margin of error of at least 10 percent, which will be considered when accessing the overall results (Census Reporter).

Additionally, while census tracts aligned perfectly with North Sacramento, South Sacramento tracts did not align and instead reflected estimated numbers. However, even with a margin of error and estimations, the 2020 Census helps approximate the economic and income distribution in North and South Sacramento. Specific indicators that will be reviewed in this study are the percentage of Black and Hispanic populations to indicate race and ethnicity and median household income, and persons below the poverty level to indicate socioeconomic status.

3.4 Indicators for Green Spaces

3.4.1 Park Distribution

The ParkScore Index, created by the Trust for Public Land, determines park distribution percentage in North and South Sacramento. The Trust for Public Land is a national nonprofit with a goal to develop parks and protect land to ensure communities are healthy and livable (The ParkScore® Index 2022). The tool is widely used by academics and decision-makers and was developed over ten years by experts to link health outcomes with park accessibility (Rigolon et al. 2018). Furthermore, it was developed using a multi-step process that incorporated input from recreation experts, public park professionals, and agencies through yearly surveys to ensure updated information (Rigolon et al. 2018). The ParkScore Index includes important social indicators in its rating system. It reviews the 100 largest U.S Cities and measures across several categories (i.e., investment, amenities, access, acreage, and equity) (The ParkScore® Index 2022). The ParkScore index is a reliable source due to its affiliation with the Public Land Trust and its effort to provide a well-rounded park score composed of important race and socioeconomic-related data. The index reviews if cities are meeting the park needs of residents, presents data to guide local park decisions, and provides evidence for additional park investments in deprived locations (The ParkScore® Index 2022).

The ParkScore Index provides data on both park acreage and a visual of park distribution and areas within a 10-min walking radius of a park for North and South Sacramento. These are important to document as parks, and the vegetation they include is an essential component of urban green space. However, while ParkScore is a robust tool with many functions to influence city decisions that encourage park investments, for the focus of this study, we will only be reviewing the park data presented in the North and South Sacramento neighborhoods and not the overall ParkScore assigned to the City of Sacramento.

3.4.2 Tree Canopy Cover

Tree canopy is considered a type of green space and will also serve as an indicator for further identifying green space distribution in the North and South Sacramento neighborhoods. The City of Sacramento's 2018 Urban Tree Canopy Assessment provides detailed information about overall canopy cover for specific council districts and communities. The 2018 Canopy Assessment calculates the exact acreage and tree canopy cover percentage to the hundredth significant figure. This was done using remote sensing software and high-resolution aerial imaging to help identify existing tree canopy cover in public and private areas throughout the City of Sacramento (City of Sacramento Urban Tree Canopy Assessment 2018). The assessment presents canopy acres, canopy percent cover, and canopy cover tree capacity for the North and South Sacramento community plans, reviewed alongside park distribution and climate risks (City of Sacramento Urban Tree Canopy Assessment 2018).

3.5 Indicators for Public Health and Climate Vulnerabilities

The following section will review the public health and climate vulnerabilities methodologies for the North and South Sacramento community areas. The indicators were derived from multiple sources and used to determine heat vulnerability, air quality, and flood risk. The results will be reviewed alongside the social and green spaces indicators to determine priority areas in both communities.

3.5.1 Heat vulnerability as an indicator of climate vulnerability

This study uses heat vulnerability as another indicator of climate risk due to green spaces' ability to cool areas through shade, evapotranspiration, and increased airflow. To quantify heat vulnerability for the North and South Sacramento neighborhoods, this study will be using the Extreme Heat and Social Vulnerability tool created by the City of Sacramento to support their general plan update. The tool presents ground-level temperature data for census tracts within the City of Sacramento. Furthermore, ground-level temperatures are also compared to those outside the city limits. It also provides a geospatial analysis of heat vulnerability for all neighborhoods and assigns a percentile for heat risk vulnerability that accounts for poverty, age, and preexisting conditions (Alverez et al. 2020). The heat vulnerability scale ranges from 0 to 100; high percentiles correlate with a greater heat risk to the selected neighborhood (Alverez et al. 2020).

The temperatures themselves were identified by a team who used NASA Earth observations from Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS), which captures accurate surface temperatures, and International Space Station's ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) which measures the temperature of plants growing in a selected location (Alverez et al. 2020). The Heat and Social Vulnerability is an effective tool. It highlights barriers to health equity and includes economically and socially vulnerable populations disproportionately burdened by high ground temperatures caused by climate change.

3.5.2 Air quality as an indicator of public health

In this study, air quality for North and South Sacramento indicates the capacity green spaces investments may have in reducing harmful pollutants. Green space vegetation interacts with pollutants in ways that can influence Air Quality Index (AQI) levels; these impacts are exacerbated by increased temperatures or changing wind patterns which only worsen pollutant levels (Chen et al. 2019, Diener and Mudu 2021). As a result, high AQI levels can negatively impact neighborhoods and lead to serious respiratory issues, especially in sensitive groups. Therefore, air quality is an essential indicator for prioritizing green space investments as they are effective methods for pollutant uptake and reducing or blocking harmful pollutants from impacting a community. A Sacramento-focused study determined that pollutant uptake is influenced by green infrastructure. A decrease in urban forest and tree canopy and forest cover led to less uptake of pollutants (Scott et al. 1998).

This study assesses ozone and PM2.5 as two primary pollutants that most negatively impact public health among Sacramento residents (SMAQMD 2017). 2021 AQI levels are exported from the EPA’s AirNow tool, providing City-specific data for a selected time frame. However, AirNow only provides one value for the entire City of Sacramento, which does not accurately represent neighborhood-specific data. Subsequently, this study will also review AQI results from PurpleAir, which provides location specific AQI data. While PurpleAir is self-monitored, it still offers helpful insight into neighborhood-specific data, which will help determine risk and vulnerability to pollutants for the surrounding North and South Sacramento neighborhoods.

3.5.3 Flood risk as an indicator of climate vulnerability

Flood risk to the North and South Sacramento neighborhoods is another indicator used in this study for assessing green spaces solutions due to their ability to mitigate and reduce the negative impacts of floods. Data about flood risks will come from FloodFactor, an online tool that assesses the overall risk of flooding in the next 30 years. Flood Factor provides in-depth data for cities in the United States to determine the overall impact of flooding and its likelihood to impact day to day life. Flood Factor is a geospatial tool created by the First Street Foundation to help Americans determine if their property is at risk of flooding and how climate change will influence future risks. The tool was created by 80 scientist, analyst and technologist and is the first peer-reviewed model that shows how property and ground level floods risk may change over time (FloodFactor). It is designed to be accessible and easy to understand so communities can prepare for risks when they become reality. Flood Factor incorporates residential, road, commercial, infrastructure, and social impacts to determine overall risk. The risk level is then divided into six categories ranging from minimal to extreme and reflected on a map for each property in Sacramento (FloodFactor).

Table 4: Indicators and their sources used in this study

	Category	Metric	Source
Social Indicators	Race and Ethnicity	- Black or African American population - Hispanic population	(Census Reporter)
	Socioeconomic Status	- Median household income - Percent below poverty line	(Census Reporter)
Green Space Indicators	Park Space Distribution	- Park Space percentage	(ParkScore - Sacramento 2018)
	Tree Canopy Cover	- Tree canopy acres and percentage	(City of Sacramento Urban Tree Canopy Assessment 2018)
Climate Vulnerability Indicators	Air Quality	- 2021 AQI levels	(AirNow 2022) (Purple Air)
	Extreme Heat	- Ground Temperature - Outside city temperature difference - Heat vulnerability percentile	(Alverez et al. 2020)
	Flood Risk	- 30-year flood risk	(FloodFactor)

4.0 Analysis and Results

The following section reviews the results of each indicator discussed in the methodology section. The goal will be to quantify impacts on park space, tree canopy cover, extreme heat vulnerability, flood risk, and air quality and assess them alongside social indicators under a multi-criteria analysis. I anticipate different results for both North and South Sacramento. Still, the research aims to advocate for green space as a single solution that could address the unique needs of both communities. Results will be reviewed to ultimately identify priority areas in North and South Sacramento and provide recommendations that can promote multifunctional green space approaches in other urban areas.

4.1 Social Indicators

The following section will review important social and economic indicators for North and South Sacramento. These are necessary as they often correlate with a community's accessibility to quality green spaces. This section will highlight race and ethnicity represented by Hispanic and Black populations and socioeconomic factors indicated by poverty levels and median household income to further encourage them as key indicators for future green space implementation.

4.1.1 Socioeconomic Status

North Sacramento has a median household income of $48,275.20 which is $17,571.80 less than the City of Sacramento's median household income. Results ranged from as low as $22,122 to as high as $90,250.00 in another census tract. The percentage of people living below the poverty line also varies across census tracts; however, census data shows about 22.50% of people living in poverty within the North Sacramento community. Poverty levels reached 45.7%, and one outlier was significantly small at 6.8% in another census tract. Both median household income and the percentage of those living in poverty are disproportionate to the numbers reflected throughout the entire City of Sacramento.

South Sacramento exhibited higher median income levels than North Sacramento, with an average of about $55,801.75, $10,045.25 less than the city's overall median household income. Results ranged as low as $27,101 and as high as $85,705 in another census tract. The percentage of people living below the poverty line is slightly lower than North Sacramento but is still 3.5% greater than the City of Sacramento average. Poverty levels reached as high as 57.9% in one census tract to as low as 8.9% in another. However, North and South Sacramento averages appear well below the median household income, and poverty levels were well above the data observed throughout the City of Sacramento.

When compared to the city average, it is clear that North and South Sacramento experience higher levels of poverty and lower median incomes. For this reason, socioeconomic status needs to be considered when implementing green spaces because poor quality parks and low tree canopy are often correlated with communities of low-income status. This is significant since communities burdened with economic hardships often experience the greater climate and public health vulnerabilities. While the data indicate that North Sacramento is slightly more disadvantaged in terms of socioeconomic status, improvements can be made in both communities to reduce poverty and promote inclusive economic efforts. Green spaces can also provide economic services that can increase tourism to surrounding businesses and protect surrounding communities from climate-related damages, which can cost households time and money.

Table 5: The median household income and percentage of people living below the poverty line in comparison to the City of Sacramento average (Census Reporter)

	Median Household Income	**Below poverty line (%)**
North Sacramento	$48,275.20	22.50%
South Sacramento	$55,801.75	19.20%
City of Sacramento	$65,847.00	15.7%

4.1.2 Race and Ethnicity

Race and ethnicity also varied across North and South Sacramento, but census data show that Black and Hispanic populations represent a significant portion of the population in both areas. North Sacramento has a significantly larger Hispanic population, while South Sacramento has a considerably larger Black population than the City of Sacramento average.

These numbers are larger than the overall percentage of Hispanic and Black populations observed across the City of Sacramento.

However, it is important to highlight the critiques often associated with Census data before moving forward. First, the term Hispanic, used by the Census Bureau, does not accurately capture Latino populations, providing a less precise value for people of color in the North and South Sacramento communities. The term Hispanic includes several identities (i.e., Hispanic, Latino, and Spanish) and races, including people who are white. Therefore, the data provides more of an estimation, and future research should consider specific identities that encompass people of color to include more accurate population data.

Yet, even with these critiques, the data still highlights diversity in North and South Sacramento as Black and Hispanic populations are either equal to or above the City of Sacramento's average. It is important to emphasize these numbers because, like with socioeconomic status, race and ethnicity also correlate with one's access to high-quality green spaces. Areas with higher Hispanic and Black communities are regularly deprived of green spaces; consequently, race must be considered to yield more equitable results.

Table 6: Percentage of Hispanic and Black population in both North and South Sacramento (Census Reporter)

	Hispanic Population	**Black Population**
North Sacramento	40%	14%
South Sacramento	29%	22%
City of Sacramento	28.9%	13.2%

* For the 2020 Census, Hispanics or Latinos may be of any race and are included in other applicable race categories as well (Sacramento Census Bureau 2020)

4.2 Indicators for green space

The following section will review the results for green space in North and South Sacramento. Indicators used to represent green space include park space cover and tree canopy cover, which will later be compared to the climate and public health vulnerabilities both areas are expected to experience.

4.2.1 Park Space Cover

Both North and South Sacramento have various types of green spaces designated for parks and recreation. Both showed similar percentages, as North Sacramento contains about 11% park cover while South Sacramento has less at about 9%. These figures are relatively close to the 10% park space cover calculated for the entire City of Sacramento. Still, it is important to note that the overall number in both communities is significantly less than the median park coverage noticed across the United States. As a result, this may depict a need for the City of Sacramento to invest in green spaces within the North and South Sacramento communities and throughout the entire city to better reflect national median percentages.

Park distribution also appears to be more evenly spaces throughout South Sacramento than North Sacramento. Yet, both appear to have areas that require additional park investments as they are outside the 10-minute walking radius. However, it is clear from Figure 8 that larger portions of North Sacramento are deprived of green spaces, which could influence how those neighborhoods respond and adapt to climate-related risks they are expected to experience. Furthermore, a case can be made that both locations need additional investments not only to reach the 15% national medium, which will yield other ecosystem services; but to also ensure the entire community has increased walking accessibility in the event these services must be utilized for climate emergencies (i.e., cooling body temperatures, rerouting flood water, blocking pollutants). Areas with no green space within a 10-minute walk should be prioritized to ensure ecosystem services are balanced across North and South Sacramento communities.

Table 7: Park Coverage (%) for parks and recreation in North and South Sacramento, the City of Sacramento, and the National median (ParkScore - Sacramento 2018)

North Sacramento	South Sacramento	City of Sacramento	National median
11%	9%	10%	15%

North Sacramento South Sacramento

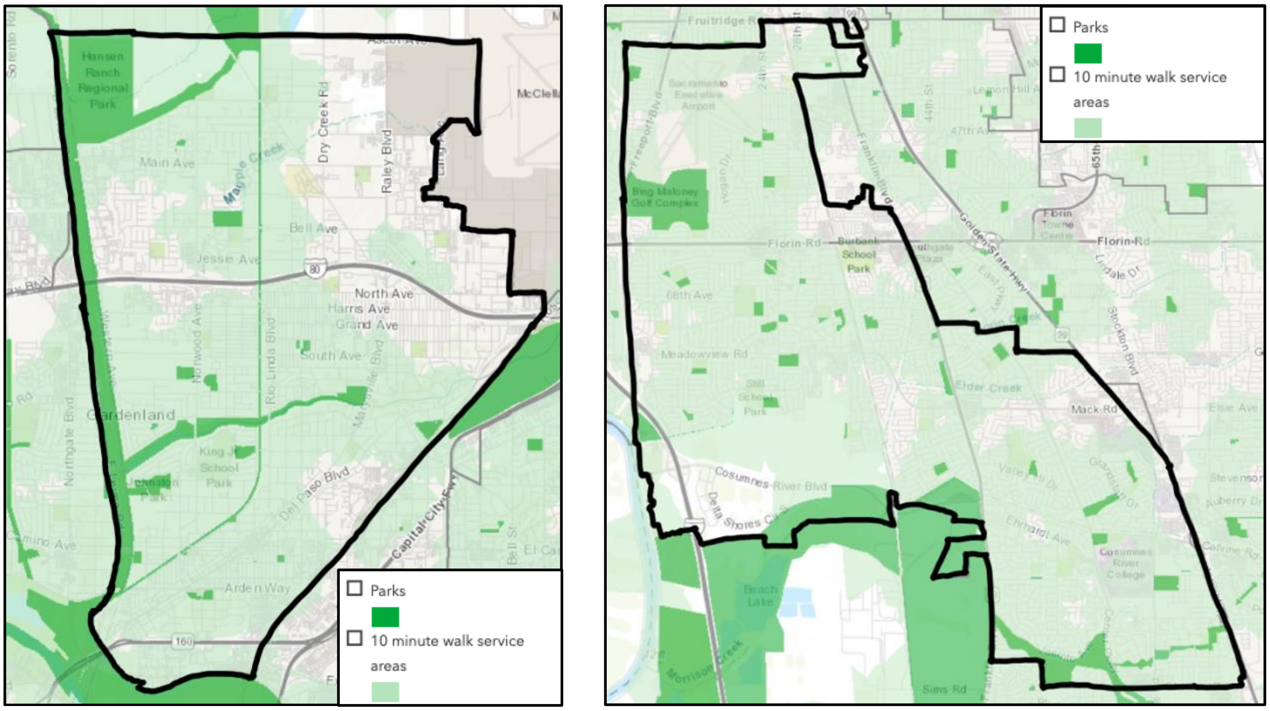

Figure 8: Park distribution in North and South Sacramento (ParkScore - Sacramento 2018)

4.2.2 Tree Canopy Cover

Tree canopy cover is another indicator for green space used in this study. The results show that North and South Sacramento have less tree canopy cover than the overall canopy cover documented across the entire city. Furthermore, while South Sacramento has a slightly lower cover, neighborhoods show 10-20% coverage across all neighborhoods except one. On the other hand, North Sacramento has a more variable cover, with some neighborhoods showing high levels of cover above 30% and others with less than 10%; however, most neighborhoods show a 10-20% cover in this area. Additionally, there is significant potential for canopy cover in both communities, as outlined in Table 8. As a result, more green space investments in the form of tree cover can and should be prioritized in locations with the capacity and communities with low percentages. Future research can compare other city areas with North and South Sacramento as significant differences were observed in wealthier communities. For example, the Land Park and East Sacramento community plans have 30-32% tree canopy cover, which is a drastic difference from the 15-17% observed in North and South Sacramento (City of Sacramento Urban Tree Canopy Assessment 2018).

Furthermore, it is essential to highlight the implications of tree cover on the surrounding communities. The literature review highlights the capacity trees have to create a barrier that reduces pollutant concentration in nearby areas. Major highways travel through North Sacramento and along the edges of South Sacramento. Additional research is needed to identify precisely how much of a pollutant is being reduced, but there may be a correlation between respiratory-related issues and tree canopy cover along these highways. Another observation involves a city's capacity to provide green space, which is often cited as a concern; however, the 2018 City of Sacramento Urban Tree Canopy Assessment includes potential tree canopy for both areas of study. With a 43% and 53% canopy potential in North and South Sacramento, availability is not an issue. Trees produce a cooling effect that positively impacts communities through increased airflow, shade, and evapotranspiration. Increased efforts to reduce temperatures through canopy cover will be needed. However, increased tree cover can help reduce summer ground temperatures and the high heat vulnerabilities noted in both areas, which will be discussed in the later sections.

Table 8: Tree canopy cover in North and South Sacramento according to the 2018 Sacramento Urban Canopy Assessment (City of Sacramento Urban Tree Canopy Assessment 2018)

	Total Acres	**Canopy Acres**	**Canopy %**	**Canopy Potential**
North Sacramento	8,380	1386	17%	43%
South Sacramento	10,586	1557	15%	53%
City of Sacramento	63,781	12,199	19%	NA

North Sacramento South Sacramento

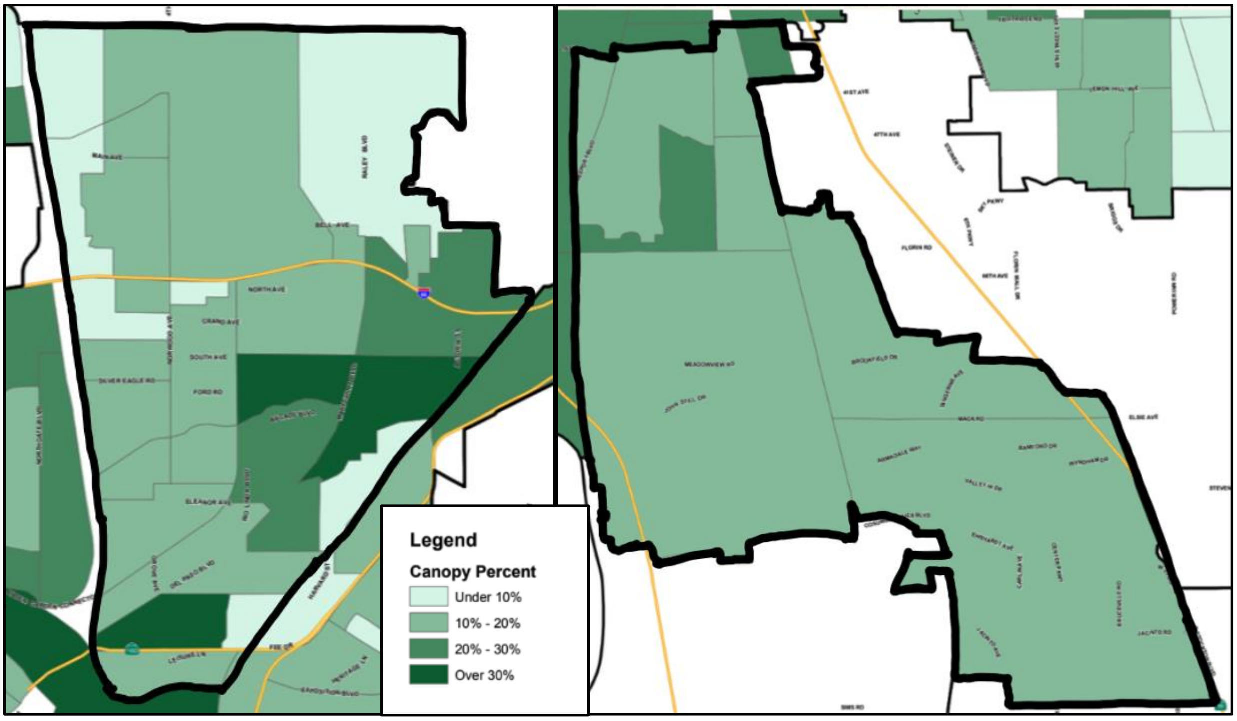

Figure 9: Tree Canopy cover by neighborhood in North and South Sacramento (City of Sacramento Urban Tree Canopy Assessment 2018)

4.3 Indicators for Ecosystem Services

4.3.1 Extreme Heat Adaption

Across the nine census tracts in North Sacramento, the average ground temperature during a typical summer day reached an average of 105.26 °F, with urban temperatures averaging 11.01 °F more than outside the city limits. All ground temperatures across each census were above 101 °F, ranging from 101.66 to a high of 108.07 °F. Furthermore, as shown in Figure 10, there was less variability among heat risk vulnerability, but heat is an apparent concern in North Sacramento, which has a vulnerability score of 71.96. Once vulnerable populations were accounted for, North Sacramento was in the 80th percentile for heat vulnerability.

South Sacramento is a larger area and consists of about 21 census tracts with various temperatures and vulnerabilities to heat. During a summer day, the average ground temperature is about 104.12 °F, and urban temperatures are an average of 9.89 °F higher than outside temperatures. Temperatures in South Sacramento range from 99.81 to 107.32 °F, and one tract is documented to have reached temperatures 13.06 °F higher than outside city limit temperatures. While heat risk vulnerability is significantly lower than North Sacramento at 47.37, accounting for vulnerable populations substantially impacts the overall heat vulnerability score and puts South Sacramento at the 70th percentile for heat vulnerability.

Uneven park concentration and low canopy covers discussed in the previous sections correlate with the high heat vulnerabilities observed in both community areas. It is clear that North Sacramento is more disadvantaged with more prominent extreme heat vulnerabilities. Still, South Sacramento is not far behind once poverty, pre-existing medical conditions, and age are accounted for. Both parks and tree canopy are well documented in reducing high temperatures in urban areas and providing cooling benefits that protect vulnerable populations (i.e., immunocompromised, senior citizens, children). Consequently, investments in both should occur to ensure North and South Sacramento have access to the ecosystem benefits that mitigate the heat urban island effect in areas with no park coverage or little canopy cover.

Table 9: Heat indicators for North and South Sacramento (Alverez et al. 2020)

	Average Summer Day Ground Temperature (F)	Average Temperature Difference outside city limits (F)	Heat Risk Vulnerability	Heat Vulnerability Percentile *
North Sacramento	105.26	11.01	71.96	81.18
South Sacramento	104.12	9.86	47.37	70.26

*Poverty, pre-existing medical conditions, and age contribute to the overall vulnerability percentile score

North Sacramento South Sacramento

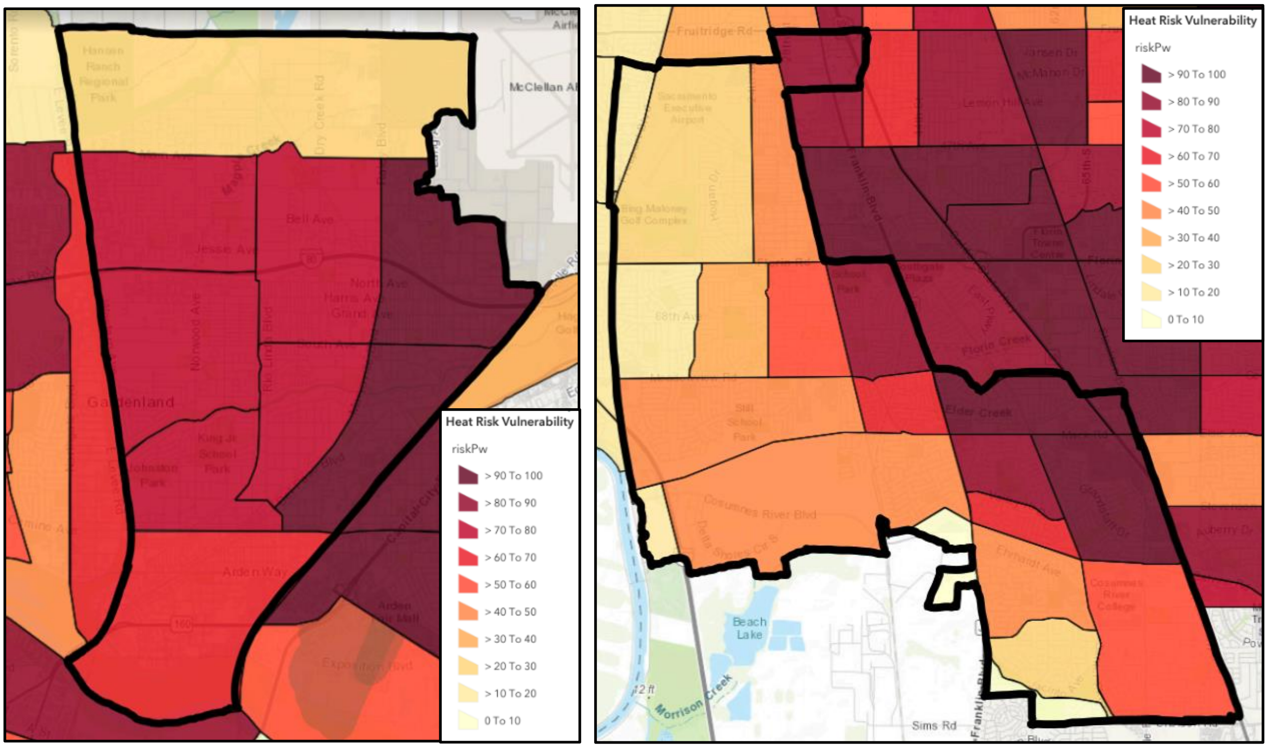

Figure 10: Ground Temperatures in North and South Sacramento by neighborhood (Alverez et al. 2020)

4.3.2 Air Pollution

Two sources were used for assessing air pollution. The first was EPA AirNow; however, this source only calculates an averaged AQI figure for the City of Sacramento. As a result, the AirNow data (i.e., ozone and PM2.5) for Sacramento will be reviewed alongside neighborhood specific PM2.5 data from PurpleAir. This reflects a significant issue regarding the lack of data obtained in marginalized communities. This study recognizes that neighborhood-focused data could yield more accurate results and suggests that neighborhood-specific data, particularly in historically marginalized communities, be periodized to help inform more equitable decisions.

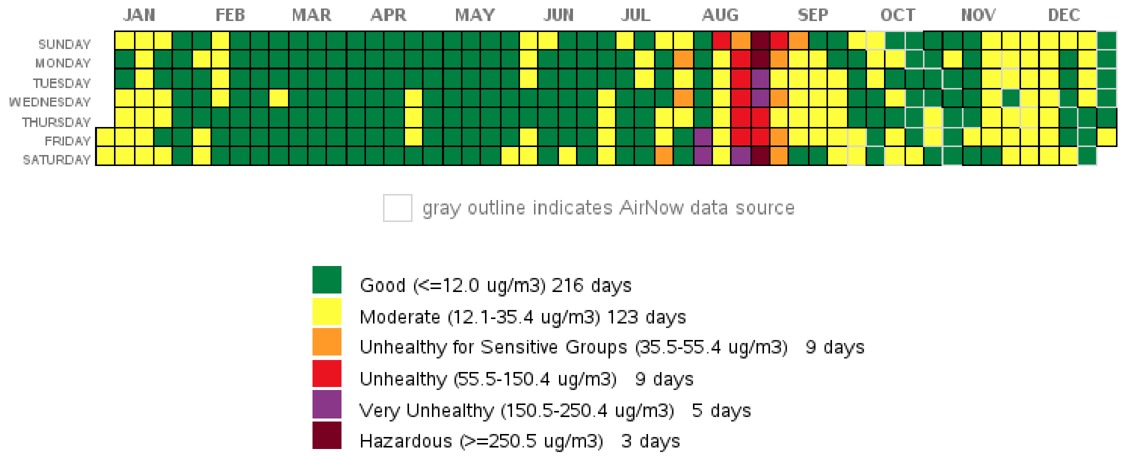

Figure 11: PM2.5 concentrations (mg/m^3) in Sacramento for 2021 (AirNow 2021)

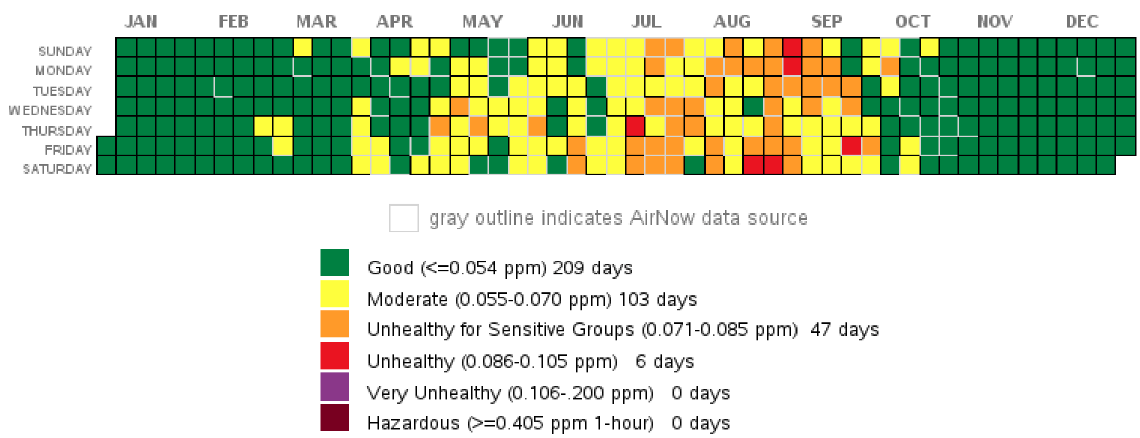

Figure 12: Ozone concentration (ppm) in Sacramento for 2021 (AirNow 2021)

Table 10: 2021 AQI levels for each category in 2021 (AirNow 2021)

	Good (0-50)	Moderate (51-100)	Unhealthy for Sensitive Groups (101-150)	Unhealthy (151-200)	Very Unhealthy (201-300)	Hazardous (301-higher)	Total Days Unhealthy for Sensitive groups
PM2.5	218 days	121 days	9 days	9 days	5 days	3 days	58 days
Ozone	209 days	103 days	47 days	6 days	0 days	0 days	

The AirNow data from the EPA represents information from the year 2021 and shows a total of 58 days where PM2.5 or Ozone reached and surpassed AQI levels unhealthy for sensitive groups. Many of the AQI levels above moderate occurred during the summer months when temperatures were highest. For this reason, it is important to recognize the amplified impact increased heat has on air pollutants, which only intensifies public health risks for sensitive populations. As mentioned in the previous section, both North and South Sacramento have high heat vulnerability percentages and are in areas with increased diversity and higher levels of poverty; consequently, a multi-criteria analysis helps reveal the magnified vulnerabilities impacting these communities due to a lack of green spaces and multiple climate risks they may encounter. Green space solutions must reflect the combined risks associated with heat and air pollution, and efforts must prioritize areas that need the parks and trees investments for public health.

Figures 13 and 14 below reflect different P.M2.5 AQI data pulled from PurpleAir, which differs from AirNow as it provides more localized information; however, it is important to note that depending on the monitor, data can be less accurate. Similar to the AirNow Data, high AQI levels are observed during the hot summer months. However, the figures provide some important insight into localized levels of PM2.5 pollution in North and South Sacramento. For example, AQI data from AirNow shows good to moderate numbers after the month of September; yet, purple PurpleAir shows that P.M2.5 continues to be an area of concern well into the cooler fall and winter months. In fact, in November and December 2021, levels almost reached 200 AQI in North and South Sacramento. This suggests that averaged city-wide data does not accurately reflect localized and neighborhood-specific results. Furthermore, it suggests that unhealthy pollution levels occur in both the summer and winter months in North and South Sacramento; as a result, green spaces through tree canopy cover could be a year-round solution that protects both areas from exposure.

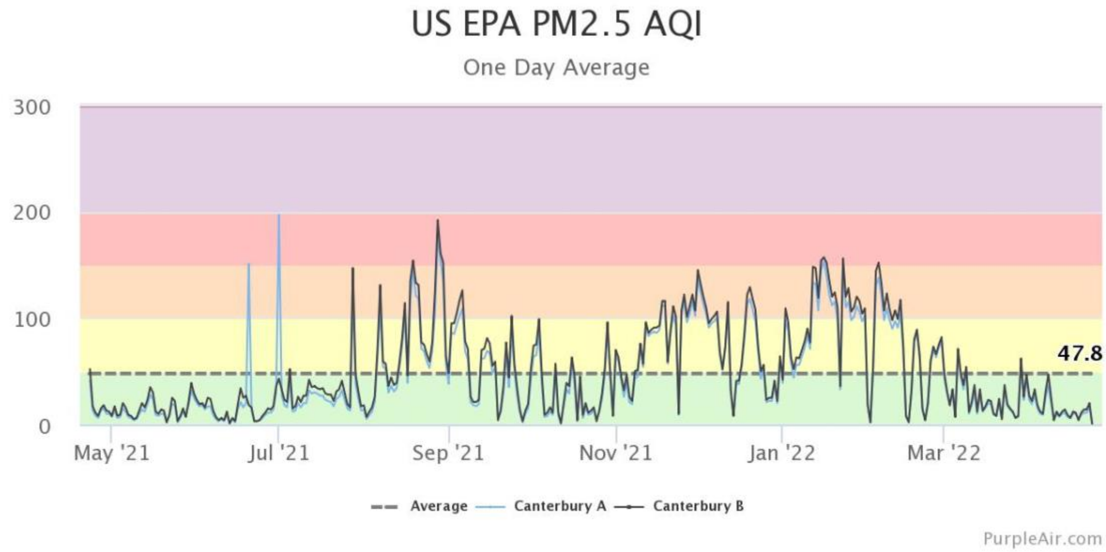

Figure 13: April 2021 to April 2021 AQI levels for Canterbury in North Sacramento (PurpleAir)

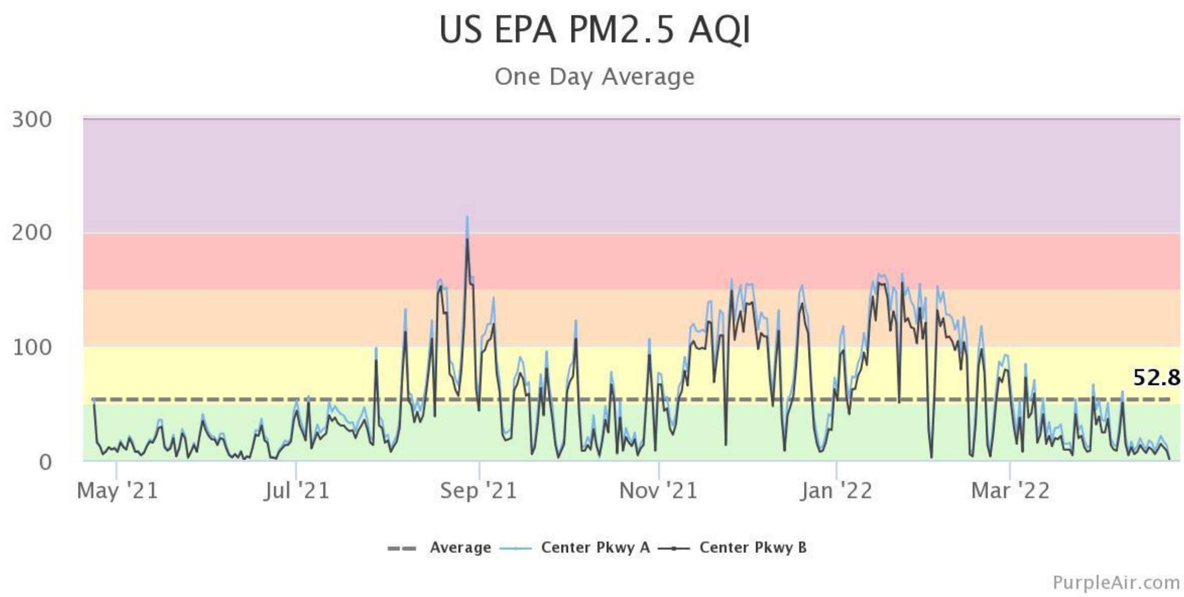

Figure 14: April 2021 to April 2021 AQI levels for Center Parkway in South Sacramento (PurpleAir)

4.3.3 Flood risk

North Sacramento South Sacramento

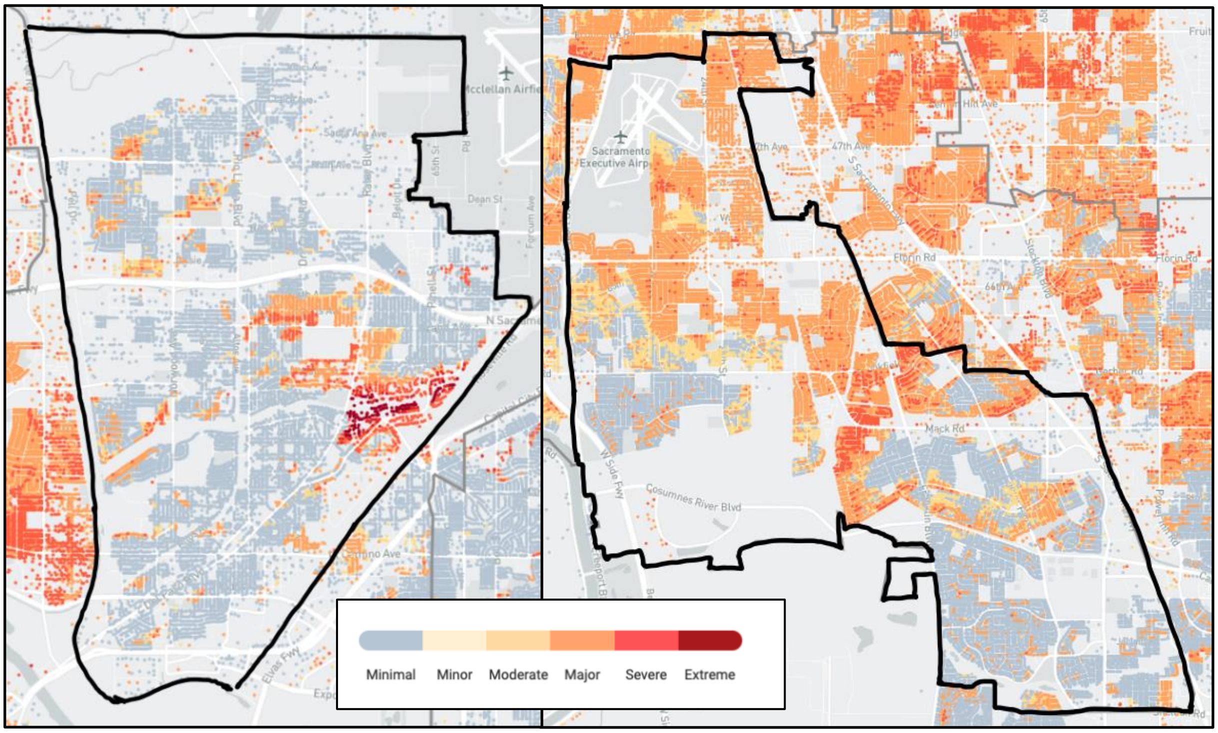

Figure 15: Flood risk for North and South Sacramento properties in the next 30 years (FloodFactor)

Data regarding flood risk in North and South Sacramento show different results for each study area. North Sacramento as an entire community is less likely to experience a flood in the next 30 years; however, unlike South Sacramento, there are properties classified with an “extreme” flood risk. The area most at risk may require strategic green space investments which complement traditional grey infrastructure solutions to reduce flood risk and expedite anticipated recovery efforts. On the other hand, South Sacramento as a community is more susceptible to flooding in the next 30 years and highlighted by the City of Sacramento as a flood zone. Results for this area range from “minimal” to “severe;” however, most properties appear to be at a “major” to “severe” risk category. For South Sacramento, planners and designers must evaluate green spaces as an entire system and coordinate park and tree configuration across the community as a whole or explore how green and blue infrastructure could better complement each other to maximize flood mitigation benefits.

4.4 Overall Findings

Table 11: North and South Sacramento green space, environmental, and social indicators

	Green Space Indicators		Indicators for Public Health and Climate Risks			Indicators Social		
	Park Cover	Tree canopy Cover	Percentage of Days above "unhealthy for sensitive groups"	Heat Vulnerability Percentile	Flood Risk	Black Population	Hispanic Population	Below Poverty Line
North Sacramento	11%	17%	16%	81%	Minimal to Minor	14%	40%	23%
South Sacramento	9%	15%		70%	Major to Extreme	22%	29%	19%

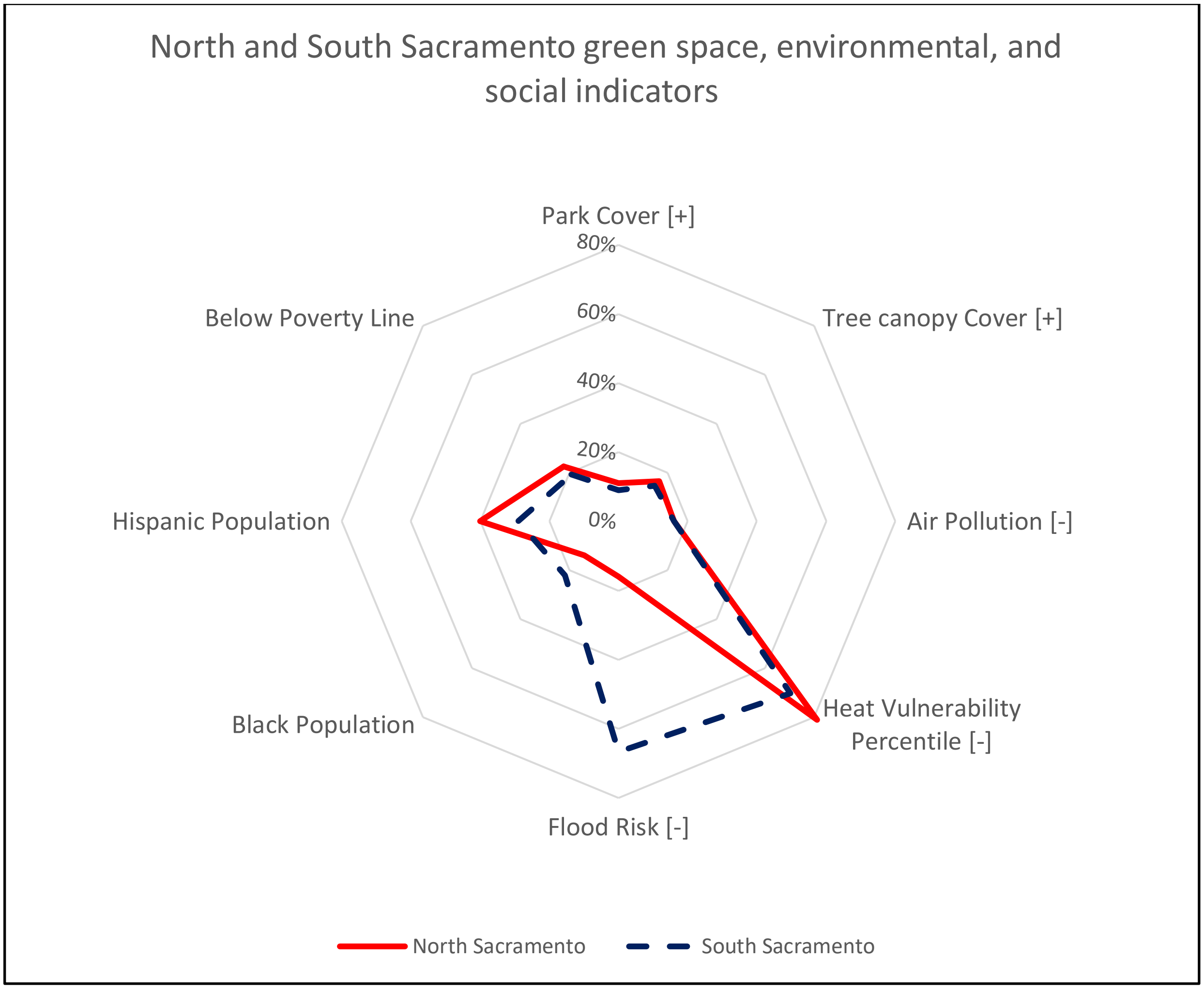

Figure 16: North and South Sacramento green space, environmental, and social indicators

This study reveals that a multi-criteria analysis does not have to be complex to understand the relationship between climate and social issues impacting urban areas. Furthermore, this research serves as an initial screening assessment that helps identify high-level problems and areas of concern so they can be explored further. The findings in this study are important because green spaces have a history of being viewed through a single lens, often only focusing on flood risk, so future implementation must account for multiple variables and indicators. This study highlights that when both socio-ecological variables are accounted for, priority areas will more accurately reflect the needs of the surrounding communities, which yields more equitable results.

After reviewing the vulnerabilities in North and South Sacramento, a series of hotspots and priority areas were identified for each community. For North Sacramento, there appears to be a lack of park space along the Northwest corner and eastern edge of the community. This area also experienced high levels of heat vulnerability, which worsens air pollution, and a more extreme possibility of flooding. While the tree canopy was higher along the eastern edge of North Sacramento, it was lower along the Northeastern corner. Nonetheless, the 2018 Tree Canopy Assessment reveals there is still significant capacity for increased tree canopy across the entire North Sacramento community. As shown in Figure 17, the Northeastern corner and eastern edge are locations that should be prioritized due to their lack of green space and multiple climate vulnerabilities. Furthermore, North Sacramento appears to be more susceptible to extreme heat than South Sacramento. Consequently, green space design and configurations should reflect efforts to provide more shade and further promote cooling benefits for the entire community.

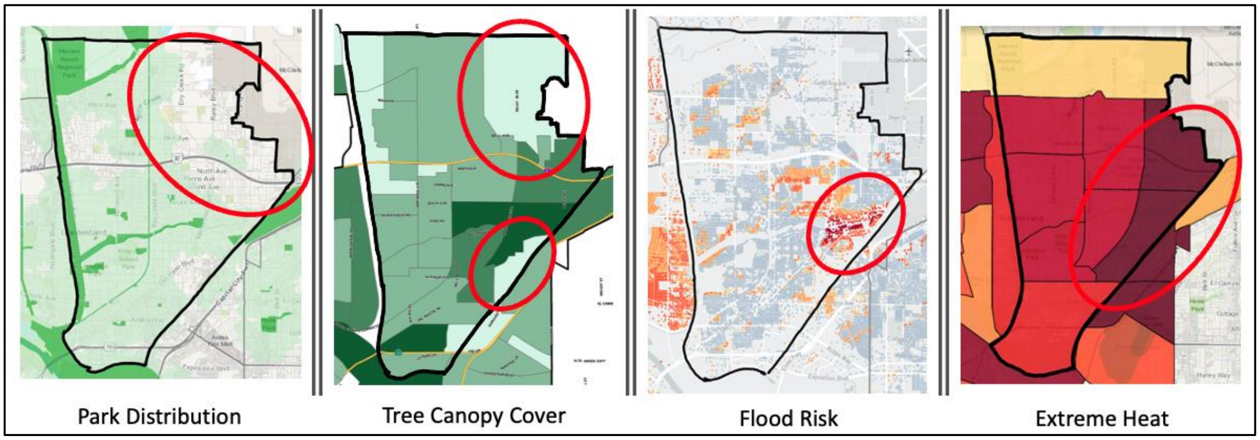

Figure 17: Priority area in North Sacramento along Northeastern and eastern edge

Green space implementation in South Sacramento will require a different focus as the area is more susceptible to flooding and less to extreme heat than North Sacramento. As a result, green spaces should reflect efforts to increase pervious surfaces and complement traditional water management tools with nature-based solutions that reroute floodwater during extreme rain events. Yet, heat vulnerability in South Sacramento, once accounted for vulnerable populations, still shows concerning numbers. As shown in Figure 18, priority areas are also identified along the middle area of the community and along the more central-eastern edge, which shows increased susceptibility to floods and high heat and limited park space, and low canopy cover. This location is also along I-99, a major freeway that makes the community susceptible to pollutants. Future green space planning must acknowledge each issue and work with needed stakeholders to develop a robust approach.

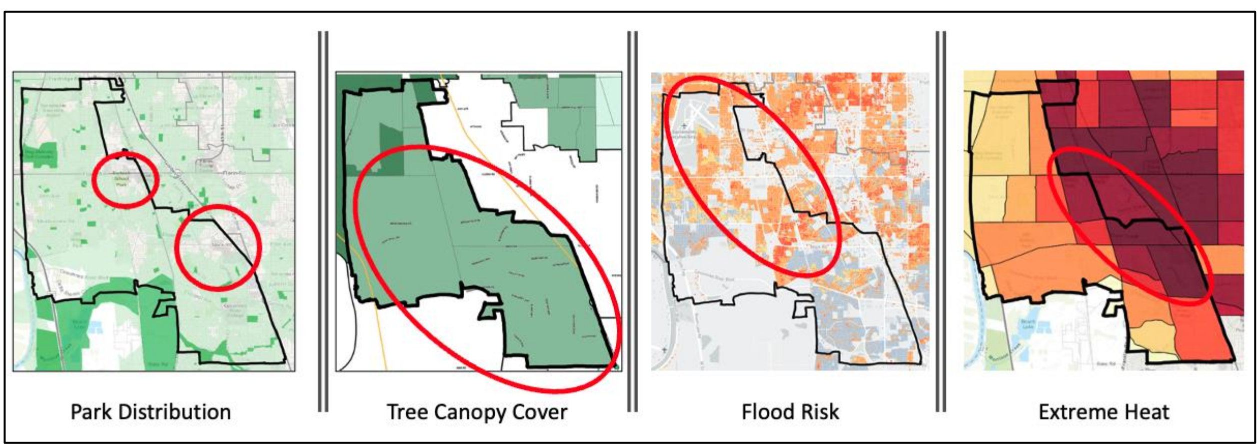

Figure 18: Priority area in South Sacramento along the center and the central-eastern edge

Overall, both North and South Sacramento can benefit from additional green spaces in the form of park and tree canopy investments. More effort must be made to increase park accessibility and distribution so it is within a 10-min walk for residents. Additionally, both communities are on the lower end of tree canopy cover with high capacities for future investments. Both communities also have increased poverty levels and include diverse populations who have been historically ignored, further leading to disproportional health and climate risks. Therefore, it is important to understand the unique components of both communities through a multi-criteria analysis so findings can be incorporated into future green spaces projects. Doing so will lead to more thoughtful green space implementation that is considerate of the immediate needs of residents as well as build neighborhoods that are better prepared for the unavoidable impacts of climate change and urbanization.

5.0 Conclusion and Recommendations

5.1 Conclusion

Green spaces are essential for promoting climate resiliency and are well documented in providing flood, air pollution, and extreme heat mitigation. However, their benefits extend well beyond environmental services as they also offer important social and cultural benefits through improved physical and mental health, economic activity, and impacts on community identity. While it is clear that green space distribution favors wealthier and whiter communities, there is an opportunity to ensure future green space investments occur in historically marginalized areas in order to meet the unique climate and social needs of those areas.

This study assesses multiple socio-ecological indicators through a multi-criteria analysis to better integrate environmental services into the future of green space implementation in North and South Sacramento. Multifunctionality on the community level better incorporates the complexity of urban areas and helps identify connections and solutions among multiple variables. Assessing for multiple indicators in North and South Sacramento helps highlight priority areas needing additional review from City of Sacramento officials. This study also reveals the unique needs of the entire community, as North Sacramento is more prone to extreme heat while South Sacramento is more prone to flooding. Overall, both areas of study can benefit from increased investments in parks and tree canopy. Still, the future implementation of green spaces should be considered from environmental justice and urban resiliency lens to ensure equitable and thoughtful green space implementation. The following section provides recommendations to encourage a multifunctional approach and opportunities to build fairer and more climate-resilient communities through green space implementation.

5.2 Recommendations

5.2.1 Assessing for multifunctionality

Green spaces must be viewed through multiple socio-ecological lenses

The foundation of this study advocates for future green spaces implementation in North and South Sacramento to be viewed through more than one lens. Currently, flood risk is the most common reason for implementing green spaces; however, the amplified risks associated with climate change require more robust planning efforts to ensure that several climate and social vulnerabilities are accounted for. Only accounting for one climate risk fails to maximize green space potential and embrace the multifunctional benefits (i.e., economic, social, and environmental services) they provide. Socioeconomic factors are also critical indicators since variables like income levels and race correlate with green space accessibility and quality. North and South Sacramento are historically marginalized communities that will be disproportionally burdened by climate change impacts; therefore, social variables must be compared alongside climate vulnerabilities. Moreover, implementing green space through a single lens could yield inequitable results that misclassify priority areas and divest green spaces away from communities that genuinely need the investment. This further perpetuates a cycle of discriminatory practices and policies experienced in North and South Sacramento.

5.2.2 Further evaluation for priority areas identified

Priority areas identified for North and South Sacramento must be reviewed further to determine the exact locations for future green spaces

This study serves as an initial environmental and equity screening for the North and South Sacramento communities, which identifies areas where green space is needed to mitigate future climate risks and uplift historically marginalized communities. Future steps will require additional work from City of Sacramento officials to give further attention to the Northwestern and western edge in North Sacramento and the middle region and central-eastern edge in South Sacramento. This study provides decision-makers and planners with general areas of focus. Yet, supplementary research will require input from experts and community members to concentrate efforts that maximize green space benefits. City officials are encouraged to use Geographic Information Systems (GIS), facilitate community outreach, and work internally with departments to identify properties to support future green space implementation.

5.2.3 Opportunity for GIS to include socio-ecological indicators

Include multiple social and ecological indicators when using GIS to determine future green space locations more accurately

Local decision-makers and planners employed by the City of Sacramento can strengthen multifunctional approaches through the use of Geographic Information Systems (GIS). There is an opportunity for the City of Sacramento to work with their GIS team to expand on the multi-criteria approach used in this study to promote equitable green space implementation. GIS can integrate Sacramento-specific information across various data sources, and this is especially helpful when addressing complex socio-ecological issues. This study highlights many disproportionalities among race, socioeconomic status, and climate vulnerabilities experienced in North and South Sacramento; as a result, it is necessary to include these variables to identify future green space locations more precisely. GIS can accurately layer the variables explored in this study and include other vulnerabilities that were not observed (i.e., public safety, loss of biodiversity, erosion), whose impacts can also be mitigated by green spaces. As a result, GIS provides an avenue to integrate similarly unique data under several scenarios to determine the best method of approach.

Additionally, GIS results can be presented in a way that weighs priority concerns which helps address the unique climate vulnerabilities observed in both areas of study. For example, North Sacramento is clearly vulnerable to extreme heat as the community is in the 80th percentile for heat vulnerability. As a result, it would be advised that green space implementation weighs extreme heat vulnerability heavier than the other data sources to ensure heat risk is minimized. On the other hand, South Sacramento is severely impacted by flooding throughout the community; therefore, flood risk should be weighted heavier when implementing green spaces to ensure communities are less prone to the economic and environmental damages floods cause. Finally, Sacramento must include social indicators like poverty levels and median household income across all green space implementation efforts to guarantee an equitable approach. Both North and South Sacramento have a history of marginalization. Incorporating GIS data reflective of race, ethnicity, and socioeconomic status will ensure that communities in need are accounted for.

5.2.4 Community and stakeholder engagement

Identify a wide range of stakeholders and community groups to provide targeted feedback

A multi-criteria approach can often be challenging as it incorporates the perspectives of many stakeholders and parties involved. This presents difficulties as these groups are often dispersed across City of Sacramento departments, neighborhoods, and nonprofits, which are often not unified under a common mission. The study helps identify Sacramento-specific stakeholders, spanning local government, nonprofit, community-based organizations, scientific communities, and residents. Representatives across multiple disciplines must be invited to the conversation about green space implementation to better facilitate a well-rounded approach to green space implementation.

From the local government side, the representatives from the Mayor and Council Offices, Office of Emergency Response (OES), Public Works, Youth Parks, and Community Enrichment (YPCE), and Utilities, as well as representatives from specific city divisions like Urban Forestry and Water Conservation should all provide input. These departments and divisions make local decisions for communities in the City of Sacramento, often helping determine the direction of funding or identifying city needs. Community-based organizations whose mission is to increase parks and trees throughout Sacramento should also be invited to the table. This includes the Sacramento Tree Foundation, the Nature Conservancy, and environmental justice-focused groups like the Sacramento Environmental Justice Coalition and the Environmental Council of Sacramento. Finally, on the community level, residents and neighborhoods are an essential component in providing input because the decisions made by the City of Sacramento departments and divisions will ultimately impact them. Consequently, decision-makers must leverage or facilitate better relationships with neighborhood associations and their constituency to ensure involvement.

Identify a boundary object or common terminology understood by all parties involved

Environmental terminology can often be exclusive and difficult to understand due to elevated definitions and complex scientific language. As a result, it is critical to identify a common term, otherwise known as a "boundary object," inclusive of all stakeholder viewpoints. For this study, a familiar term to unite green space implementation approaches should be defined as vegetation—trees, trails, parks, and gardens—which uplift historically marginalized communities and help neighborhoods adapt to the unavoidable impacts of climate impacts. This terminology includes the environmental justice work presented by community-based organizations and goals outlined by the City of Sacramento. Yet, it is simple enough to be understood by various individuals with differing levels of expertise.

5.2.5 Environmental justice

Green space implementation must not promote eco-gentrification in North and South Sacramento

This study reveals the inequitable distribution of parks and low tree canopy cover in North and South Sacramento. Both areas also have increased Hispanic and Black populations than the city average and higher levels of income inequality due to increased poverty levels. On the surface, green spaces appear to be a perfect investment opportunity for these areas due to the socio-ecological benefits. However, they can easily lead to eco-gentrification, where urban greening leads to increased prices that are only affordable to wealthy and white populations. This will defeat the purpose of green space implementation in low-income areas and will only further displace marginalized communities in North and South Sacramento. To avoid a narrow-minded approach to green spaces, decision-makers and planners must be mindful of this effect. City officials should remember that green space implementation does not need to be groundbreaking or market-driven to be effective. While North and South Sacramento need green space investments, smaller-scale urban greening projects led by community organizers within both areas should be prioritized. However, there should be coordination across multiple projects to ensure urban resiliency is implemented across green space systems. If a more extensive project is necessary, then greater efforts to engage residents to protect community culture must be considered.

Engagement must be equitable and accessible to a range of stakeholders and community members

It is important to be mindful of engagement and ensure that it also is being done from an equitable lens. City of Sacramento officials should avoid prioritizing the economic and political priorities of elite classes, which will lead to an uneven distribution of power and ultimately inequitable investments in vulnerable communities. A recommendation would be to avoid a top-down approach and ensure green space suggestions come directly from North and South Sacramento communities or non-state actors. Local Sacramento City officials, as a result, must take the role of listeners and truly work with the North and South communities to address the concerns they highlight. Failure to do so will reflect colonialism and assimilation efforts forced upon immigrant, indigenous, and African American communities noted in the history of the United States. Therefore, to truly engage the local community, local government involvement must not engage in social control but rather help communities organize and achieve their desired needs.

Hire grant writers and ensure funds are distributed in historically marginalized areas

Funding is also a component that may hinder environmental justice efforts in green space implementations. While federal and state grants exist, the City of Sacramento should set aside funds for grant writer positions to secure additional monetary funds for green space implementation. Grant writers should prioritize funding opportunities that focus on marginalized communities and areas needing green space investments to combat the vulnerabilities identified throughout North and South Sacramento. This will have a positive impact because it ensures funds reach areas that need them most. This is also a critique for grantmakers on the local, state, and federal levels. They should draft grants with specific criteria that prioritize low-income areas or cities with low park or green space percentages. Consequently, grants should outline specific requirements that ensure investments will be made in vulnerable and low-income communities that need it most, and the City of Sacramento should be prepared to access these as they become available.

5.2.6 Planning for the unique needs of communities

Green space planning and design techniques must reflect the unique climate needs of the North and South Sacramento communities

This study notes differences among climate and public health vulnerabilities experienced in North and South Sacramento. While green spaces are single solutions that can address the climate issues they will encounter, green space planning, design, and configuration must be different in order to reflect the unique needs of both community areas. North Sacramento is more impacted by extreme heat and will therefore require specific planning that includes higher tree canopy to provide shade and more opportunities for air circulation as well as increased access to high quality parks so the general public can cool themselves during extreme heat events. A large portion of South Sacramento, on the other hand, will be severely impacted by flooding in the next 30 years which will require increased pervious surfaces and strategic park placement to divert heavy rains away from homes and businesses. Additionally, both areas could benefit from strategic tree placement to mitigate and reduce exposure to the levels of air pollution both areas experience in the summer and winter months. Trees can be configured to block or disperse particulate matter and ozone from impacting communities. Overall, the planning and design approaches must embrace the multifunctional components of green spaces to maximize benefits for the community.

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