ABSTRACT

Title of Thesis:	APPLYING GREEN COMPLETE STREETS ON GEORGIA AVENUE NW: REDESIGNING AN URBAN RIGHT-OF-WAY FOR SUSTAINABLE MOBILITY AND URBAN WATER QUALITY
	Aliya Mejias, Master of Landscape Architecture, 2023
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The public right-of-way (ROW) makes up nearly one-third of all the public space in cities. With the majority global population expected to reside in cities by 2050, climate change posing a significant threat to urban residents and infrastructure, impervious urban surface impacts on water quality, and knowing traffic fatalities in the US reached a 16-year high, cities must reconsider how this public good can serve people and the environment over to car-centric mobility. Using a segment of Georgia Avenue NW in Washington, DC, this thesis removes automobiles from the ROW to demonstrate how Green Complete Streets, which prioritizes sustainable transportation and urban water quality, can support urban livability on a corridor scale.

APPLYING GREEN COMPLETE STREETS ON GEORGIA AVENUE NW: REDESIGNING AN URBAN RIGHT OF WAY FOR SUSTAINABLE MOBILITY AND URBAN WATER QUALITY

by

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Dedication

This is dedicated to all the people that have died too soon due to traffic violence. I am so sorry our society values capitalism more than life itself but you are seen and we are working on it.

Acknowledgements

First to Dr. Ellis, my thesis chair, this project exists because of your steady guidance, patience, and confidence in me. Thank you to my committee members, Dr. Ruggeri and Dr. Iseki, for your thoughtful discussions, critiques, encouragement, and eagerness to explore this topic together.

I am grateful to the entire LARC department and my cohort for creating such an inspiring, challenging, and supportive space to learn and grow. Thank you to Maryland Sea Grant for making my education possible with a paid graduate assistantship and to Jenna Clark, Dr. Mike Allen, and Hannah Cooper for your support. Jean Senechal Biggs, my lovely ASLA Mentor, thank you for helping identify the throughline of my initial proposal and for the countless hours you dedicated to my growth and development over the years. Audrey Seiz thank you for sharing your workflow and suggestions to improve the visuals and overall organization of this work. Stephanie Buglione, thank you for demystifying this profession and guidance throughout this program and project. Thank you to my fellow volunteer members of the ANC 4C Vision Zero Committee, specifically, Hannah Sheehy, Avery Ash, and Joshua Hertzberg, first, for your dedication to improve the safety of our community and for your enthusiasm and willingness to share feedback for this idea. Family and friends, thanks for your patience, love, and support as I "got through this thing."

Finally, Josh Mahan, my partner, there are no words to appropriately capture how deeply grateful I am to you.

Table of Contents

List of Figures

Chapter 1: Introduction

This project was inspired by questioning how the right-of-way (ROW) can better support livability to serve residents and ecology in cities. The ROW is the lifeblood of cities and have been recognized by urbanists such as Jane Jacobs, Donald Appleyard, and Allen Jacobs as vital public infrastructure that builds strong community bonds. But its purpose has shifted in the last 100 years from supporting human connection and providing access to opportunities, to primarily only supporting car-centric mobility. This shift has degraded our streets to become increasingly dangerous places, killing tens of thousands of people on American roadways every year. With immediate climate action needed to prevent devastating climate change-induced impacts, and over two-thirds of the global population projected to reside in urban areas by 2050, it is imperative urban areas are livable spaces for people to reside.

This thesis removes automobiles from a segment of Georgia Avenue NW in Washington, DC (DC) to demonstrate, at a corridor scale, what an urban arterial ROW could look like if sustainable transportation and urban water quality were prioritized through the application of Green Complete Streets, with the intention to support livability. It explores whether an urban ROW has enough space to serve people, mobility needs, and ecology through stormwater management. This thesis aims to achieve two goals:

1. To encourage the use of sustainable transportation and community engagement by allocating dedicated space for each transportation mode

and by increasing public space for non-modal purposes through the use of the Complete Streets model; and

2. Improve water quality by treating DC's 2-year stream protection and 15-year flood prevention stormwater runoff requirements on site using green infrastructure.

These two goals can be summarized as the application of Green Complete Streets. Impacts of Green Complete Streets are measurable and this project demonstrates how to begin to quantify and hold cities accountable to their climate action commitments. Green Complete Streets also goes beyond mobility and water quality, which is reviewed in chapter two's literature review. This thesis uses a segment of Georgia Avenue NW to begin the conversation around today's current use of the ROW in hopes society critically reconsiders its priorities in the context of climate change.

Terminology

Throughout this thesis the following terms will be used extensively: "sustainable transportation" refers to public transit, micromobility, and pedestrian travel. "Micromobility" is used to refer to human- and electric-powered lightweight vehicles that are either individually owned or shared, such as traditional pedal bicycles, electric bicycles, push scooters, electric scooters, skateboards, hoverboards, tricycles, cargo bikes, and other iterations of light-weight non-motorized vehicles. "Pedestrians" is used to refer to people in general as well as people walking or using wheelchairs/powerchairs. "Automobiles" is used as a broad term to refer to both single-occupancy and high-occupancy internal combustion engine (ICE), electric, zero emission, battery electric, and plug-in hybrid electric vehicles both privately owned and shared between individuals through private rideshare services. Finally, “Green Complete Streets” is used to combine the Complete Street design model and green infrastructure, which is further defined and discussed in the next chapter.

Chapter 2: Literature Review

This chapter provides a brief overview of literature related to the concept of livability, the Complete Streets and Green Streets model, and green infrastructure. It is structured to first define livability, characteristics of a livable community, and its importance with today’s reality of climate change. The Complete Streets and Green Infrastructure for Urban Water Quality sections define these interventions and share literature on how they relate to livability. At the end, this chapter concludes with a discussion and summary.

Livability

Livability, as a term, is used widely. Broadly, it means a place that supports a high quality of life. It can also be used narrowly within a discipline. In transportation, livability often refers to the safety, accessibility and equity of the transportation system in a community through on the ground changes and enhancements. (DDOT, 2016) The American Society of Landscape Architects (ASLA) states “livable communities are spaces that weave elements of daily life while creating ecologically, economically, and socially sustainable communities." (ASLA, 2021) They define "elements of daily life" as the following:

a) Land Use and Development
b) Housing
c) Transportation
d) Educational and Institutional Landscapes
e) Restorative and Therapeutic Landscapes
f) Parks and Open Space
g) Environmental Mitigation, Restoration and Conservation

And, ASLA outlines six principles (Fig. 2.1) of livability as:

a) Equitable and sustainable economic development
b) Housing and accessibility for all
c) Healthy and safe neighborhoods
d) Social and environmental equity
e) Sense of place and connection
f) Active transportation options (ASLA, 2021)

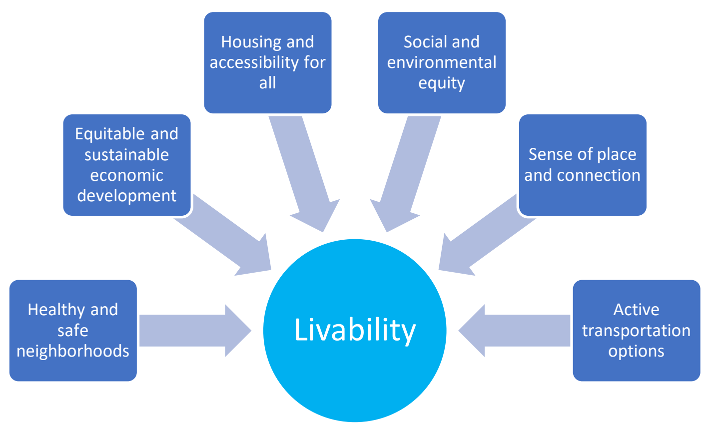


Fig. 2.1 ASLA's Six Livability Principles (ASLA, 2021)

Each principle contributes to providing fulfilling, supportive and livable communities, which theoretically would result in residents having a high quality of life. The public ROW, which includes streets, sidewalks, utilities, planting beds, and everything else between buildings seen as public, have been argued as the biggest public asset in cities as it directly influences the livability of communities. (Appleyard, 1981; Gehl, 2011; A. B. Jacobs, 1996; J. Jacobs, 1961; Loukaitou-Sideris & Ehrenfeucht, 2009; Verkade & Brömmelstroet, 2022) Allen Jacobs identifies five physical qualities all great ROWs have or contribute to:

1. create community;
2. are physically comfortable and safe;
3. encourage participation;
4. are remembered; and
5. are representative: "an epitome of a type." (A. B. Jacobs, 1996, p. 8)

To better understand how these qualities translate to physical characteristics, we can look to Donald Appleyard's *Livable Streets*. Appleyard surveyed people to understand what street characteristics they considered "very important" to consider living on a particular street, the percentage of responses included the following characteristics:

1. clean, unlittered, 86% respondents;
2. safe from crime, 86% respondents;
3. access to public transportation, 79% respondents;
4. minimal air pollution, 75% respondents;
5. attractive appearance, 74% respondents;

6. greenery, 71% respondents;
7. peace and quiet, safe from traffic, 70% respondents;
8. backyard, privacy, social and good for children, 69% respondents.

   (Appleyard, 1981, p. 50)

Some of these characteristics cause a great street and others are effects, but regardless of which is which, they all impact each other.

The ROW network has been argued as a city's "nervous system" and even ecology, formed by a series of "complex webs" that support the diverse activities, connections, and function a healthy (i.e., livable) city has. (Cervero et al., 2017, n. Jane Jacobs, "Downtown Is for People" (1958); Mehta, 2015; NACTO, 2017, p. 5). Unfortunately, the ROW's prioritization of automobile mobility in the last 100 years have resulted in the transformation of this public good into unpleasant, dangerous, and nearly impossible for other uses. (Cervero et al., 2017, Chapter 2; Global Designing Cities Initiative et al., 2015) This is explored further in subsequent sections of the literature review through the lens of Green Complete Street benefits, but is the central issue of existing urban ROW conditions that prevent livability in cities.

Urban Livability and Climate Change

The issue of urban livability is becoming more concerning with climate change and the increasing global population. The 2021 IPPC report states that, "without immediate and deep emissions reductions across all sectors, limiting global warming to 1.5-degree Celsius is beyond reach."(IPCC, n.d.) Cities are particularly vulnerable to climate change induced extreme heat and storm events due to their physical structure, concentration of people, and economic activity. (Ellena et al., 2020) As urban populations are expected to increase, hosting more than two-thirds of the global population by 2050, cities must be livable and healthy places for people to live otherwise unchecked urban sprawl, or low-density development, will increase. (Simkin et al., 2022; UN, 2019) Sprawling developments will increase habitat loss critical for supporting biodiversity. (Simkin et al., 2022) William K. Reilly, then President of The Conservation Foundation, states in the introduction of *The Social Life of Small Urban Spaces*, "quite simply, if people find cities uninhabitable, they will want to move out of them. So our challenge is to conserve both country *and* city." (Whyte, 2001) This message aligns with the United Nation's Sustainable Development Goal 15 "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss." (UN, n.d.-b) Therefore, making cities livable will encourage people to remain in them, reducing the compounding impacts the built environment has on our natural ecology. This thesis addresses the definitions and principles of livability using the application of Green Complete Streets where sustainable transportation and green infrastructure are prioritized to support, encourage, and as a means to livability.

Complete Streets

Complete Streets in the United States (US) is a comprehensive initiative that "ensure the safe and adequate accommodation of all users of the transportation system, including pedestrians, bicyclists, public transportation users, children, older individuals, individuals with disabilities, motorists, and freight vehicles." (*Infrastructure Investment and Jobs Act*, 2021; USDOT, 2023a) They not only provide adequate space, but they are intended to *feel* safe to all those that use it. (FHWA, 2022) The National Complete Streets Coalition formed in 2005 to change how roads are planned, funded, designed, and built. (McCann, 2013) Since forming, over 1,700 Complete Street policies have been adopted in the US, including DC. (DDOT, 2010; Smart Growth America, 2023) Complete Streets shift the narrative from "roads are for cars" to "roads are for all."

Green Streets

The US Environmental Protection Agency (EPA) defines Green Streets as the use of green infrastructure on roadways to reduce stormwater runoff through the interception, infiltration and evapotranspiration while supporting transportation needs. (EPA, 2021) The National Association of City Transportation Officials (NACTO) puts it best: "a flooded street is not a complete street." (NACTO, n.d.) NACTO's *Urban Street Stormwater Guide* identifies six principles of green streets:

1. "Protect and restore natural resources;
2. Promote healthy, equity, and human habitat;

3. Design for safety and mobility;
4. Design for life cycle;
5. Design for resilience; and
6. Optimize for Performance." (NACTO, 2017, p. 2)

The term "Green Complete Streets" is not trademarked and is used in this thesis to combine the concept of Complete Streets and green streets to harness goals of both models to achieve this thesis's design proposal goals, which are to provide safe, equitable, accessible and connected sustainable transportation while improving urban water quality through the application of green infrastructure (nature) within the ROW.

Design Model

There is not a set guidebook to follow if a jurisdiction wants to implement Complete Streets in their community. Instead, the Federal Highway Administration (FHWA) encourages context-sensitive design, which prioritizes safety for all users, to apply appropriate interventions to achieve a Complete Streets system. (FHWA, 2022) Fig. 2.2 displays the five components of the Safe System Approach, which is the U.S. Department of Transportation's (USDOT)

National Roadway Safety Strategy guide. The National Roadway Safety Strategy and Safe System Approach (SSA) were adopted by USDOT to achieve the long-term goal of zero roadway deaths. (USDOT, 2023a) Complete Streets supports safe speeds using safe road design, construction, and operation (i.e., traffic signals). (FHWA, 2022)

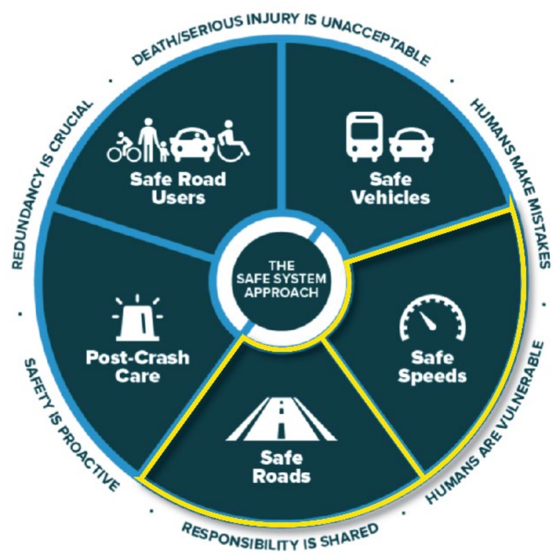


Fig. 2.2 The Safe System Approach combines five strategies to seek zero death fatalities, Complete Streets applies safe roads that support safe speeds (yellow). (FHWA, 2022)

Though the Complete Streets model does not have a specific guidebook, there are many streetscape, bicycle, transit, and traffic safety standards. For this thesis, pedestrian, transit, and micromobility (see Terminology) were the primary mobility focuses as they are more efficient in their energy and spatial usage. (Reed, 2019)

The following subsections provide a brief summary of ROW design standards and guidelines referenced for this thesis. Washington D.C.'s Department of Transportation's (DDOT) Design and Engineering Manual, Public Realm Design Manual, and Bicycle Facility Design Guide were reviewed for DC-specific requirements. (DDOT, 2019a, 2019b, 2020) Guides by the National Association of City Transportation Officials, Silver Spring (Maryland), New York City (New York), San Francisco (California), and Portland (Oregon) were referred for other components of the ROW. (MNCPPC, 2019; NACTO, n.d., 2013, 2016b, 2016a, 2017, 2023; NYC DCWP, 2020; Opfell & DeLuca, 2019; PBOT, 2021) A more robust list of references are included in the bibliography.

Sidewalk Design

Sidewalks are a general term used for the space dedicated for the movement of pedestrians. (MNCPPC, 2019, p. 13) Sidewalks can be broken down into different zones: pedestrian through zone, planter/furnishing zone, frontage zone, and curb zone, Fig. 2.3 illustrates these zones. (Ibid., p. 7) The pedestrian through zone is the area of the sidewalk dedicated for clear pedestrian passage without obstructions. (Ibid.) The planter/furnishing zone is the area dedicated for street trees and other planting material, as well as the space traditionally used to install public benches, bicycle racks, lighting, and other public amenities. (Ibid., p. 8) The frontage zone is the area directly adjacent to buildings and acts as a transition space between the building and pedestrian through zone. DC does not have specific frontage requirements other than limitations for bay window projections; instead, DC requires a minimum of clear passage for pedestrians and set specific widths depending on land use. (DDOT,

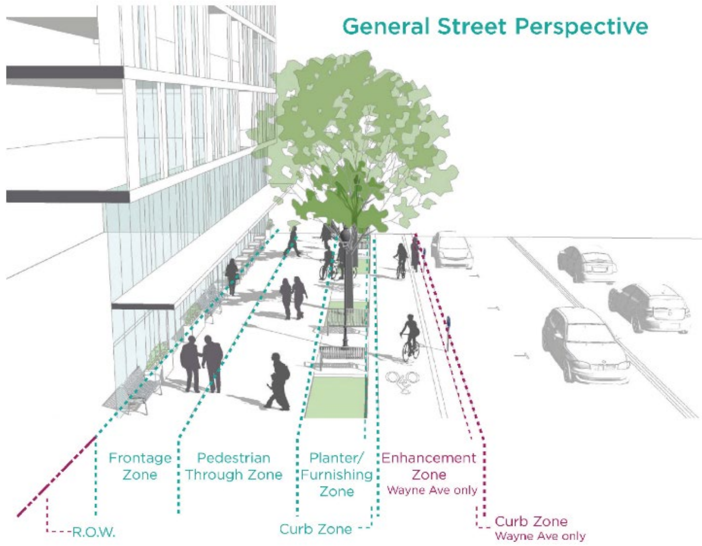


Fig. 2.3 "General Street Perspective," taken from Silver Spring's Streetscape Standards, delineates the sidewalk zones. (MNCPPC, 2019, p. 7)

2019b, pp. 5–9) The curb zone allows access between parked vehicles and pedestrians.

According to DC's Public Realm Design Manual, this clear passage must be at least 6 ft wide with an additional buffer of 4 ft, ideally 6 ft, for trees. (DDOT, 2019b) The Public Realm Design Manual states a sidewalk's unobstructed clear path for commercial areas require 10 ft at minimum, and 7 to 10 ft for streets with vendors. (Ibid., 3-4). DC's Design and Engineering Manual states collector and commercial streets should have sidewalks 8 to 10 ft wide, which contradicts the Public Realm Design Manual. (DDOT, 2019a, pp. 30–17) Fig. 2.4 illustrates the spatial designation of the ROW in DC. (Ibid., p. 3-3) The absolute minimum unobstructed width of sidewalks is 4 ft to accommodate wheelchair access. (DDOT, 2019a, pp. 31–33)

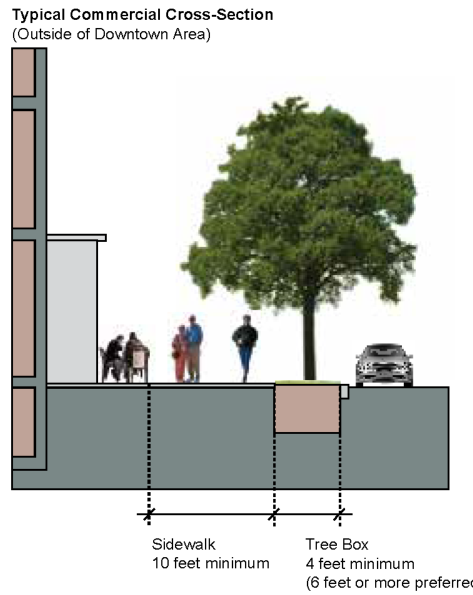


Fig. 2.4 "Typical Commercial Cross-Section (Outside of Downtown Area)" displays spatial relationship between sidewalk and tree planting area for DC. (DDOT, 2019b, p. 3-3)

Sidewalk cafes in DC are not required to have a minimum width to operate, instead they are required to provide at least 15 square feet for every seat. (DDOT, 2019b, pp. 3–14) Silver Spring, Maryland recommends frontage zones be at least 5 ft wide to accommodate business functions such as café seating. (MNCPPC, 2019) New York City's "small unenclosed cafes" can take no more than 4.5 ft of ROW width. (NYC DCWP, 2020)

These dimensions then should be applied to the concept of human spatial relationships. The basic scales of space are intimate (one-half foot to one foot), personal distance (1.5 ft to 4 ft), social distance (4 ft to 12 ft), and public distance (12 ft or more). (Hopper, 2007, p. 76).

Bicycle and Micromobility Infrastructure

The DC Bicycle Facility Design Guide states 6 ft wide bicycle lanes are preferred, 5 ft is the minimum width, but lanes may reduce to 4 ft when adjacent to curb gutters. (DDOT, 2020, pp. 2–1) The minimum buffer width, which separates micromobility users from other vehicles on the roadway, is 18 in but 3 ft is preferred. (Ibid., p. 2-2) NACTO also states 6 ft bicycle lanes are preferred, but as narrow as 3 ft is permitted when adjacent to a street edge and in tight conditions. (NACTO, 2013, p. 6) NACTO encourages these minimums to be challenged as wider facilities permit users to cycle side-by-side and increase overall comfort for users. (Ibid.) Portland, Oregon is an example where these widths are challenged, slightly. Portland uses peak hour bicyclist volume to determine bike land width minimums and preferences. (PBOT, 2021, p. 24) Though at the most constricted areas with short distances are permitted to construct 4 ft bike lanes, 5 ft is their minimum for roadways with less than 150 riders per hour and 6.5 ft is preferred. (Ibid.) For more than 750 riders per hour, 8 ft bike lanes are the minimum and 10 ft bike lanes are preferred. (Ibid.)

Protected bicycle lanes are facilities with a physical barrier separating different road users to increase safety. In one study, protected bicycle lanes had a 28% lower injury rate than roadways without dedicated bicycle infrastructure.

(National Association of City Transportation Officials, 2014, p. 30) Zilca Zebras, wood, movable planters, concrete wheel stops, pre-cast concrete slabs, rails, flexible post delineators, and cast-in-place/granite curbs are examples of different physical barriers used as design interventions in DC to create protected bike lanes. (DDOT, 2020, pp. 3–9) Buffer widths to host these barriers can range from a minimum of 6 in (flexible post delineator) to 5 ft (moveable planter). (Ibid.)

Traditional bicycle infrastructure guidelines were standardized prior to the increase in micromobility choices, but the standard pedal bike is no longer the sole user. (NACTO, 2023) Today, micromobility options include inventive vehicles such as pedal, electric, and adaptive (i.e., sit-down) scooters; pedal and electric cargo bicycles and tricycles; standard electric bicycles; and powered skateboards. In the United states, electric bicycle sales tripled between 2019 and 2021 and there have been over a half billion trips using shared micromobility systems (i.e., bikeshare and shared electric scooters) since 2010. (Ibid., p. 3) Additionally, it is projected more companies will shift to electric cargo bikes for last-mile deliveries due to their economic and efficiency benefits. (Lee et al., n.d., p. 122; Reed, 2019) NACTO published a new working paper in early 2023 to demonstrate the needed

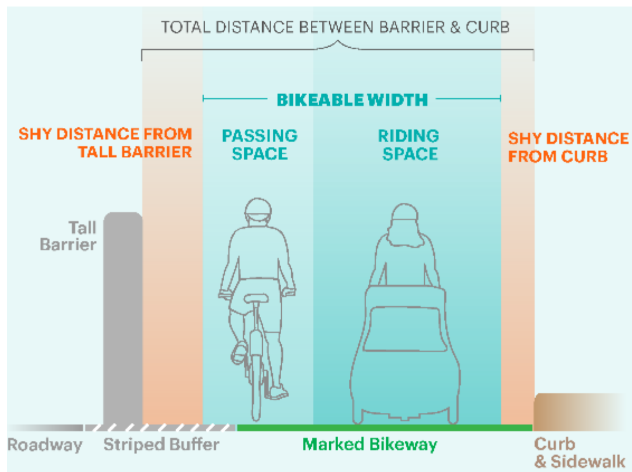


Fig. 2.5 Illustration taken from NACTO of spatial needs for safe passing in bicycle lanes. (NACTO, 2023, p. 10)

space for safe accommodation of these new modes as they vary by size and speed (Fig. 2.5). (NACTO, 2023) Their findings recommend minimum 9.5 ft for one-

Design bike passing space representing the faster rider passing	Control bike riding space representing the slower rider being passed		
	Typical bike Riding space is 4-5 ft (1.2-1.5 m)	**Cargo bike** Riding space is 4.5-5.5 ft (1.4-1.7 m)	**Extra-large bike** Riding space is 6.5-7.5 ft (1.9-2.2 m)
Typical bike passing Passing space is 3 ft (0.9 m)	7-8 ft (2.1-2.4 m)	7.5-8.5 ft (2.3-2.6 m)	9.5-10.5 ft (2.8-3.1 m)
Cargo bike passing Passing space is 3.5 ft (1.1 m)		8-9 ft (2.5-2.8 m)	10-11 ft (3.0-3.3 m)
Extra-large bike passing Passing space is 5 ft (1.6 m)			11.5-12.5 ft (3.5-3.8 m)

Fig. 2.6 "Bikeable width needed for passing on a one-way bikeway." (NACTO, 2023, p. 12)

way bike lanes to accommodate a typical bicycle to pass an extra-large bicycle (Fig. 2.6). Unfortunately, this publication was not available until after the final site plan was designed but highlights how traffic design standards are shifting.

Public Bus Transit Design

NACTO states curbside bus lanes should be between 11 and 12 ft and center running can be 10 ft wide. (NACTO, 2016b) In-lane stops save time as the bus does not need to navigate into a designated boarding zone. (Ibid.) This can either be achieved through sidewalk expansions to bring bus stops closer to the travel lane or using transit islands. Fig. 2.7 is an example of a transit island with a raised crossing within a two-way bike lane, taken from Walk San Francisco’s Getting to The Curb Guide. (Opfell & DeLuca, 2019) This intervention maintains pedestrian access to transit stations while reducing potential injury if a collision occurs with a vehicle – in this case, bicycles – as it reduces vehicles' speed. (Ibid.)

Fig. 2.7 "Two-way protected cycle track with a wide raised crossing to a transit island." (Opfell & DeLuca, 2019)

Regarding bus stop requirements, a single 40-foot bus must have at least 100 ft in length designated as the bus zone prior to the bus stop pole. (DDOT, 2019a) The bus stop pole must be no closer than 5 ft from crosswalk. (Ibid.) Single 60-foot articulated buses must have at least 120 ft dedicated as the bus zone. (Ibid.)

Safe Pedestrian Crossing Interventions

Pedestrian facilities also must be designed in safe and accessible ways, beyond appropriate widths of sidewalks and meeting American Disability Act requirements. "Inconvenient deviations [of pedestrian paths and crosswalks] create an unfriendly pedestrian environment." (NACTO, 2013, p. 113) NACTO's Urban Street Design Guide suggests studying pedestrian networks, desire paths, and overall built environment conditions to determine pedestrian connection improvements. (Ibid., 111) Reducing crossing distances and increasing connections will prevent pedestrians from deviating from safe crossing areas. (Ibid.) Raised crosswalks, as previously discussed in the application to access a transit island, reduce vehicular speed and "have been shown to increase motorists' yield rate by as much as 45%." (NACTO, 2013, p. 165)

Benefits

This section discusses the benefits of Green Complete Streets that support urban livability. This includes health and safety, biophilia, economic, social, environmental, and equity.

Health and Safety

Complete Streets address health and safety in two ways: the first, is through the design, construction, and operation of traffic infrastructure – or, the physical experience of the roadway – to create safe roads. (FHWA, 2022) Safer roads lead to safer speeds that then prevents life-threatening consequences if/when two modes collide. (Ibid.) The second way Complete Streets address health and safety is in the post-adoption of sustainable multimobility (the use of multiple sustainable transportation modes) as Green Complete Streets are a climate adaptation strategy to make cities more livable and improve people physically and psychologically.

In 2021, 42,915 people died on American roadways, a 16-year high in 2021, with 13% and 5% increases for pedestrians and pedal bikes, respectively, from 2020 to 2021. (NHTSA, 2022; USDOT, 2023b) Despite less drivers on our roads due to COVID-19, traffic deaths increased. Pedestrian deaths disproportionately impact people of color, low-income residents, and older adults. (Smart Growth America, 2022) And these alarming realities have pushed for national safety initiatives such as Vision Zero, Complete Streets, and the larger umbrella of SSA. (DDOT, 2014) DC adopted a Vision Zero campaign in 2015 to remove all traffic related death fatalities in the city by 2024. (DDOT, 2015) Dangerous streets do not support livability and federal initiatives like SSA demonstrate the dire need to reprioritize the ROW's purpose and design.

Safe roadway design has a direct correlation to the use of sustainable transportation. A study from 2022 found the leading barriers for adults to use bicycles as transport was having to share roads with motor vehicles. (Pearson et al., 2022) And, well-connected bicycle networks have been shown to increase bicycle, and other micromobility, use. (Shi, 2020) A study cited in Alison Sant's *From the Ground Up* found protected bike lanes significantly increase ridership and has a snowball effect on safety for cyclists: as more people feel safer to bike, more people do, which increases cyclists' visibility on roadways, which further increases safety. (Sant, 2022, art. Monsere et al., 2014) The FHWA recently published a study on six US cities that found upgrading traditional bicycle lanes to be protected resulted in lowering the expected crash rates by half. (FHWA, 2023) But, safe infrastructure must be provided for all modes, not just vehicles (i.e., automobiles and micromobility), and pedestrians need adequate infrastructure as well. One study found sidewalks with a buffer strip and street trees impacted parents to walk to school and improved their perception of roadway's safety and willingness to allow their children to walk. (Kweon et al., 2021)

Speck's book *Walkable City Rules: 101 Steps to Making Better Places* cites a study from Massachusetts Institute of Technology that found vehicle emissions were the leading cause of premature deaths from air pollution. (Speck, 2018) Dangerous pollutants from motor vehicle use and fuel combustion, such as Carbon Monoxide (CO), Nitrogen Oxides (NOx), Ozone (O_3) and Particulate Matter (PM) all have serious health impacts on humans. (Alemani et al., 2018; FHWA, 2016) And exposure to these pollutants can have compounding effects. An early study done during the COVID-19 pandemic found an increase in the long-term average PM exposure was linked to significant COVID-19 mortality rate. (Wu et al., 2020) Shifting to sustainable multimodal transportation has found to both improve health benefits and reduced the number of years lost from heart disease. (Woodcock et al., 2009) Safer facilities for walking also reduce deaths caused by car crashes and air pollution exposure. (Speck, 2018)

Noise pollution has direct negative impacts on the health of people and livability of communities. (Chepesiuk, 2005) Road traffic is "a dominant noise source in urban" environments with volume of traffic, speed of traffic and number of trucks as variables contributing to noise levels. (FHWA, 2011; USDOT, n.d.) A 2020 study found overall significant reductions in urban noise during the COVID-19 lockdown in the United Kingdom. (Aletta et al., 2020) The authors recognize the pandemic lockdown's significant reduction in overall people in urban environments as an extreme case but suggest "infrastructural changes (*e.g.*, a change in vehicles fleet, reduction of volumes of car traffic in favor of other types of mobility, etc.) should be implemented" to support reduction in noise pollution. (Ibid.) Complete Streets permits the shift from primarily noisy automobiles to quieter modes such as micromobility and electric bus transit. (Borén, 2020) Increasing vegetation in the ROW using Green Complete Streets can further reduce noise pollution exposure as vegetation can shield people from exposure, absorb some noise pollution, and can positively impact peoples' perception of noise exposure. (Perez & Perini, 2018, Chapter 3.9)

Cities experience significantly higher temperatures than outlying areas due to an environmental phenomenon called Urban Heat Island (UHI). (EPA, 2022a; Zhu et al., 2017) DC is expected to experience an increase in extreme temperature due to climate change, which will be exasperated due to UHI. (DOEE, 2021, 2022) Historically, DC experiences 13.1 "extreme heat days" (above 95°F) per year. (DOEE, 2021, tbl. 3) If emissions are not reduced significantly, DC is projecting over 70 days with temperatures above 95°F and 106 days with a heat index above 95°F in 2080. (Ibid.) Extreme heat is the leading cause of weather-related mortality and the World Health Organization expects it to be the leading cause of additional deaths due to climate change. (Ellena et al., 2020) Green Complete Streets will reduce UHI as additional trees and vegetation cools surface and air temperatures through evapotranspiration, shade, and reducing atmospheric carbon-dioxide (CO_2) through storage and absorption. (EPA, 2008; Perez & Perini, 2018, p. 324)

Theory of Biophilia

It is worth mentioning the theory of biophilia, popularized by Edward O. Wilson, which is defined as "the innately emotional affiliation of human beings to other living organisms. Innate means hereditary and hence part of ultimate human nature." (Kellert & Wilson, 2013, p. 31) Studies supporting the evidence of nature's important role in improving quality of life is mounting and has led to the application of biophilic design, such as the "biophilic city." (Beatley, 2011) Biophilic cities are urban areas with abundant nature through the mindset of both increasing nature for the improvement and restoration of both the urban and natural environment, and where people can enjoy the splendor of nature. (Ibid.) The concept goes beyond a single narrative such as "nature for nature's sake," or beneficial environmental services. (Ibid.) Biophilia and biophilic cities center on the "innate" connection humans have with nature. And fostering this connection have shown to support conservation efforts. (Turner et al., 2004) Green Complete Streets prioritizes the application and increase of nature in the ROW and should be a strategy used to apply the concept of biophilia.

Economic

Transit-oriented development (TOD) is concentrating urban development along public transportation corridors. For a much lower social, economic and environmental cost, these projects create walkable and accessible communities that increase people's access to jobs, housing and recreation opportunities. (Cervero et al., 2017) Walkable communities have shown to improve property values, attracts young talent for jobs, creates more and better jobs, reduces personal costs on transportation, and reduces subsidies and externalities associated with road maintenance. (Speck, 2018, p. 2) A study from 2021 found bicycle lanes adjacent to retail and food businesses had a positive or nonsignificant economic impact, even when travel lanes or car parking was removed. (Volker & Handy, 2021)

Social

Jan Gehl writes in *Life Between Buildings* that improving conditions for outdoor stays that encourage more people use public spaces and stay for longer periods of time is the key way to improve quality of life. (Gehl, 2011, p. 79) Though the application of Green Complete Streets shift spatial priorities to support non-modal activities that support urban life, dedicating the minimum width requirements for each specific mode will not alone result in strong community bonds if there is not enough space to encourage lingering. (Global Designing Cities Initiative et al., 2015, p. 35) Improving the ROW environment encourages people to spend more time there, which creates a positive feedback loop as people want to spend time where other people are. (Gehl, 2011; Whyte, 2001) Fig. 2.8 is taken from *Life Between Buildings*, representing the relationship between how optional activities greatly improve in frequency when

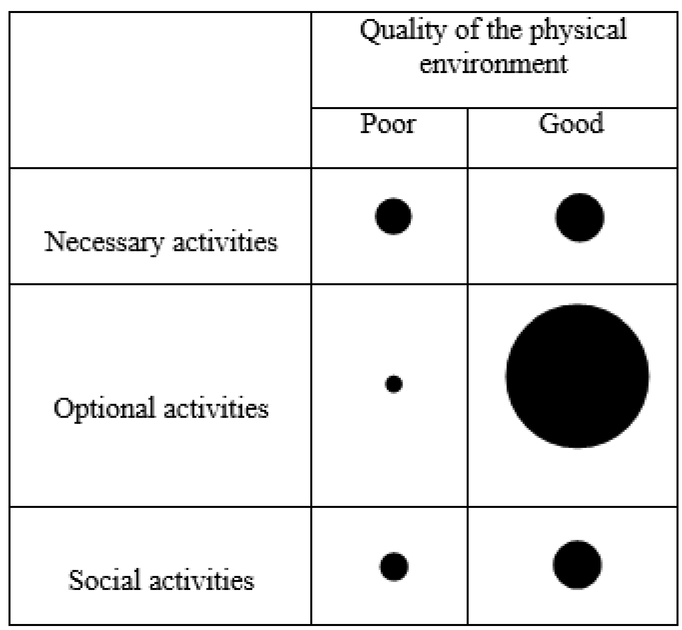


Fig. 2.8 Relationship between activity type and quality of physical outdoor environment, circle size represents frequency of occurrence and higher frequency. The optional activities greatly increase in occurrence when the outdoor space is better as only these activities are likely to occur if conditions support engagement. (Gehl, 2011)

the outdoor environment is supportive for them. Optional activities and overall increase in street use create opportunities for organic interactions between neighbors. (Ibid.)

Eric Klinenberg, author of *Heat Wave: A Social Autopsy of Disasters in Chicag*o and *Palaces for the People*, writes of streets, and other public commons such as public libraries, as social infrastructure that creates strong community connections. His study A study found communities where neighbors checked in on each other during the 1995 Chicago heatwave was a key indicator for their survival that killed 739 people. (Sant, 2022, p. 164) This ties back to the health and safety of a community in relation to climate change, communities that have caring relationships between neighbors could be less impacted by harmful exposure to environmental conditions, such as extreme heat, than those without. (Ellena et al., 2020; Sant, 2022)

Though the application of Green Complete Streets begin to shift spatial priorities in support of more diverse uses, dedicating the minimum width requirements for each specific mode will not alone result in these types of community bonds. (Global Designing Cities Initiative et al., 2015) Green Complete Streets is just one component of the six principles of liability, it begins to reshape the ROW to better serve people over automobiles, but it still prioritizes mobility over place.

Environmental Impact

Cities often get a lot of negative attention for being toxic, pollution filled spaces as they are responsible for around two-thirds of the world's greenhouse gas emissions. (UN, n.d.-a) Deeply reducing cities' emissions and shifting to climate resilient development are critical in preventing global temperature increases, and the IPCC identifies public transport and active mobility (i.e., micromobility) as effective adaptation and mitigation strategies. ("IPCC AR6 SYR SMP," 2022)

Currently, the transportation sector contributes the largest proportion of GHG in the US, responsible for 27%. The top two contributors to this figure are cars, 57%, and trucks, 26%. (US EPA, 2015) Electric vehicles are often touted as the transportation sector's climate change solution, pushing for internal-combustion engine (ICE) vehicles to electric, but electricity is responsible for 25% of the US's GHG emissions. (Ibid.) And a study found that reducing the overall total vehicle miles traveled (VMT) is critical in meeting climate targets, rather than just shifting all internal combustion engine automobiles to electric. (Alarfaj et al., 2020) Which is why cities pose great potential for the adoption of Green Complete Streets as urban areas have greater density that is better suited for sustainable transportation.

According to the Intergovernmental Panel on Climate Change, shifting to sustainable transportation, as defined by this thesis (see Terminology), will play a direct role in reducing global GHG emissions. ("IPCC AR6 SYR SMP," 2022) A study from 2015 found if a dramatic shift in cycling worldwide could cut CO_2 emissions by 11%. (Mason et al., 2015) Studies have shown transit-oriented developments that prioritize people-oriented design, in addition to providing reliable, high-quality transit, were most successful in reducing car dependence. (Cervero et al., 2017, p. 10) And a 2008 study found that shifting the shortest trips, less than a mile, with walking or biking could prevent between 12-22 million tons of CO_2 emissions annually. (McCann, 2011) Shifting the ROW to accommodate more efficient and sustainable transportation will lead to a shift in mode choice that will reduce overall VMT and associated GHG impacts.

Reallocating ROW space to accommodate public transit and micromobility can lessen environmental impacts beyond GHG emissions the transportation sector has. Specific best management practices to improve urban water quality is discussed in the next section, but it is important to recognize how shifting to sustainable modes of transportation will also reduce overall pollution entering the environment in the first place. Particulates, heavy metals, nutrients, chloride, sulfates, PCBs, pesticides, cyanide, petroleum and ethylene glycol are all primary sources of highway runoff (Fig. 2.9) and release polycyclic aromatic hydrocarbons (PAHs). (EPA, 2004b, p. 353) These pollutants directly impact the

Table 7.1: Primary sources of highway runoff pollutants (Adapted from NCHRP, 1999).

Pollutants	Primary Source
Particulates	Pavement wear and vehicle maintenance
Lead, cadmium, copper	Tire wear, lubricating oil and grease, bearing wear
Nitrogen, phosphorus	Roadside fertilizer application
Chromium, copper, nickel, cadmium	Metal plating, moving engine parts, brake lining wear
Chloride, sulfates	Deicing salts
PCBs, pesticides	PCB catalyst in synthetic tires, spraying highway rights-of-way
Cyanide	Anti-cake compound used to keep deicing salt granular
Petroleum, ethylene glycol	Spills and leaks of motor lubricants, antifreeze, hydraulic fluids

Fig. 2.9: "Table 7.1: Primary sources of highway runoff pollutants (Adapted from NCHRP, 1999)." (EPA, 2004)

health and survival of aquatic species and overall water quality health. (Ibid., p. 355) In 2004, 50 to 68% of DC’s brown bullhead catfish that inhabits the Anacostia River were found to have liver tumors and 13 to 23% had skin tumors from PHAs created from motor vehicles. (Ibid., p. 352) Public transit, especially ICE buses, emit similar pollutants and PAHs. (Gao et al., 2015) And manual bicycles do not have combustion engines but require tires, deicing salts for roadway use, and other petroleum-based products to function (i.e., lubricants). However, most emissions related to motor vehicle transportation are related to air quality and studies on shifting to sustainable micromobility are hopefully being explored. For the purposes of this paper, the assumption of shifting transportation mode to sustainable transportation will have an overall reduction in pollutants generated by automobiles. (Just Economics, 2022; Lee et al., n.d.)

Green Complete Streets also provide opportunity to support urban ecology and biodiversity. This is achieved through the general concept of increasing nature (plants) to treat stormwater runoff. Biodiversity and ecological health of urban environments can improve when ecological principles, such as appropriate plant selection for the existing site conditions, are followed. (Beck, 2013, Chapter 1) Rather than focusing on fragmented green space within urban communities, urban ecology should consider the overall matrix of the city's connected ecology. (Ibid., p. 242) This matrix is well suited for the connected web of corridors and hubs urban ROWs and public green spaces create. (Perez & Perini, 2018, p. 253) Studies have shown the application of green streets have led to increases in urban biodiversity due to this structure. (Ibid.) Reducing space allocated to automobiles use within the ROW allows for an increase of vegetation and habitat for all urban species to benefit.

Equity

Safe, accessible, and well-connected sustainable transportation networks should be available to all people regardless of their demographics because it provides people with freedom and choice. There are 41.8 million adults with disabilities, 40 million seniors, and 32 million people living below the poverty line in America and nearly one-third of Americans cannot drive. (FHWA, 2022; Speck, 2018; Zhao et al., 2013) A Green Complete Street has accessible sidewalks, affordable public transportation, and safe micromobility infrastructure to ensure everyone can access and use these resources to get to where they need. These features are also critical for maintaining independence and access for under-served groups. Low-income households were found to spend 37% of their post-tax income on transportation, which significantly reduces the remaining funds for other necessities. (*Equity Action Plan*, 2022) Transit disproportionately serves women, low-income and minority groups, and improving walkability has a disproportionately positive impact for people with disabilities. (Criado-Perez, 2019, Chapter 1; Speck, 2018) Additionally, modal shifts to transit and micromobility from automobiles will reduce pollution and traffic deaths that disproportionately affect marginalized communities. (FHWA, 2022) And, as discussed in the Health and Safety section, pedestrian deaths disproportionately impact people of color, low-income residents, and older adults. (Smart Growth America, 2022).

Access to nature is not equal across demographics either. Ten cities were analyzed in a study to better understand the distributional equity of urban vegetation. (Nesbitt et al., 2019) The report concludes that “urban vegetation is inequitably distributed in multiple urban areas in the US, and that this inequity is associated with traditional socioeconomic divisions in many cases.” (Ibid.) Jessica

Sanders, former director of Casey Trees a DC-based nonprofit, speaks on this point in Sant's *From the Ground Up*:

> *People interact with street trees the most. When they think about where they want more trees planted, it's on the streets. The streets really are the first thing they see in the morning. That may be the most interaction that they're getting with nature all day. (Sant, 2022, p. 136)*

Therefore, the application of Green Complete Streets within the public ROW can directly increase the amount of access to nature an urban resident has on a daily basis. Which, tying back to biophilia, can be beneficial to the physical and psychological wellbeing of urban residents while also building stewardship for the natural environment, creating a positive feedback loop. (Beatley, 2011)

Two specific points of concern arise from this inequity in regards to access to nature in urban spaces in relation to Green Complete Streets. The first is to ensure the application of Green Complete Streets are applied equitably. DC's 2021 Sustainability Plan includes an emphasis "of improving access to small parks and natural spaces in underserved areas of the city with less access to these resources currently." (DOEE, 2018). The second is related to green gentrification. Nesbitt & Quinton write green gentrification typically results from "applying a top-down 'green is always good' approach to greening that does not consider the needs and desires of local communities or their potential vulnerability within a capitalist system." (Nesbitt & Quinton, 2023) The authors suggest efforts must be grounded in context sensitive design and challenging "the systems that created harm in the first place." (Ibid.) This project scope does not include strategies to prevent green gentrification and recognizes the impact this proposal could have on the community if implemented.

Green Infrastructure for Urban Water Quality

Historically, cities were designed to remove stormwater from roadways and structures as fast as possible through a series of gutters and pipes, also referred to as “gray infrastructure.” The combination of impervious surfaces (up to 80% in some urban areas) and channelized rerouting of stormwater directly impacts our hydrological and ecological systems. (NACTO, 2016b; Walsh et al., 2016) Large areas of impervious surfaces lead to both increase of volume and speed of stormwater runoff, which directly impacts sewer system capacity and degradation of both water quality and stream bank erosion. (DOEE, 2020) In 2009 President Barak Obama issued Executive Order 13508 on Chesapeake Bay Protection and Restoration as its considered a “national treasure.” (Executive Order No. 13508, 2009) The order is "to protect and restore the health, heritage, natural resources, and social and economic value of the nation's largest estuarine ecosystem and the natural sustainability of its watershed.” (Ibid.) The US Clean Water Act formalized states’ requirements for establishing total maximum daily load (TMDL) calculation of pollutants permitted to enter waterways to ensure water quality standards. (EPA, 2022b) This project uses green infrastructure to reduce impacts of stormwater runoff on urban water quality and seeks to reduce potential pluvial flooding.

Green infrastructure is the application of nature to “attenuate, restore, and recreate a more natural flood response, bringing hydrological responses closer to preurbanized conditions” to reduce impacts on water quality and ecologies, and pluvial flooding. (Green et al., 2021; Nazarpour et al., 2023; Walsh et al., 2016) Green infrastructure installed in Philadelphia was evaluated and results were overall a success, surpassing the expected infiltration rates; larger quantities of runoff volume were successfully managed than initially designed for; less frequent events of overtopping systems; and draindown times were shorter than planned for. (Philadelphia Water Department, 2022, pp. 3–19) Fig. 2.10 displays the site (red rectangle) in context of DC’s sewer system regions. The site is within the boundaries of the Piney Branch subwatershed and, due to a 2015 consent decree, is specifically targeted for the application of green infrastructure as a combined sewer overflow control strategy. (*First Amendment to the District of Columbia Water and Sewer Consent Decree*, 2015) DC’s stormwater detention requirements for stream bank protection are based on 2-year, 24-hour storm event volumes. (DOEE, 2020) For flood protection, 15-year, 24-hour storm event volumes are required as this is the typical capacity of the DC’s sewer system. (Ibid.)

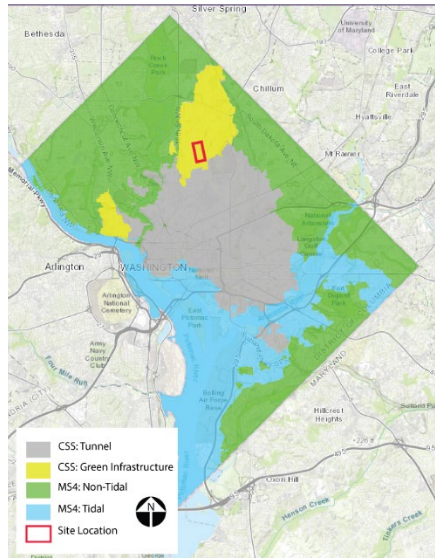


Fig. 2.10 Sewer System Regions, site region outlined in red. (DOEE, n.d.)

Combined Sewer Systems Impact on Water Quality

DC has both combined sewer systems (CSS) and municipal separated sewer systems (MS4), also known as separated sewer systems (SSS), within its boundary, Fig. 2.11 is a diagram by DC Water that shows the differences between CSS and MS4. (DC Water, 2017; EPA, 2004a) A CSS is "wastewater collection system owned by a state of municipality (as defined by Section 502(4) of the Clean Water Act) that conveys domestic, commercial, and industrial wastewaters and stormwater runoff through a single pipe system to a publicly-owned treatment works (POTW)." (EPA, 2004a, p. ES-2) This shared infrastructure has limited conveyance capacity during large storm events and are designed to relieve excess volume directly into surface waters and is called a combined sewer overflow (CSOs). (Ibid.). The EPA defines CSOs as "the discharge from a CSS at a point priority to the POTW." (Ibid.) Storm events in DC with one inch of rainfall or more can cause CSOs. (Ibid.) Though treating stormwater runoff is important to reduce pollutants and litter from roadways,

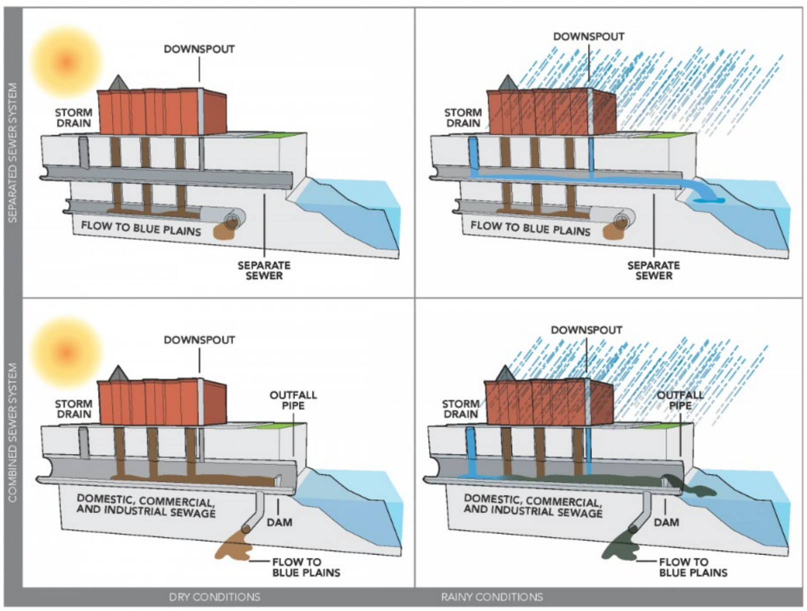


Fig. 2.11 Separated and combined sewer system diagram by DC Water. (DC Water, 2017)

CSOs contain untreated wastewater that contain pathogens, bacteria, and pollutants that can lower water quality, contaminate potable water sources, prevent fishing and swimming in water bodies, lead to fishkills, and other environmental and human impacts (Fig. 2.12). (DC Water, 2017; EPA, 2004a) Additionally, pluvial flooding can be a direct cause of death, exposure to pathogens and contaminants, significant property damage, and disrupt transportation systems and networks which urban communities rely on. (Rosenzweig et al., 2018) Historically, DC experiences just under 10 days per year that have precipitation accumulation above one inch and is projected to have over 14 days in 2080. (DOEE, 2021, tbl. 2) TMDLs for each contaminant are set to ensure water quality. Green infrastructure is one way to reduce TMDLs from entering water ways and aid in reducing pluvial flooding in urban areas. (Austin, 2014; Green et al., 2021) TMDLs for the site's watershed can be found in Appendix A.

Pollutants of Concern in CSOs and SSOs Likely to Cause or Contribute to Impairment	Aquatic life support	Drinking water supply	Fish consumption	Shellfish harvesting	Recreation
Oxygen-demanding substances	•				
Sediment (TSS)	•				
Pathogens		•	•	•	•
Toxics	•		•	•	
Nutrients	•	•			
Floatables					•

Fig. 2.12 Pollutants and likely impacts of CSOs (EPA, 2004a, p. 5-3)

Best Management Practices

There are multiple BMPs to handle two primary goals: the general management of stormwater and water quality. (Austin, 2014) BMPs in DC include green roofs, rainwater harvesting, impervious surface disconnection, permeable pavement, bioretention, filtering systems, infiltration, open channels, ponds, stormwater wetlands, storage practices, proprietary practices, and tree planting and preservation. (DOEE, 2020, p. 31) This section will only discuss rainwater harvesting, permeable pavement, bioretention, infiltration, and storage practices based on site feasibility requirements and limitations identified in DC's Stormwater Management Guidebook. (Ibid.) This thesis also uses Silva Cell® technology as a green infrastructure application.

Rainwater Harvesting

Rainwater harvesting is the practice to collect, store, and reuse stormwater runoff in cisterns for non-potable use. (Ibid., p. 51) Overflow mechanisms are required in the design to accommodate higher stormwater volume than the capacity of the cistern. Pretreatment of sediment, leaves, and first flush contaminants are also required. (Ibid.) Stored runoff can be used to irrigate planting beds, lawns, and other vegetation. Cisterns should be no closer than 10 ft from building foundations to avoid ponding. (Ibid., p. 54)

Permeable Pavement Systems

Permeable pavement refers to the storage and filtration of stormwater through the voids between interlocking paving stones, porous asphalt, or pervious concrete. (Ibid.) Two design configurations exist in DC: standard and enhanced. Standard uses an underdrain but does not require an infiltration sump or water quality filter. Enhanced can either use an underdrain with a water quality filter and infiltration sump to handle the designed storm in 48 hours, or there is no underdrain as stormwater volume can infiltrate within 48 hours. (Ibid., p. 82) The

Contributing Drainage Area (CDA) is recommended to be twice the area of the permeable pavement area but not exceed five times and should be 100% impervious to reduce sediment buildup. (Ibid., p. 84) Permeable pavement can be used on low-speed roadways. (Ibid., p. 85) Permeable concrete or asphalt, as opposed to interlocking pavers, is recommended for use in micromobility lanes to maintain a smooth riding surface. (NACTO, 2017, p. 88) However, they are not the best suited for areas with high traffic, frequent stopping and starting, heavy vehicles, or on slopes greater than 5%. (Ibid.)

Bioretention

Bioretention is the general term for the capture and storage of stormwater. Stormwater passes through engineered filter media and then either infiltrates to recharge groundwater or returned to the gray water infrastructure. (Ibid., p. 104) Bioretention includes streetscape bioretention, engineered tree pits, stormwater planters, and raingardens but have specific design criteria depending on which is applied. Standard design requires at least 18 in of filter media and underdrain, the enhanced design requires at least 24 in of filter media and either infiltration sump or storage layer or will support the designed storm volume within 72 hours. (Ibid., p. 104)

Infiltration

Infiltration refers to the capture and temporary storage of stormwater runoff to slowly dissipate through ground soil. The storm volume, which the BMP was designed for, must infiltrate within three days. The maximum CDA should be less than two acres and nearly all impervious as possible. (Ibid., p. 162) This BMP should be applied under turf grass.

Silva Cell System

Silva Cells® are "modular green infrastructure facility that can be designed to provide stormwater management benefits." (Deeproot, 2018) The system creates a cage-like structure to eliminate soil compaction (Fig. 2.13). Soil compaction directly impacts tree and plant health – as volume is compressed, there is less room for nutrients, water, and air to reach roots. (Urban, 2008) As urban ROWs are both constricted in space and withstand significant weight of traffic, Silva Cells® permit traversable paving at grade while giving needed soil volume for vegetation below grade. (DeepRoot et al., n.d.) The modular structure links together to create volume beneath pavement for healthy tree growth and act as bioretention.

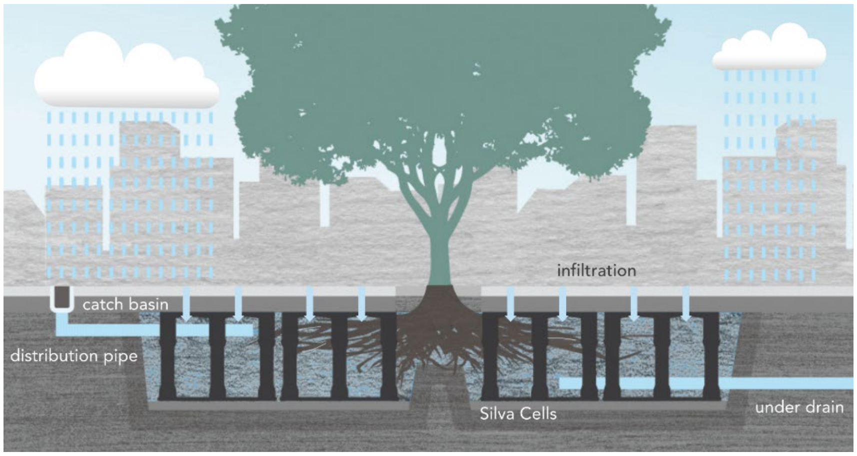


Fig. 2.13 Diagram of Silva Cells under pavement. (Deeproot, 2018)

Discussion and Summary of Literature

Though Complete Streets contribute to livability improvements through the prioritization of safety, the main objective is still mobility and moving people through spaces. The "Complete Streets concept reinforces hierarchies and further compartmentalizes an already fragmented space, thus augmenting the path-place dichotomy of the street." (Mehta, 2015, p. 96) In other words, if mobility was not the main objective, placemaking and livability would be. As stated earlier, studies found TOD projects that prioritized placemaking and livability were most successful. (Cervero et al., 2017, p. 10) Green Complete Streets expands the scope to include the environmental impact ROWs have on people and the environment, which is a more holistic approach to support livability.

As the urban ROW is limited in space, accommodating *every* mode as implied by the Complete Streets model is unrealistic in most spaces. Jane Jacobs writes, "the problem that lies behind considerations for pedestrians […] is how to cut down absolute numbers of surface vehicles and enable those that remain to work harder and more efficiently." (J. Jacobs, 1961, p. 349) She concludes "something has to give" when it comes down to determining how space will be used in cities as bulldozing buildings down to accommodate appropriate widths for bike lanes alongside existing roadways just causes another problem, one cities are still dealing with today. (Archer, 2020) Jacobs highlights the need for determining priorities: either automobiles use will continue and degrade urban quality of life, or decrease the space dedicated to them to improve quality of life. (J. Jacobs, 1961) It is worth mentioning whatever transportation mode(s) that replace automobiles, in this case public transit and micromobility, will become the new “enemy” of the pedestrian. For example, Amsterdam is actively working on reducing conflicts and tensions between bicyclists and pedestrians. (Knight, 2019) This thesis removes one type of vehicle (automobiles) and replaces them with another (sustainable transportation) to improve overall quality of life, but recognizes the need for separation of modes and public space uses.

Based on the literature, it is recommended each mode is delegated a separate section of the ROW to reduce conflict and increase safety. The addition of green infrastructure builds the Complete Streets’ livability case as added vegetation contributes to stormwater interception, filtration, and recharging of groundwater that prevents flooding while increasing biodiversity and opportunities for people to connect with nature in urban spaces. In summary, the Green Complete Streets design model can be used to meet goals of providing safe infrastructure for sustainable transportation use, increase urban water quality, and begin to shift paradigm of the ROW’s purpose to include services beyond mobility.

Chapter 3: Site Inventory and Analysis

The subsequent section outlines features of the site, primarily obtained from DC’s Open Data website unless otherwise noted.

The site, Fig. 3.1, is located on Georgia Avenue NW, a DC principal arterial roadway and U.S. Route 29, between New Hampshire Avenue NW and Iowa Avenue/Varnum Street NW in Washington, DC. It is located in Ward 4, and split between the neighborhoods of Petworth (east) and 16th Street Heights (west), though most residents refer to this area as Petworth. The site is comprised of five blocks and focuses primarily on the ROW of Georgia Avenue NW. The site was

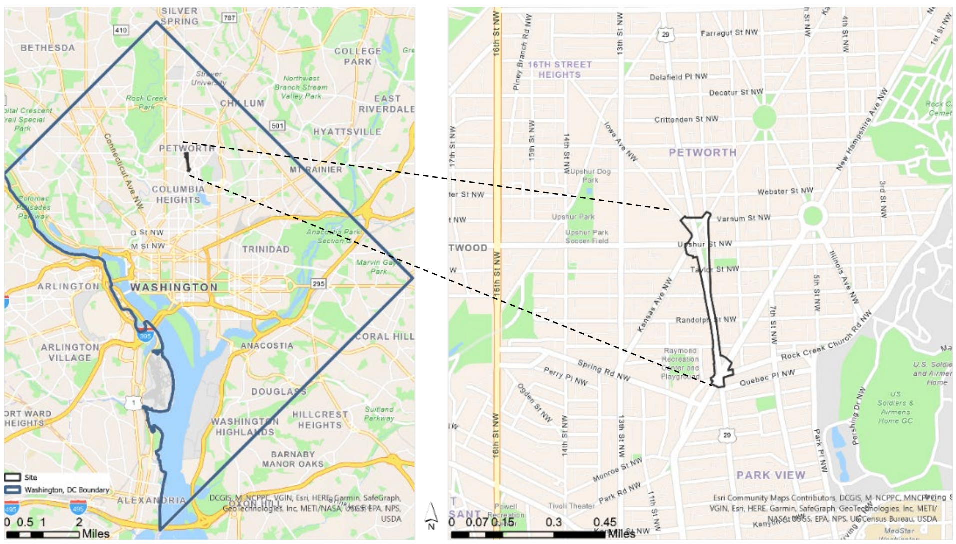


Fig. 3.1 Left: Map of site in context of DC, Right: map of site with context of surrounding area.

picked as the author resides one block west of Georgia Avenue NW and volunteered as a member of the Advisory Commission Committee 4C's Transportation and Vision Zero Committee. This proposal builds on the committee's safety exploration conducted in 2021, which is further discussed in the Traffic Safety section.

Urban Development History

With much of DC's downtown region built, developers began looking north of Florida Avenue NW to expand housing stock. (Prologue DC, 2022) In

1888, Congress passed an act requiring all land development within the city limits to follow L'Enfant's plan. The 1889 Petworth plat was the first formal adoption of this enactment, matching in the same street system as downtown DC. (National Park Service, 2017, p. 17) This led to the diagonal avenues (Georgia, Kansas, and New Hampshire Avenues NW) and why intersections within the site are so complicated. (Ibid.) Georgia Avenue NW has experienced a variety of development investments over the years to revitalize and build more economic opportunity and stability. And is recognized as a Great Streets Corridor, which is a program in DC to target roadways for reinvigoration. (DMPED, n.d.) Traffic circles would not be a foreign design intervention for this community as DC has a number of traffic circles, two of which (Grant Circle and Sherman Circle) are less than a half-mile from the site.

Population and Demographics

Early housing development to the east of the site was restricted to white owners through restrictive covenants. (Prologue DC, 2022) This resulted in a primarily white neighborhood, and Ward, with small pockets of non-white enclaves. (Ibid.) The Supreme Court ruled restrictive covenants unconstitutional in 1948 and in 1954 desegregated public schools. (Ibid.) This ruling, in combination with White Flight, basically flipped the demographics where nearly all residents were Black. (Ibid.)

Ward 4's residents are 78% Black/African American, 32% white, 15% "some other race," 4.73% two or more race, 2.54% Asian, and 0.51% American

Indian/Alaskan Native. (DC Health Matters, 2022) Additionally, 25.75% is Hispanic/Latinx. (Ibid.) DC's and this Ward's residents experienced significant gentrification in the last 20 years, 20,000 Black residents were displaced in the city between 2000 and 2013. (Richardson et al., 2019) This is important context as efforts must be made to prevent future displacement and gentrification as more development is approved for this site. However, this proposal does not include strategies to prevent gentrification.

The median age for Ward 4 is 38.64 years, which is slightly older than DC's median age of 34.8 years. Twenty-one percent of the Ward is below the age of 18, 23.05% is between 18-34, 27.87% is between the ages of 35-64, and 17.17% is over the age of 65. To compare, DC's population breaks down to 19.18% below the age of 18, 31.34% is 18-34, 36.49% is 35-64, and 12.99% of the city is over the age of 65. Ward 4 has more children and more seniors than DC's average. (DC Health Matters, 2022) This highlights the needs for accessible and safe infrastructure so all community members, especially the most vulnerable – children and seniors – can move freely throughout the site.

Ward 4's population based on the 2020 census is 84,660, which is an increase of 11.7% when compared to the 2010 census of 75,773 people. DC experienced an overall 14.6% population growth, which resulted in redistricting Wards, Advisory Neighborhood Commissions (ANCs), and Single-member Districts (SMDs) boundaries. Redistricting does not impact the site significantly as the site remains in the same ANC and Ward, 4C and 4, respectively. However, the SMDs for the site have shifted. (Office of Planning, 2022) Fig. 3.2 shows the

2018 and 2023 SMD boundaries, which rather being split between four SMDs, now the site lies within three. (Office of Planning, 2018, p., 2022, p. 4) Though development will likely require all of Ward 4 and, for this proposal, all of DC's approval, for smaller efforts this redistricting will aid in smoother coordination as the eastern and western sides of Georgia Avenue NW's ROW are no longer divided. This information also indicates a growing population that can support more density and need for wider pedestrian infrastructure and public space.

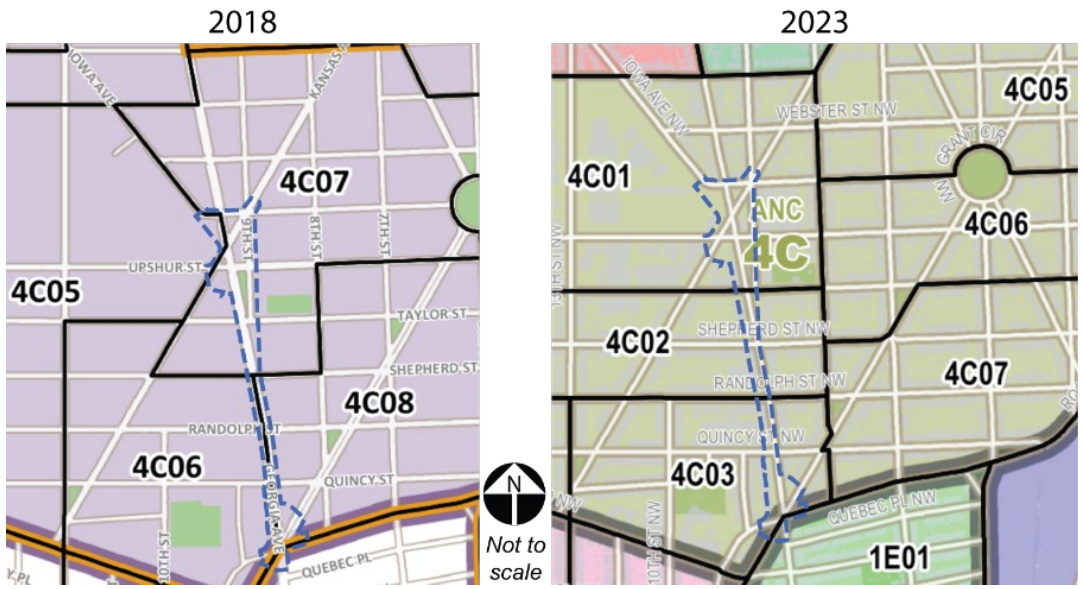


Fig. 3.2 ANC 4C SMD District Maps, Left: 2018, (Right: 2023. Blue dashed line is the site boundary.

Zoning and Existing Land Use

The zoning surrounding (Fig. 3.3) the site is primarily residential, but within the site's boundaries (Fig. 3.4) there is a mixture of Neighborhood Mixed-Use (NC) Zones (NC-7 and NC-8), Mixed-Use Zones, Residential Flat (RF) Zones, and a small area of Production, Distribution, and Repair (PDR) Zones. The existing land use surrounding the site is primarily residential as well (Fig. 3.3),

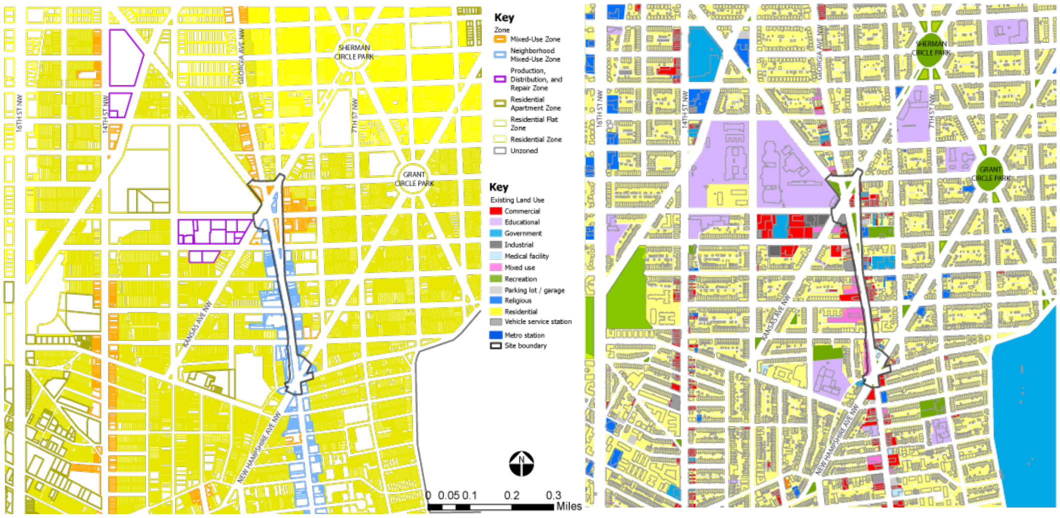


Fig. 3.3 Zoning (left) and Existing Land Use (right): Zoning is primarily residential surrounding the site (yellow) with mixed-use within the site's boundaries. Existing land use is also primarily residential parcels around the site, within the site's boundaries.

but there is a range of land use including commercial, educational, government, industrial, medical, mixed use, recreation, parking/garages, religious institutions, vehicle service stations, and residential. There are nine education sites within a mile of the site. Additionally, the southern region has less green space than the northern. Looking just within the site boundary, there are some notable land use and zoning considerations. First, two sites are being considered for future mixed-use zoning (Fig. 3.4). The southern lot, which currently hosts a single-story CVS pharmacy, has just the very tip of the boundary included within the site. The area within the site currently serves as paved public space. The lot that hosts the eastern metrorail station is fully within the boundaries. (Office of Planning, 2020) This proposal maintains both existing open spaces, but proposes improved conditions to support green infrastructure and amenities. Second, the vehicle service station located at the corner of Kansas Avenue NW, Upshur Street NW and Georgia Avenue NW was initially identified in a 2004 revised corridor plan

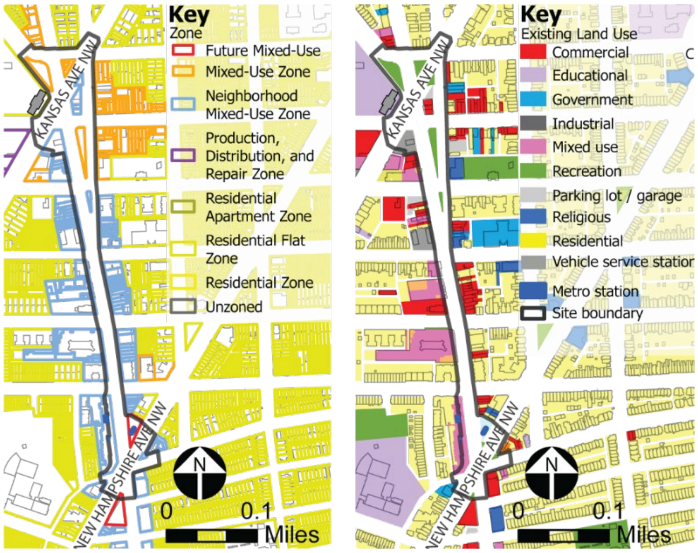


Fig. 3.4 Site Level Zoning (left) and Land Use (right)

to be redeveloped for mixed-use with up to 106 dwelling units and 4,000 square feet of commercial space. (Office of Planning, 2004) This historic information supports potential future mixed-use development for this property. Additionally, gas stations are likely to become obsolete when transportation shifts towards sustainable modes. Considering this, it is recommended that DC purchase the property to be used to aid in the rearrangement of traffic patterns if additional space is needed.

Transportation: Then and Now

Georgia Avenue NW has always served as a main corridor for residential and commercial activity for DC. (Office of Planning, 2004) Originally known as Seventh Street Turnpike, it connected Rockville, Maryland to downtown DC all the way to the Southwest Waterfront. (DeFerrari, 2015; Konsoulis, 2008) Streetcars traversed this corridor beginning in the early 1900s until 1962 when bus transit replaced them. (Konsoulis, 2008; Shoenfeld, 2011) Currently, automobiles and bus transit are the two primary surface modes on the roadway. DDOT considered bringing back the streetcar to Georgia Avenue NW but failed to secure funding. (Malouff, 2014) The site is within the boundaries of DDOT's Bus Priority Project, which is discussed in the next section, but knowing of previous streetcar lines and the recent consideration to bring back the streetcar could pose future opportunity to adapt this proposal to support a streetcar, which may generate additional population and economic growth along the corridor. It also highlights the need for safe separation between transit and micromobility users.

Vehicle Volume and Noise Pollution

Georgia Avenue NW is designated as a principal arterial roadway, which "typically serve major activity centers and serve longer trip lengths," act as a "primary commuter route," and "carry between 40 and 60% of a city's total traffic volumes."(DDOT, 2019b) Automobiles take up most of the roadway space but the corridor does serve public transit use. In 2018, there was an average of 28,000 automobiles per day on the roadway. (*2018 Traffic Volumes*, n.d.) The National Transportation Noise Map indicates the site's noise a-weighted decibel (dBA) ranges from 45.0-59.9 dBA. (USDOT, n.d.) Fig. 3.5 is a screenshot of the National Transportation Noise Map, the site is outlined with a white rectangle. (USDOT, n.d.) Unfortunately, the map did not permit a closer view of the site, but it does show that the site has higher dBAs and bigger areas at the ends of the site, where the intersections are located. This is likely due to the larger amount of roadway in those areas, less trees and vegetation to buffer noise, and lack of buildings which help block noise. Reducing the amount of roadway surface area, number of automobiles, converting ICE vehicles to electric, and increasing trees and vegetation will reduce noise pollution.

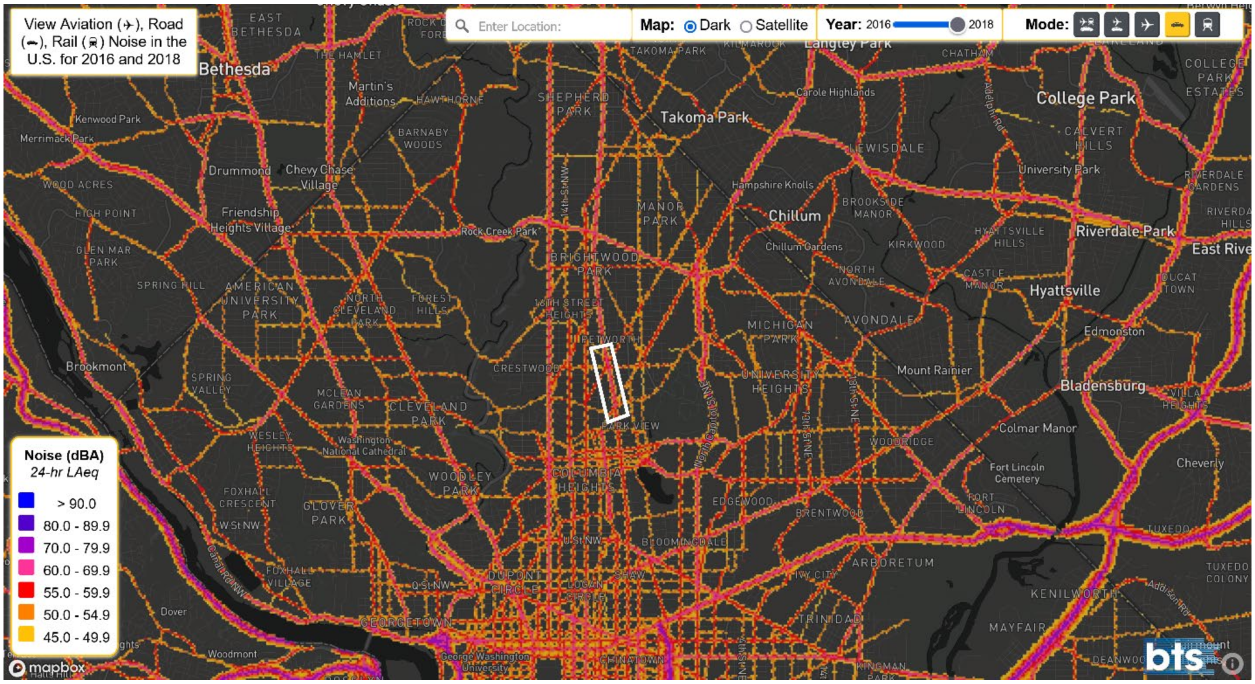


Fig. 3.5 National Transportation Noise Map from road vehicles, the white rectangle indicates the site area. There is a larger area at both ends of the site, where the two intersections are, this is likely because there is more surface area for vehicles to pass through, and less buildings and trees to buffer sound.

Public Transit and Site Conditions

The Washington Metropolitan Area Transit Authority (WMATA) services the 70 and 79 bus routes along the length of Georgia Avenue NW from Silver Spring, Maryland to Downtown DC. (WMATA, 2022) WMATA services the 62, 63, 64, 60, and H8 through the site, traveling across Georgia Avenue on Kansas Avenue NW, Upshur Street NW, and Rock Creek Church Road NW. (Ibid.) Average daily entries per year peaked in 2014 at 27,124 riders using one of the seven routes that operate within the project scope. (WMATA, 2023) Though the pandemic resulted in a steep reduction of riders, 2023 has so far passed 2022 in total passengers (Fig. 3.6). (Ibid.) The 70 bus route was the busiest metrobus route between 2018 through 2021 in DC and route 79 was the fifth busiest route in 2019 and 2021. (Gambetti-Mendez & Finnerty, 2022). Fig. 3.7 breaks down the average daily entries by route. (Ibid.) In terms of site conditions, bus stops either

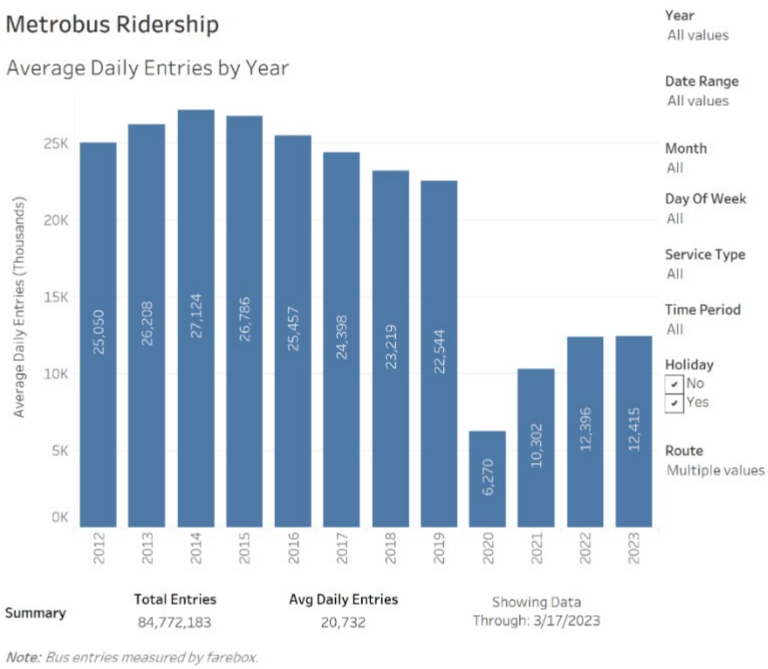


Fig. 3.6 Metrobus Ridership Average Daily Entries by Year: Routes included are 70, 79, 60, 62, 63, 64, and H8 WMATA routes. (WMATA,

feature a covered three-sided glass and metal shelter or a mere signpost.

The Georgia Ave-Petworth WMATA metrorail station is located at the southern end of the site which serves the Green and Yellow metrorail routes. Peak average daily entries of riders reached 5,271 in 2019, similar to buses, metro experienced a drop in ridership during the pandemic but 2023 also has already surpassed all 2022 counts (Fig. 3.8). (Ibid.)

Metrobus Ridership

Average Daily Entries by Route

Route	AM Early (4am-6am)	AM Peak (6am-9am)	Midday (9am-3pm)	PM Peak (3pm-7pm)	Evening (7pm-11pm)	Late Night (11pm-4am)	Grand Total
60	5	94	67	120	5	0	291
62	1	25	330	153	141	36	686
63	66	630	142	681	56	9	1,584
64	63	615	761	793	349	113	2,694
70	379	1,179	2,806	2,183	1,368	513	8,428
79	10	1,156	1,702	1,643	129	3	4,643
H8	46	476	800	805	290	64	2,481

Year
All values

Date Range
All values

Month
All

Day Of Week
All

Service Type
All

Time Period
All

Holiday
☑ No
☑ Yes

Route
Multiple values

Summary	Total Entries	Avg Daily Entries	Showing Data
	84,772,183	20,732	Through: 3/17/2023

Note: Bus entries measured by farebox.

Fig. 3.8 Metrobus Ridership Average Daily Entries by Route: Routes included are 70, 79, 60, 62, 63, 64, and H8 WMATA routes. (WMATA, 2023)

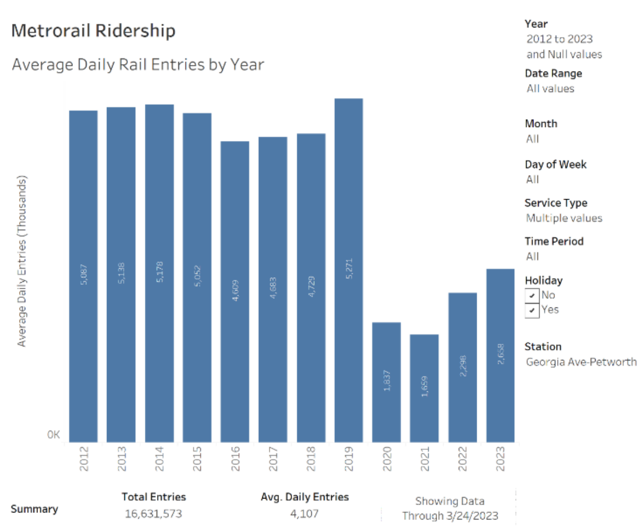


Fig. 3.7 Metrorail Ridership Average Daily Rail Entries by Year: Georgia Ave-Petworth (WMATA, 2023)

In terms of conditions, two station entrances are located mid-block on both west and east sides of Georgia Avenue NW between New Hampshire Avenue NW and Quincy Street NW. The western entrance is located under a mixed-use building, where a covered paved area can be used as shelter during storm events. No seating is available, and beyond a trash can, no other amenities are provided under the building. Three escalators are available at this entrance and an elevator is located about 50 ft south. Bicycle racks are available on the sidewalk but are not covered for weather protection. The eastern metrorail station entrance is an independent, covered structure. The entrance faces the northeast and features two escalators. Trash cans, uncovered bicycle racks, and bikeshare are nearby as well as a sculpture. No seating is available in this area beyond the bus shelters located on Georgia Avenue NW and New Hampshire Avenue NW, respectively.

DDOT's December 2021 Bus Priority Program has proposed Georgia Avenue NW to feature two dedicated offset bus lanes between Barry Place NW and Kansas Avenue NW to improve bus travel speeds and reliability (Appendix J). (Gambetti-Mendez & Finnerty, 2022) This was derived from a thorough assessment to prioritize an equitable transportation system that is accessible, reliable, safe, affordable and fast. (DDOT, 2021) It also includes improvements to pedestrian and multimodal safety to access bus stop. (Gambetti-Mendez & Finnerty, 2022) Though DDOT's Bus Priority Project is a great first step, this thesis improves bus service removing nearly all traffic conflicts with automobiles within the site: automobiles are only permitted to cross Georgia Avenue NW east-west. The proposal also increases public space and aims to support pedestrian connections to benefit transit users.

Traffic Safety

Since adopting a Vision Zero campaign, DC has had an increase in traffic deaths, this year DC has lost 11 people from traffic violence. (DDOT, 2023) DC tracks all traffic crashes on their Vision Zero Dashboard that updates nightly. (Ibid.) Fig. 3.9 displays the number of traffic crashes near the site for the last five years and displays vehicle crashes with pedestrians, cyclists, and all road users. There have been 128 number of traffic crashes so far in 2023 (1/1/2023-4/1/2023) in Ward 4 for all modes, 13 between vehicles and pedestrians and 4 between vehicles and bicycles. (Ibid.) One pedestrian lost their life, three had major injuries. Three drivers had major injuries and one passenger had a major injury. (Ibid.) The site has improved traffic safety through design interventions, primarily through curb extensions at intersections but speeding has been observed during various site visits.

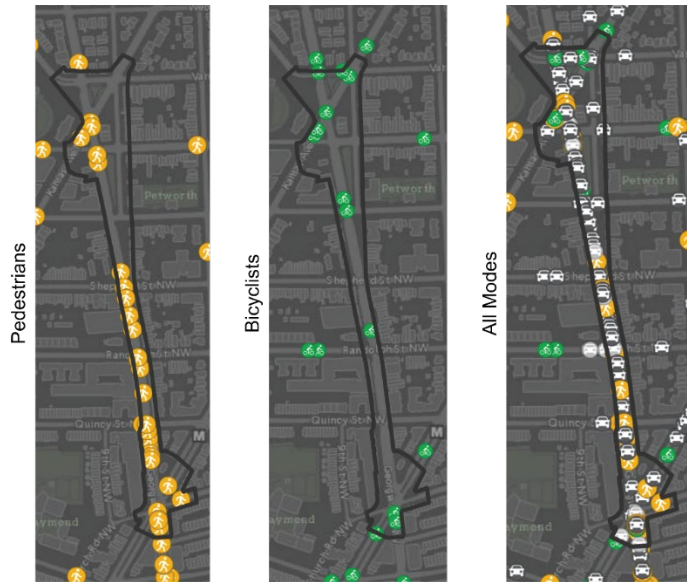


Fig. 3.9 Traffic Crashes, each circle represents one person traveling by the identified mode and a collision with a vehicle. These are crashes from January 1, 2018 through March 22,

Due to safety concerns, the Advisory Commission Committee 4C organized a Transportation and Vision Zero Committee made up of volunteers from each SMD to conduct a safety audit and make recommendations to DDOT in Fall 2021. After conducting walk audits and surveyed parents of children that attended nearby schools, the Committee recommended six priority areas for safety improvements, three of which are within this site's boundaries:

1. Georgia Avenue NW (Rock Creek Church to Missouri Avenue),
2. Kansas Avenue NW (Shepherd Street to Allison Street); and
3. New Hampshire Avenue NW (Georgia Avenue NW to Grant Circle). (Ash et al., 2022)

Additionally, the site is within the boundaries of a 2016 livability study that indicates systemic changes to the area for increased pedestrian and traffic safety, however no interventions were proposed within the site's boundaries. (DDOT, 2016)

Right-of-Way

This section documents, in detail, the dimensions of each block segment. Appendix B provides sections to compare the ROW of existing dimensions, proposed Complete Street, and proposed Green Complete Street layouts. Sidewalks are measured from the curb to the front of the building, including tree boxes and furnishing zones and the clear pedestrian passage space.

Georgia Avenue NW: New Hampshire Avenue NW to Quincy St NW

Total width of ROW is 97 ft with six travel lanes at 11 ft wide each. There are two paid street parallel parking spaces located on the northeast side of Georgia Avenue NW. Sidewalks on the western side are at least 16 ft wide and 14 ft feed on the eastern side. Tree box widths are primarily 5 ft wide, leaving around at least 11 ft and 9 ft of sidewalk for pedestrian passage, frontage, and curb zone for both the western and eastern sides respectively.

This segment of the site has the least green space and despite a few paved plaza areas (Fig. 3.10), has just two public seating locations available, which are retaining seat walls. It hosts one of the two complicated intersections, where four roads intersect: Georgia Avenue NW (two-way, north-south, five lanes), Rock Creek Church Road NW (one-way, eastbound, two lanes), New Hampshire Avenue NW (two-way, northeast-southeast, two lanes), Rock Creek Church Road NW (one-way, westbound, one lane). The diagonal crosswalks elongate pedestrian paths and encourage pedestrians to cut across the roadway to save time (Fig. 3.11, Fig. 3.10).

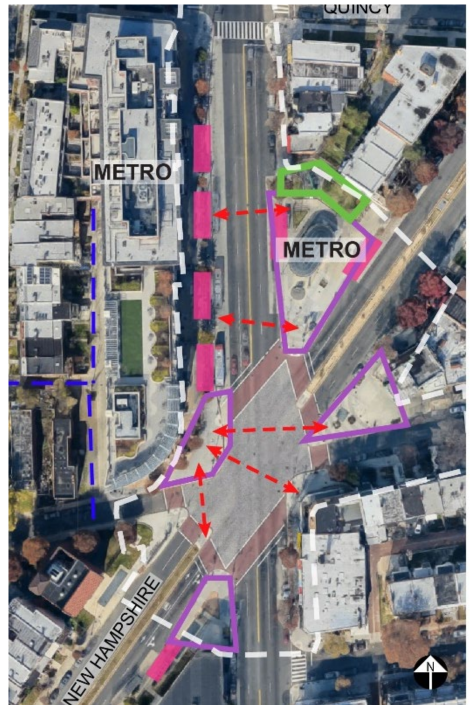


Fig. 3.11 Aerial of Georgia Ave. NW and New Hampshire Ave. NW intersection, red dash line is pedestrian crossings outside crosswalks, pink rectangles are bus shelters, purple solid polygons are paved public spaces, green polygon is green public space, blue dashed line is alleyway, and white dashed line is site boundary.

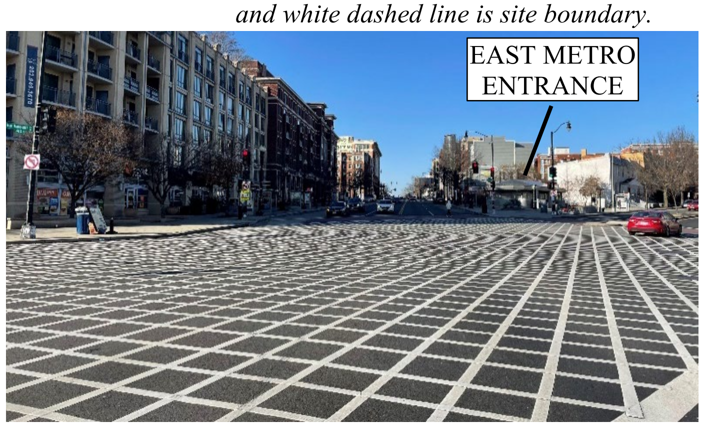


Fig. 3.10 Photo of site's southern intersection, Georgia Ave NW and New Hampshire Ave NW, the hatching pattern is for vehicles, not pedestrians. Many pedestrians have been observed crossing outside crosswalks for more direct access to destinations.

Georgia Avenue NW: Quincy Street NW to Randolph Street NW

Total width of the ROW is 89 ft with four travel lanes at 11 ft wide each, parallel parking on both sides at about 9 ft wide each, and total 29 ft dedicated ROW for sidewalk. Sidewalks on the western side are 15 ft wide and 14 ft on the eastern side. Tree box widths are primarily three to 5 ft wide, leaving around 9 ft of sidewalk for pedestrian passage and curb frontage.

Georgia Avenue NW: Randolph Street NW to Shepherd Street NW

Total width of right of way is 90 ft with four travel lanes at about 11 ft and 9 ft wide street parking on both sides. Sidewalks on the western side are 15 ft wide and 14 ft feed on the eastern side. Tree box widths are primarily three to 7 ft wide, leaving around 9 ft of sidewalk for pedestrian passage and curb frontage. There is one streaterery located in this block segment, on the eastern side, which uses around three parallel parking spaces and hosts one bus stop on the northeastern side. (Fig. 3.12, Fig. 3.13) This outdoor dining is the only example that uses parking space for other uses.

Fig. 3.12 Image of sole streatery located on the eastern side of Georgia Ave. NW between Randolph and Shepherd Streets.

Georgia Avenue NW: Shepherd Street NW to Taylor Street NW

Total width of right of way is 89 ft with four travel lanes at about 11 ft and 9 ft wide street parking on both sides. Sidewalks on the western side are 12 ft wide and at least 16 ft on the eastern side. Tree box widths are primarily three to 7 ft wide, leaving around 9 ft of sidewalk for pedestrian passage and curb frontage. One bus station is located on the southwestern end.

Georgia Avenue NW: Taylor Street NW to Upshur Street NW

Total width of right of way is 85 ft with four travel lanes at about 11 ft and 9 ft

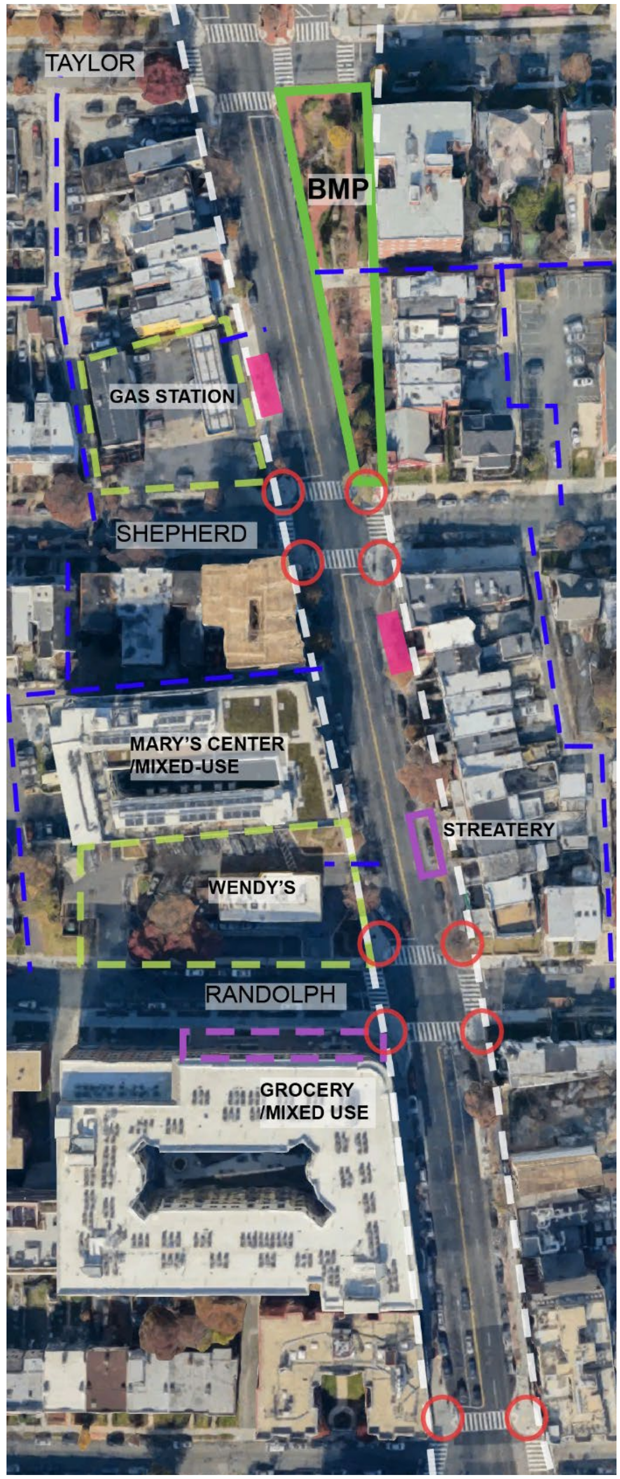


Fig. 3.13 Aerial of Georgia Ave. NW between Quincy St NW and Taylor St. NW, red circles are bulbouts, pink rectangles are bus shelters, purple solid/dashed polygons are paved public spaces, green polygon is green public space, blue dashed line is alleyway, and white dashed line is site boundary.

wide street parking on both sides. Sidewalks on the western side are at least 16' wide and 9' on the eastern side. Tree box widths are between 5 and 6 ft wide, leaving about five and 4 ft of sidewalk for pedestrian passage and curb frontage.

Georgia Avenue NW: Upshur Street NW to Varnum Street NW

This section covers the last two blocks on Georgia Avenue NW within the site, and includes the second complicated intersection: Upshur Street NW to Kansas and Kansas Avenue to Varnum Street NW, (Fig. 3.14). The ROW for the first block is 77 ft with four travel lanes at about 11 ft wide. There is no parking. Sidewalks are at least 16 ft wide on both sides. There are only two tree boxes located on the eastern side, which are

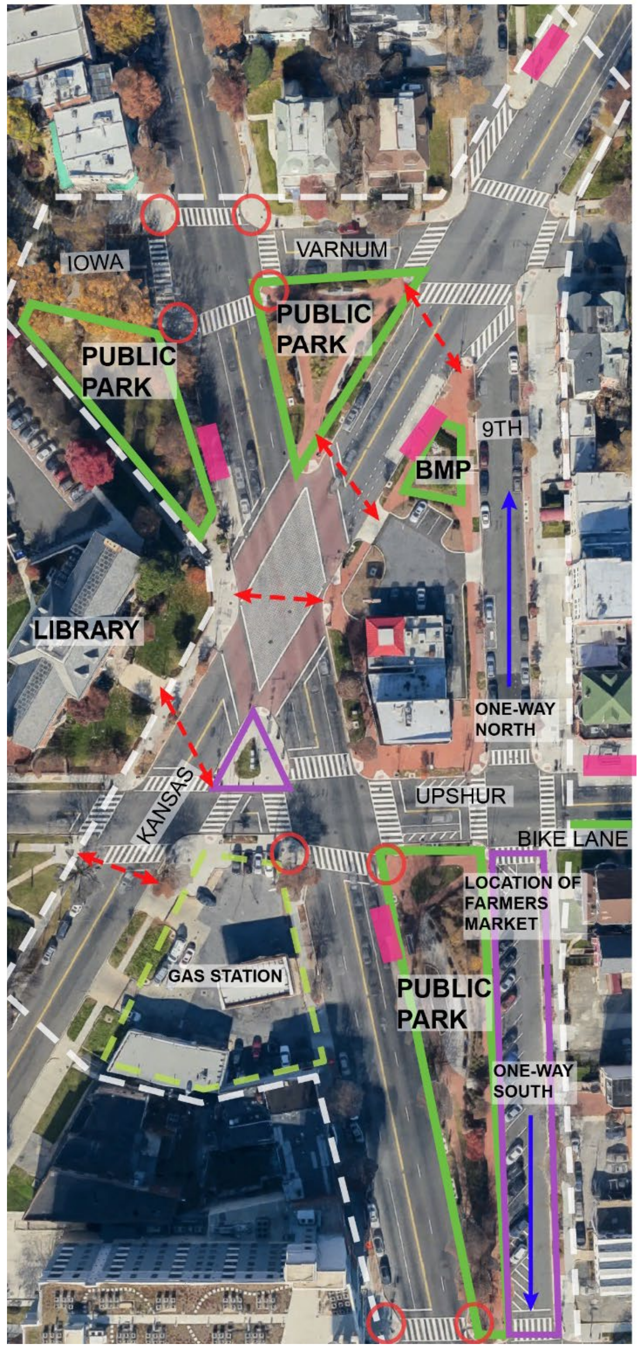


Fig. 3.14 Aerial of Georgia Ave. NW and New Hampshire Ave. NW intersection, red dash line is pedestrian crossings outside crosswalks, pink rectangles are bus shelters, purple solid polygons are paved public spaces, green polygon is green public space, blue dashed line is alleyway, and white dashed line is site boundary.

4 ft wide, leaving the remaining for pedestrian passage and curb frontage. Though this ROW is the narrowest within the site, there is a public park to the east of the ROW and a gas station to the west, both these areas can be potentially used for providing adequate space for each priority.

The second block, Kansas Avenue NW to Iowa Avenue NW is 79 ft in total width. There are four travel lanes, each at 11 ft wide. There is no street parking. Sidewalks are 11 ft wide on the west side and 8 ft wide on the east. The western tree boxes are between three to 4 ft wide and the western tree buffer is about 8 ft wide. The eastern side is also boarders a public park. Similar to the Upshur Street NW to Kansas Avenue NW segment, this ROW is narrower than the other blocks. Also, like the previously discussed segment, it is bordered by public parks that can be used to provide adequate space for Green Complete Street components.

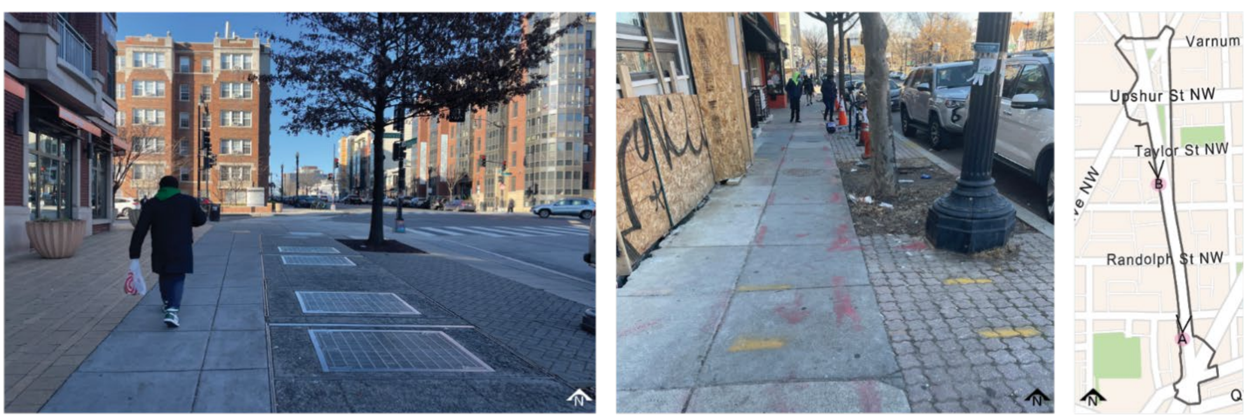
9th Street NW: Taylor Street NW to Varnum Street NW

This section includes the two blocks on 9th Street NW between Taylor Street NW and Varnum Street NW (Fig. 3.14). Ninth Street NW is a one-way street that is southbound between Taylor and Upshur and northbound between Upshur and Varnum. The segment of ROW for 9th Street NW between Taylor Street and Upshur Street aren't included in Appendix H as the park allows for more space for traffic accommodation, however it is worth nothing this area has diagonal street parking on one side as opposed to parallel parking on both. Additionally, this segment of the site hosts the farmers market that runs during the spring through fall months each weekend. Nineth Street NW between Upshur

Street NW and Varnum Street NW has a ROW of 87 feet with two lanes of parallel parking and one travel lane at around 14 ft. There are no bicycle facilities nor bus stations, however there is a bicycle lane that begins at Upshur Street NW and 9th Street NW and runs the length of Upshur Street NW towards the east. This street has light traffic and primarily serves businesses and customers. These two ROW segments and the public park pose opportunity for redirecting traffic if needed.

Overview of Sidewalk Conditions

Sidewalks vary between nine and 16 ft northbound and 5 to 16 ft southbound. Some sidewalks feel grand, such as the western segment of Georgia Avenue NW between New Hampshire Avenue NW and Quincy Street NW, while most feel tight (Fig. 3.15). Trampled tree pits with exposed, compacted dirt elude negotiation of space between pedestrians and need to use this space for clear



A - West-side GA Ave NW approaching Quincy St NW

B - West-side GA Ave NW, between Shepherd & Taylor St. NW

SITE MAP

Fig. 3.15 Sidewalk conditions vary throughout the site, some areas are wide (A) and well maintained, others are degraded and barely meet minimum passage widths of 6 ft (B). Most do not meet the 10 ft commercial width requirement.

passage. Dimensions support these observations: multiple areas on site do not meet or just barely meet the required sidewalk width for pedestrian passage for commercial areas. Most sidewalks are considered 9 ft, including frontage, but there are sections of the sidewalk that barely meet the 6 ft minimum requirement. This can encourage pedestrians to step into tree pits for refuge, enter the roadway, and can cause tension and discomfort between groups of people.

Climate

Washington, DC's climate can experience hot and humid summers, temperate falls and springs, and cold, snowy winters. Though temperatures average between 30°F and 88°F throughout the year, the trending increase in temperature poses serious concern to the health and wellbeing of DC's residents. (DOEE, 2022; NOAA, n.d.; Weather Spark, n.d.) In terms of precipitation, DC can expect a 30% chance of precipitation between April and August. (Weather Spark, n.d.) The increase in extreme heat events and precipitation pose direct threats to people living, working and visiting DC. DC has adopted a number of strategies to address these impacts, such as Keep Cool DC, Climate Ready DC Plan, Resilient Design Guidelines. The significant amount of pavement and insignificant number of trees and greenspace exacerbate these conditions and pose opportunity for rebalancing albedo especially with the expected changes due to climate change.

Watershed and Stormwater

Fig. 3.16 shows the site's subwatershed, Piney Branch, which is within the Rock Creek subwatershed of the Potomac watershed. The site is required to detain

2-year stormwater volumes and retain 50% on-site. Fig. 3.17 diagrams stormwater flow direction. Beyond the site, stormwater moves from the west to east, the highest elevation northeast of the site and channeled to a CSO in Rock Creek Park. Within the site, water flows from the peak elevation of 220 ft at Randolph Street NW and sheds water to the north and south. The low points are 182 ft (north) and 190 ft (south) (Fig. 3.17). The rainfall volume for a two-year storm in DC is 3.19 inches per 24-hour period, or 0.266 ft per 24 hours

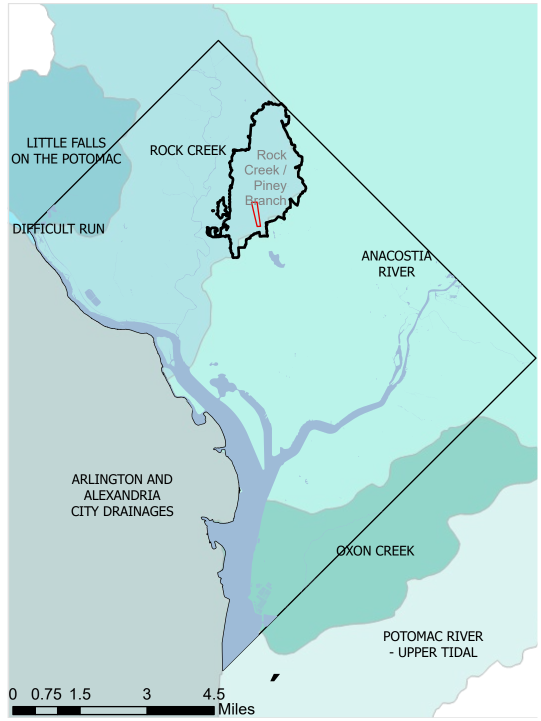


Fig. 3.16 Watershed & Subwatersheds: Thick black outline denotes subwatershed the site is located within the red rectangle.

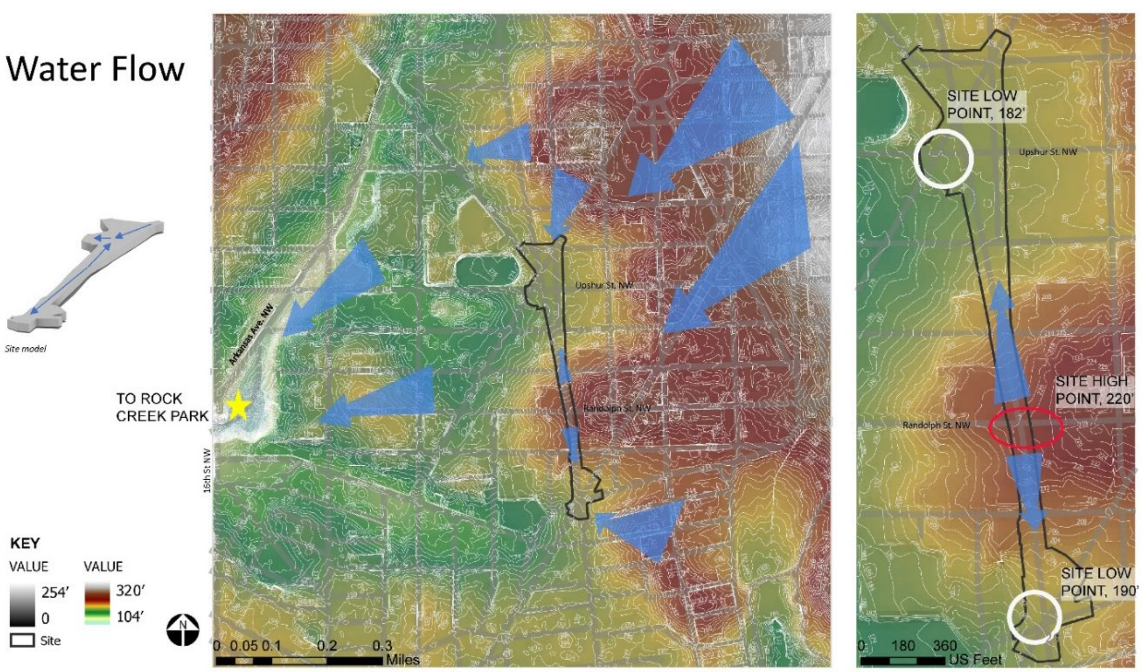


Fig. 3.17 Water Flow: Blue arrows represent stormwater movement near and on the site.

period. The catchment area, which is the full area of the site, is about 494,194 square feet in area, which is about 11.3 acres. Peak runoff for a two-year storm for the site is 2.614 acre-feet per day and will be the base requirement for this proposal to detain, 50% will be required to retain. See Appendix M for full calculations and final results of the proposal.

The site is primarily impervious at 94.89%, leaving just about 5% to pervious areas (Appendix M). Nature is on site in the form of street trees, public parks and bioretention. The existing soil conditions are considered primarily Urban land-Sassafras complex, with small percentages of Urban land-Woodstown complex and Udorthents, Sandy, Smoothed. A soil test is recommended to better understand full conditions but for this project, the assumption is these soils are compacted and serve little stormwater absorption. Existing street tree pits are observed to be very compacted, with exposed dirt and no ground cover. These conditions can contribute to additional sediment intrusion and soil erosion during intense storm events. There are two formal BMPs on site located in the northern region with a combined area of 1,810 ft with a volume capacity of 3,618 cubic feet which do not meet DC stormwater requirements (Fig. 3.18). Unfortunately, there is no seating provided where existing BMPs are nor any educational information to learn about stormwater management.

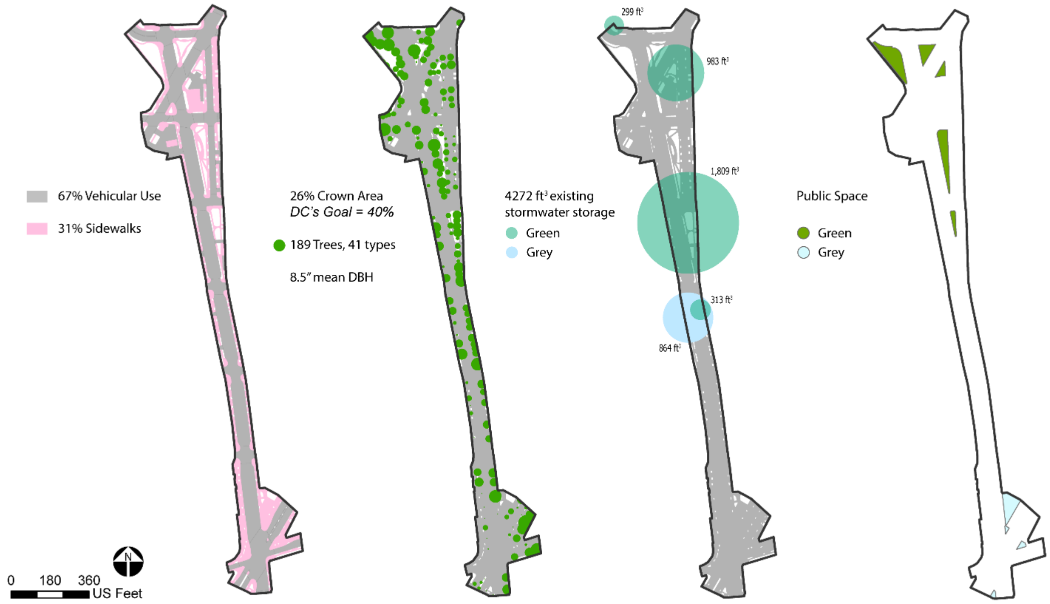


Fig. 3.18 Spatial Mapping: A: Impervious surface by mode use; B: Tree Canopy Area; C: BMPs, D: Public Space

Trees

DC's urban tree canopy goal is 40% by 2032, the surrounding area of the site has lower tree canopy area than other areas of DC (Fig. 3.19) and 26% within the site's boundaries (Fig. 3.18). On site there are currently 41 different tree species are within the site with a total of 189 trees, with a mean diameter at breast height (DBH) of 8.5 inches (Fig. 3.18). There are trees that have been recently planted, which is one reason the tree canopy coverage is so low. However, based on the existing tree box conditions, trees within the site boundary, especially those along Georgia Avenue NW, will likely have a shortened lifespan due to the amount of poor soil quality, especially due to compaction. Trees should be provided more space to meet adequate soil volumes.

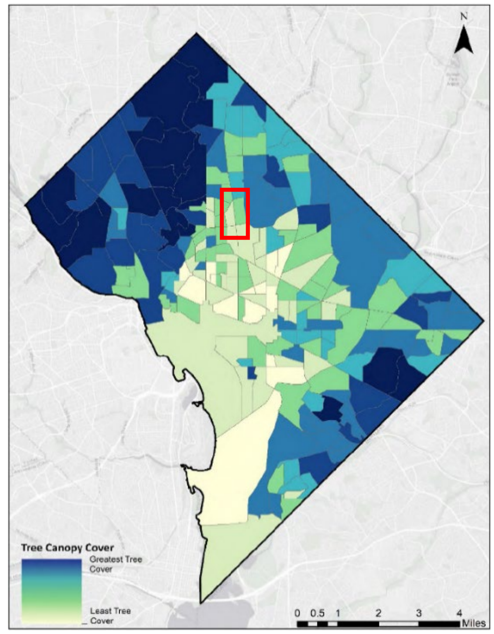


Fig. 3.19 Tree Canopy Cover: Site area within red boundary. (Cadmus, 2022)

Chapter 4: Assumptions & Limitations

There are a number of assumptions and limitations that are important to address related to automobile use, utilities, conceptual nature of this project, literature, traffic engineering, and livability.

Automobile Use

With the increase of safe, accessible, and affordable sustainable transportation networks, it is assumed less dependence on automobiles will result and have little impact on the surrounding roadways' congestion due to the concept of triple divergence. Induced demand, the opposite of triple divergence, is the concept of when more roadways are built to relieve automobile congestion, more congestion is created. (Downs & Downs, 2004, p. 86) Reduced, or little impact on, automobile congestion after removal of automobile infrastructure has been studied and shown to be effective tactics. (Tennøy et al., 2016) In DC, Upper Beach Drive in Rock Creek Park and along M St NW in Georgetown are two recent examples where a reduction in automobile travel lanes had little impact on nearby congestion. (Symmetra Design, 2022; WABA, 2022) More traffic analysis would be required for this type of proposal to be built out but for the purposes of this paper a blanket assumption of little to minor impacts would result.

Additionally, this thesis assumes last-mile deliveries would primarily be done using electric cargo bicycles. It also permits trucks and emergency vehicles to use the bus lanes. During emergency evacuation situations private automobiles are permitted to use the bus lanes as well. Micro-transit is also permitted to use the bus lanes but private rideshare vehicles are not. A full city-wide strategy would be required to significantly reduce automobile dependence in DC, this thesis does not assume this half-mile ROW redesign would have significant impact on modal shifts throughout the city.

Utilities Below Grade Do Not Pose Conflict

This thesis assumes underground utilities pose no conflicts to prevent suggested design interventions in the final corridor plan. Information on location, orientation, and types of underground utilities was not accessible publicly. Depending on actual conditions, detention depths, cistern location, and cistern model choice are likely to shift and final results will be impacted.

Conceptual and Theoretical

This thesis is conceptual and theoretical in its nature; the design proposal is at a master plan level, not site plan level. The intention of the site design is to demonstrate how this space can better serve the community compared to its existing conditions within a very narrow scope. It does not specifically program and identify public amenities.

Literature

In terms of literature, most pollution of the transportation sector is related to emissions, specifically related to air quality. Studies on shifting to sustainable micromobility are hopefully being explored but it was difficult to determine how particulate matter, noise, and roadway wear changes when transportation shifts to either public bus transit or micromobility. For the purposes of this paper, the assumption of shifting transportation mode to sustainable transportation will greatly reduce overall pollution emitted and entering the environment than automobiles.

Unfortunately, NACTO's working paper *Designing for Small Things With Wheels*, was not published until March 2023, far after new iterations of the final site plan were explored. Had this publication came out earlier, adjustments in criteria may have been adjusted to accommodate wider micromobility widths.

Traffic Engineering Needed

This is a landscape architecture thesis, not traffic engineering thesis, therefore signaling is not discussed nor explored and detailed turn radii were not tediously maintained. This proposal intends to challenge roadway design minimums as these standards have led to the existing conditions that are killing people, see section Health and Safety. (Smart Growth America, 2022) The traffic circle's inner-lane turning radius is 45 ft to accommodate buses and trucks. (Hopper, 2007, p. 238)

Livability

This thesis aims to demonstrate how livability must be the main objective in urban traffic planning through the application of Green Complete Streets. It prioritizes green infrastructure as a key component to providing livable communities, so rather than compromising space for vegetation this project tries to maximize space dedicated to vegetation. Due to restraints, this thesis primarily focused on the application of Complete Streets and green infrastructure and does not include design interventions for placemaking and community programming. It assumes placemaking will occur in future iterations.

Chapter 5: Design Proposal

Design Goals

The overarching goal of this thesis is to support urban livability through the application of Green Complete Streets. This thesis aims to demonstrate what an urban ROW can look like when sustainable transportation and urban water quality are prioritized over car-centric mobility. Two specific goals, through the application of Green Complete Streets, are:

a) Prioritize the pedestrian experience to support sustainable transportation (walking, transit, and micromobility), while increasing space for planned and spontaneous engagement between people through:

    a. Increasing pedestrian space: DC's Public Realm Design Manual states a preferred width of 10 ft for commercial sidewalks and as discussed in both the Livability and Social sections of the literature review, additional sidewalk space can lead to improved community connections that can improve overall livability conditions. (DDOT, 2019b)
    b. Increasing public green space: as it will support the associated benefits of biophilia while also managing stormwater runoff, increase recreation opportunity, reduce urban heat island effect, and lead to improved community connections.
    c. Improving safety for all ROW users by dedicating space for different mobility types: adopting the Complete Streets model to allocate appropriate widths for travel lanes and physical barriers will improve overall safety for all ROW users.

b) Improve urban water quality by meeting DC's minimum of stormwater runoff requirements through the application of green infrastructure: beyond being a requirement for DC, treating both the 2-year and 15-year stormwater runoff volumes will improve water and ecological conditions of the regional environment. Using green infrastructure will increase vegetation within the urban site area, improving urban ecology and increasing opportunity for biophilia.

Design Process

Concept development began first by understanding the cross-section of the ROW and how much space each block segment had. Using Streetmix.net a variety of ROW orientations were explored. Appendix B outlines the initial rearrangements of one segment of ROW on Georgia Avenue NW between New Hampshire Avenue and Quincy Street NW. Examples of other streetscape redesigns aided in prioritizing spatial needs and understanding arrangement of modes. Pico Boulevard in Los Angeles, Octavia Boulevard in San Francisco, and Pennsylvania Avenue NW and Connecticut Avenue NW in DC were observed. Pico Boulevard and Octavia Boulevard are two examples of ROW redesigns that prioritized livability. Pennsylvania Avenue NW, as it currently exists, features center running bike lanes, a leading feature in the initial concept diagrams, and is currently in the process of exploring a new redesign. Connecticut Avenue NW recently approved a redesign that introduces dedicated bicycle lanes. Though as a pedestrian Georgia Avenue NW feels to be at a very large scale, the ROW is much narrower than Pico Boulevard, Octavia Boulevard, and Pennsylvania Avenue NW. Though Pennsylvania Avenue NW is larger, the proposed redesigns for the corridor prioritizes pedestrian, transit and micromobility over car-centric mobility; one proposal removes automobiles completely. Connecticut Avenue NW on the other hand does not challenge the traditional ROW use and, though the redesign includes dedicated bicycle lanes, automobiles are prioritized spatially as their travel lanes take up most space. (Appendix D)

Exploration of traffic circles and ellipses influenced the design as well. Traffic circles and ellipses in DC were measured to better understand the spatial requirements needed for both traffic flow and community needs. Dupont Circle, Logan Circle, Sherman Circle, Grant Circle, Ward Circle, Thomas Circle, Benjamin Banneker Park, and Scott Circle were observed (Appendix E). Redesigns of multi-street intersections such as Pennsylvania Avenue SE and 14th Street SE and Dave Thomas Circle, which is not a circle nor is being proposed to be one, were also observed. Dave Thomas Circle's redesign (Fig. 5.1) used emenint domain to reclaim a Wendy's (fast food restaurant) located in the center triangle parcel of land to reorganize traffic and increase greenspace.

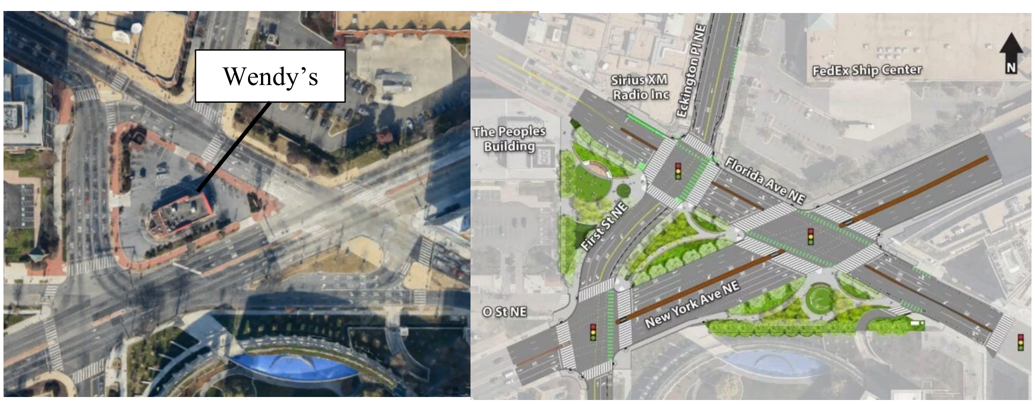


Fig. 5.1 Dave Thomas Circle as it currently exists (left) and the proposed redesign (right) for safer conditions. (Image source Google)

These exercises led to more diagramming and ROW layouts. Two concepts (Fig. 5.2) were selected to further explore in plan view to apply it within the full site: one which prioritized pedestrian space and the other which prioritized tree canopy. Appendix F includes sketches of possible ROW layouts in plan and explores intersection layout. Initially, the orientation of lanes followed DDOT's bus priority project, maintaining curb-side running bus lanes (Appendix J). This was to ease the transition from automobiles to micromobility in the center running

Fig. 5.2 Two initial concepts explored in site plan.

lanes and to reduce conflicts between micromobility and transit users at bus stations. Additionally, there may be associated costs saved if this newly installed bus lane could be maintained. However, cars were removed due to limited space and needed space for micromobility, buses, and pedestrians.

This led to a concept site plan (Fig. 5.3) that was shared with the ANC 4C Vision Zero Committee on January 25, 2023. This concept has 9 ft center-running micromobility lanes (dark green) with 11 ft curb-side bus lanes (red), 8 ft tree pits (light green) and on average 14 ft sidewalks (beige) that include frontage.

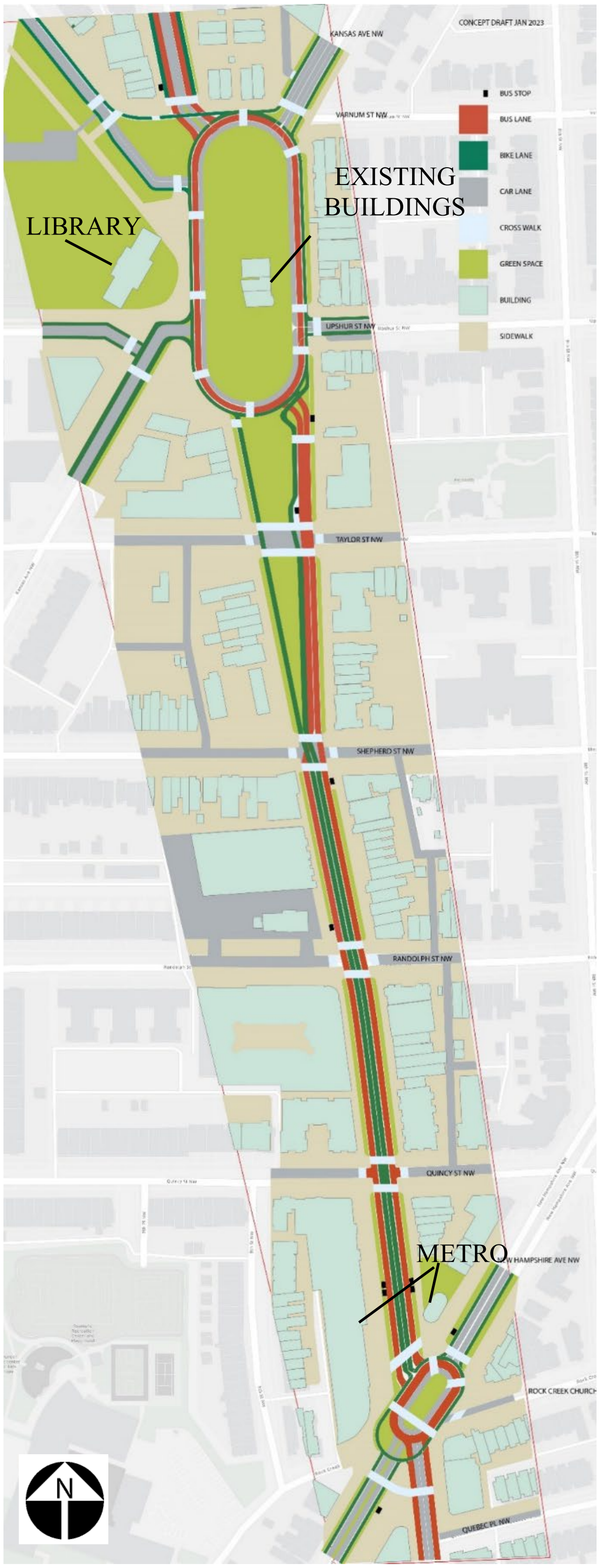


Fig. 5.3 Initial Concept Plan

Three Committee Members joined (Appendix K) for one hour over video conference and shared feedback on the initial concept. Safety was a main priority, which aligns with the group's purpose, and one participant suggested using raised crosswalks at all intersection crossings. This suggestion highlighted possible conflicts between micromobility users and pedestrians at crosswalks. Initially, the plan would include rules for micromobility users to dismount at the crosswalk to access the sidewalk, but in application this will likely not be followed and instead users will do what the roadway design permits most convenient.

Participants saw benefits to both removing and keeping the existing buildings located within the proposed traffic circle (Fig. 5.3). Benefits identified to keep the existing buildings were to support the existing local businesses, making the space more active, the existing parking could act as a staging space for the weekend farmers market, and the structure can host other amenities like public restrooms and drinking water access. Benefits of removing the buildings would increase space for more park/green space and support additional recreation programming, such as a potential ice rink. Though the final design does not extensively identify programming opportunities, this feedback highlights the need for community engagement and co-design for future site planning.

The Committee Members were most excited by the increase in safety and public space, and the width of the micromobility lanes. The wider micromobility lanes were identified to support wider micromobility vehicles (NACTO's *Designing For Small Things on Wheels* working paper focuses on this topic) that are becoming more popular. The wider sidewalks and added public space inspired a robust discussion on potential public amenities the community could gain.

Participants envisioned covered and secure electric micromobility parking and charging, public restrooms and water fountains, education space, public seating and furniture, and community events. These comments highlighted the lack of amenities currently on site. Appendix I identifies a list of potential programming and amenities different spaces could support.

After receiving feedback, a second round of concept development occurred. First, remapping pedestrian, micromobility and transit routes to understand desire lines, potential conflicts, and how to accommodate both mobility and placemaking (Fig. 5.4). This exercise informed spatial relationships for programming within larger public spaces and more direct pedestrian access through rearranging traffic lanes and crosswalks (Fig. 5.5). Before redesigning the

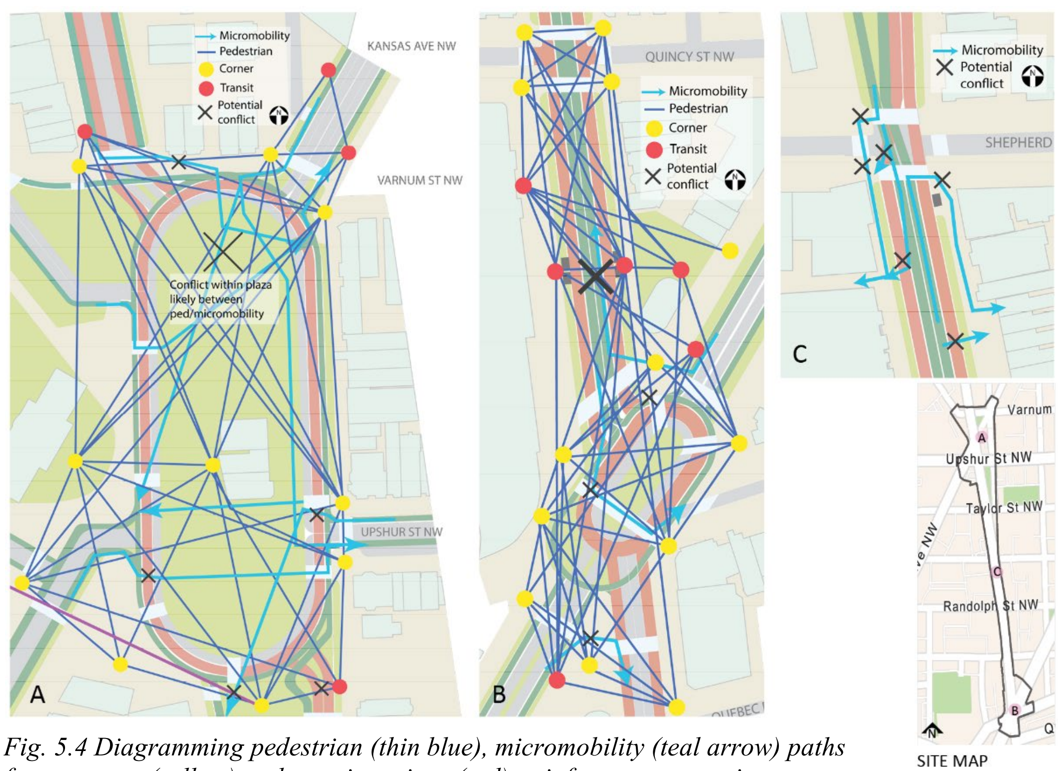


Fig. 5.4 Diagramming pedestrian (thin blue), micromobility (teal arrow) paths from corners (yellow) and transit stations (red) to inform programming.

entire site, a set of criteria were established to guide the design.

Fig. 5.5 Diagramming of potential programming based on pedestrian and micromobility mapping.

Design Criteria

After diagramming potential ROW and programming designs, the following criteria were established for the final site plan proposal:

a) Redesign the ROW to prioritize sustainable transportation:

  a. 10 ft minimum sidewalk (between tree buffer and building frontage zone);

  b. 8 ft protected curb-side micromobility lanes, 2 ft buffers separation from bus lanes;

  c. 10 ft center-running bus lanes, 1 ft buffer between lanes;

i. Floating transit islands with bus shelters. Access to islands from crosswalk and sidewalk, micromobility to traverse speedbump.

d. 4 ft minimum frontage; and

e. 8 ft tree buffers.

Fig. 5.6 summarizes these in a table.

ROW PROPOSAL CRITERIA			
Type	Green Complete Street		Traffic Circles
	One Way (ft)	Full Width (ft)	Full Width (ft)
SOV	0	0	10
Bus	10	20	12
Buffer: Bus/Bus or Bus/SOV	1	1	0.5
Micromobility	8	16	6
Buffer: Bus/Micromobility	2	4	1.5
Tree Buffer	8	16	8
Sidewalk Clear Passage (min.)	10	20	10
Sidewalk Frontage Zone (min.)	4	8	4
TOTAL ROW WIDTH (ft.)	43	85	52

Fig. 5.6 ROW Proposal Criteria: Spatial orientation of the ROW based on guidelines and requirements.

b) Improve urban water quality by meeting DC's minimum of stormwater runoff requirements:

a. Meet 2-year stormwater runoff volume detention requirement, 2.46 acre-feet/day;

b. Meet 2-year stormwater runoff volume retention requirement, 1.23 acre-feet/day;

c. Meet 15-year stormwater runoff volume detention requirement, 4.01 acre-feet/day;

d. Meet 15-year stormwater runoff volume retention requirement, 2.01 acre-feet/day; and

e. Meet DC's tree canopy goal of 40% within the site boundaries.

GREEN INFRASTRUCTURE PROPOSAL CRITERIA	
2-yr Stormwater volume: Detention	2.46 acre-feet/day
2-yr Stormwater volume: Retention	1.23 acre-feet/day
2-yr Stormwater volume: Detention	4.01 acre-feet/day
2-yr Stormwater volume: Retention	2.01 acre-feet/day
DC Tree Canopy Goal	40%
Trees Needed for 40%	280

Fig. 5.7 Green Infrastructure Proposal Criteria: Requirements to meet based on DC regulations.

Fig. 5.7 summarizes these criteria in a table.

Full Corridor Plan

The full corridor plan for this site is broken down into three main typologies: Transit Hub, Green Complete Streets, and Community Green (Fig. 5.8). Within the inner blocks of the site, between each proposed traffic circle, only sustainable transportation is permitted. Automobiles are permitted within the traffic circles, to cross east-west Georgia Avenue NW and use alleys (Fig. 5.9).

Fig. 5.8 Final master plan

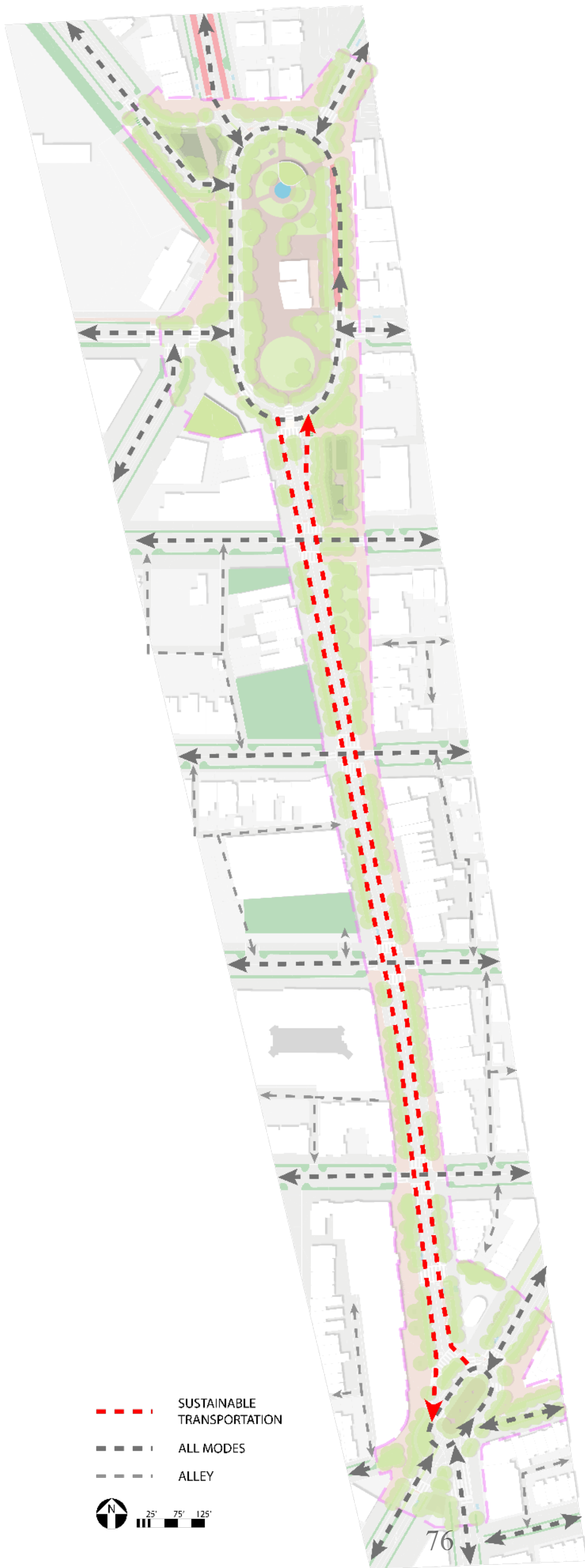


Fig. 5.9 Final site plan displaying traffic flow, red is sustainable transportation only, dark grey is all modes, and thinner and lighter grey is to show alleyways.

Transit Hub

Though this region is deemed the "Transit Hub," it is not limited to only mobility (Fig. 5.10). Pocket parks, 8 ft tree buffers with seat walls, plazas with moveable furniture and vendors entice people to spend time

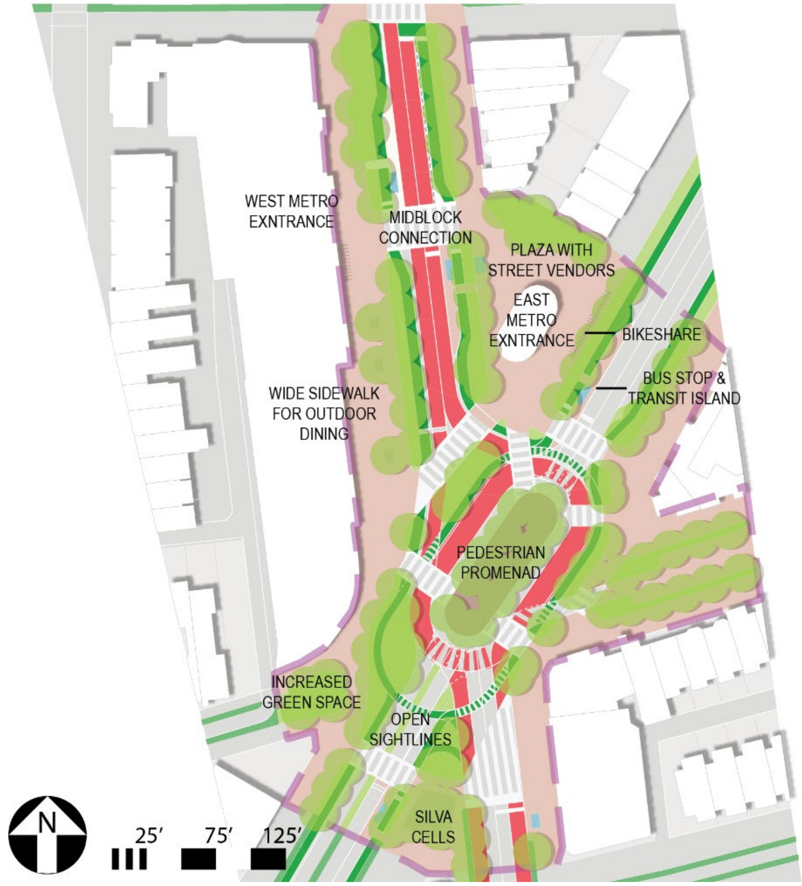


Fig. 5.10 Zoomed-in image of "Transit Hub" area.

here. The traffic circle maintains movement of passing traffic but allows pedestrians and micromobility users to travel safely. Crosswalks are placed to support desire lines identified in earlier diagramming (Fig. 3.10). Permeable paving, Silva Cells®, cisterns, and bioretention is used throughout the site to slow, store, and treat stormwater runoff.

The traffic circle accommodates automobiles, buses and micromobility with three distinct lanes. The inner most lane (gray) is dedicated to automobiles and is 10.5 ft wide. The middle lane (red) is for public bus transit, can be used for larger trucks if needed, and is 12 ft wide. A protected buffer of 1.5 ft separates motor vehicles from micromobility, and micromobility (dark green) users have a

6 ft wide lane. All traffic flow moves in one direction and signaling would be required but is beyond the scope of this proposal.

Green Complete Streets

The Green Complete Streets (Fig. 5.11) segment aligns with a more traditional linear streetscape layout but incorporates added space for non-mobility activities. Mid-block access for micromobility users is accommodated and intends to host secure, covered storage space as well as a loading and drop-off zone for cargo bike deliveries (Fig. 5.12). Designating space for each mode improves safety and added raised

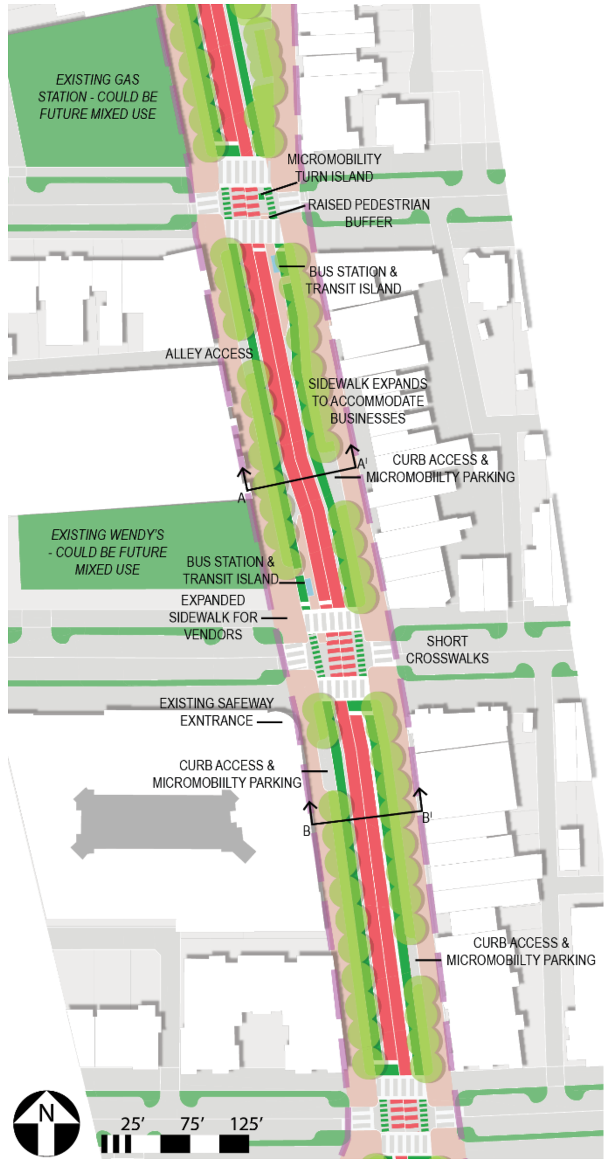


Fig. 5.11 Zoomed-in view of "Green Complete Streets" segment.

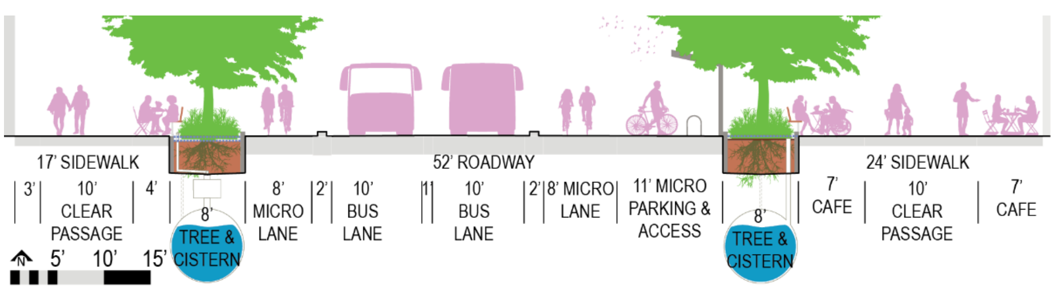


Fig. 5.12 Section A-A[1] illustrates streetscape redesign with micromobility parking and cafe seating.

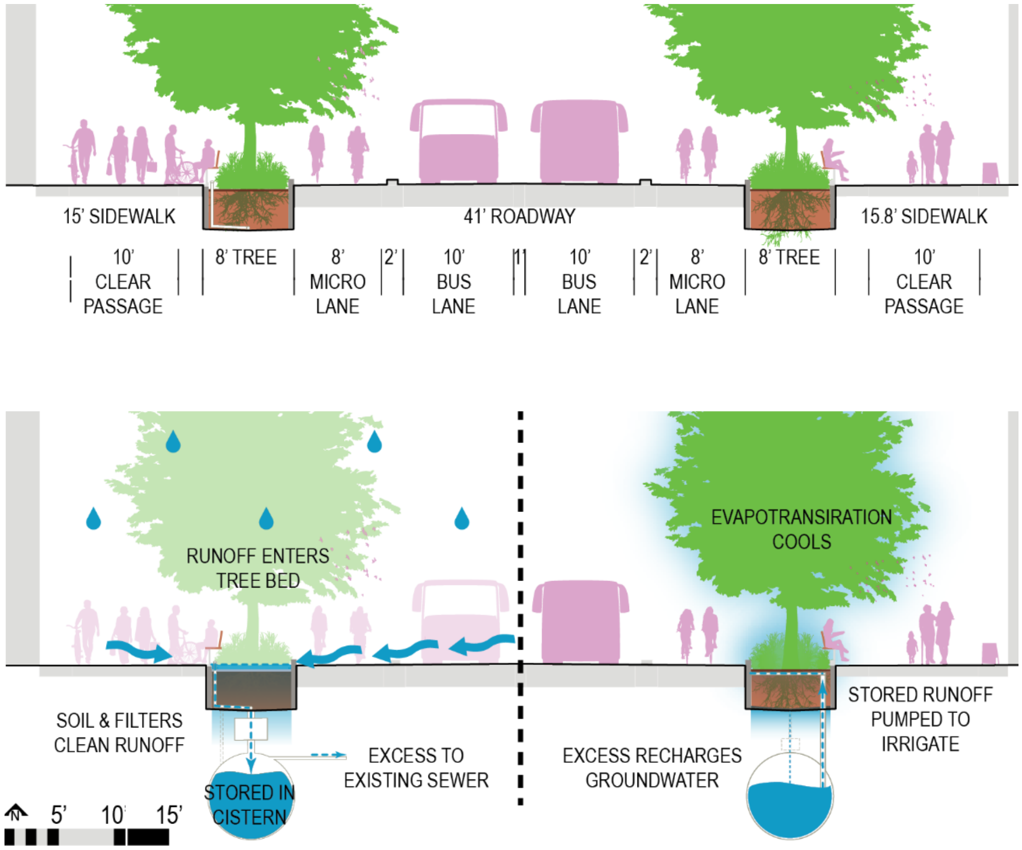


Fig. 5.14 Two diagrams of Section B-BI, top illustrates the dimensions of the proposed ROW, bottom diagrams expected stormwater flow and circulation.

Fig. 5.13 View of proposed streetscape from the SW corner on Georgia Ave. NW and Randolph St. NW.

pedestrian barriers block potential conflicts (Fig. 5.14). Shifting micromobility storage to the road further reduces conflict at crosswalks and congestion when micromobility users intend to access the sidewalk. Throughout the site, cisterns are placed underground to capture stormwater runoff that the BMP planting beds cannot hold (Fig. 5.13). This water is then recirculated to irrigate planting beds. Appendix G diagrams all segments of the site's ROW.

Community Green

The Community Green mimics the Transit Hub's oval shape and features and features the most public space (Fig. 5.15). It is intended to serve community programming throughout the year while increasing green space, managing stormwater runoff, and supporting safe

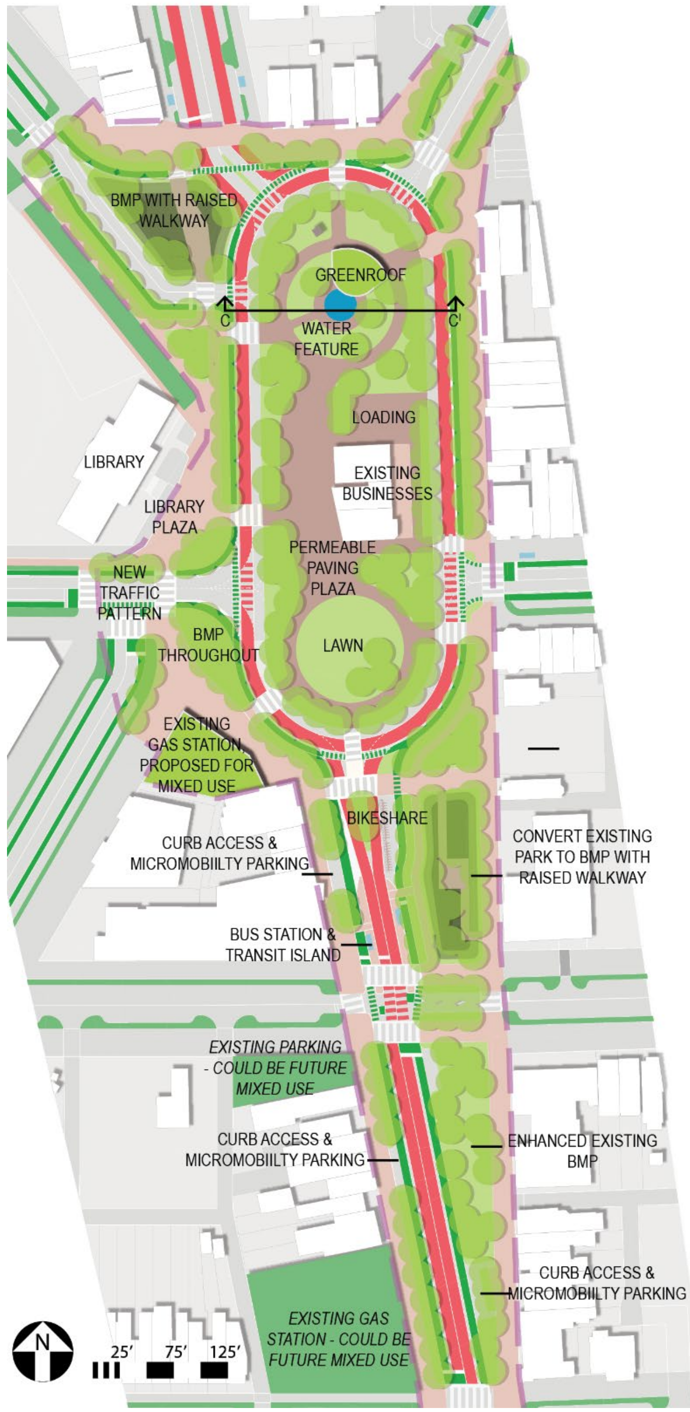


Fig. 5.15 Close-up of the "Community Green" segment of the site proposal.

transportation needs. Besides the existing buildings within the traffic circle boundaries, all surfaces are permeable. A combination of permeable paving, lawn with engineered soil for optimal stormwater absorption, and bioretention planting beds are used. There is a small parking area for maintenance, deliveries, and host farmers market trucks. The large plaza can host vendors, café seating, and entertainment while maintaining pedestrian access. Since this is a shared space, micromobility users must yield to pedestrians and encouraged to dismount when passing through for safety. Fig. 5.16 is an image to depict what a day could look

Fig. 5.16 View inside the central park area, looking east towards the water feature.

like inside the park. And to achieve the 15-year flood prevention requirements, a series of cisterns would be placed under the central park area (Fig. 5.17).

Following the assumption that the volume of automobiles, especially ICE SOVs, will reduce and the remaining operated are electric, the site absorbs the existing gas station lot to accommodate the traffic circle and increase opportunity for larger multipurpose bioretention areas. These spaces not only accommodate more stormwater volume but allow for the opportunity to connect with nature

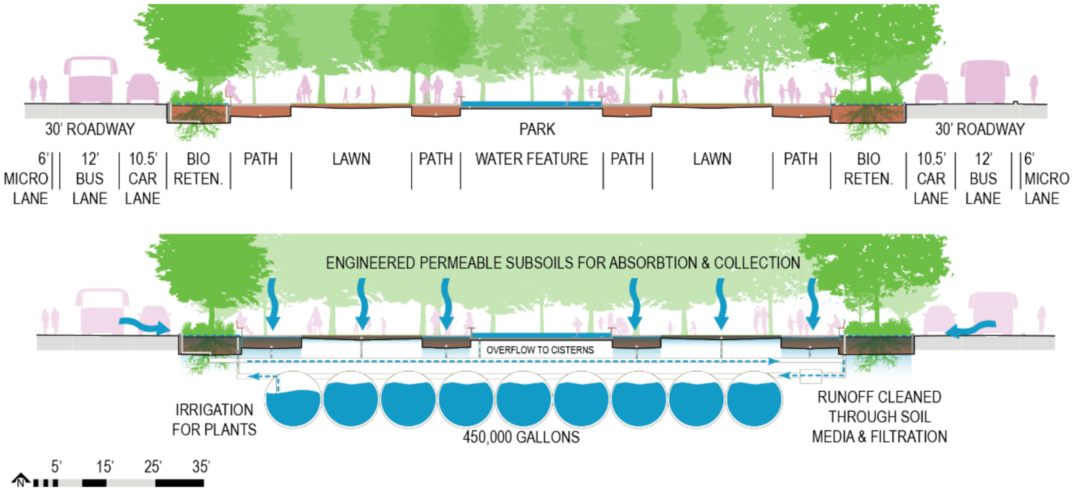


Fig. 5.17 Section C-C' of park.

through raised walkways, seating, and educational diagrams. The library could host outdoor lessons in these spaces on a variety of topics, beyond stormwater, as well.

Chapter 6: Results

Reviewing the site criteria, the proposed site plan had the following results. The specific dimensions of the ROW width are as follows:

1. 10 ft sidewalks for pedestrians;
2. 8 ft tree buffers separating pedestrians from roadway;
3. 8 ft micromobility lanes;
4. 2 ft buffer with 1.5'x8' pre-cast concrete barriers;
5. 10 ft bus lanes, which can be used for emergency and authorized vehicles; and
6. Where applicable, minimum of 4 ft of frontage

The design proposal shifts the site area to the following spatial orientation:

- **Automobiles**: 51% to 12%, total area

- **Bus lanes**: 0% to 11%, total area
- **Bike lanes**: 0% to 1%, total area
- **Sidewalks** (including transit islands): 26% to 30%, total area
- **Crosswalks**: 8% to 6%, total area
- **Permeable paving**: 0% to 9%, total area
- **Bioretention**: 1% to 10%, total area
- **Lawn (grass):** 5% to 3%, total area
- **Tree boxes/planting:** 8% to 10%, total area
- **Public space**: 39% to 62%, total area
    - **Hardscape**: 26% to 39%, total area
    - **Green space:** 13% to 23%, total area

Within the site, total public space increased from 39% of the total site area to 62%. Hardscape public areas that include sidewalks (and transit islands) and permeable paving increased from 26% to 39% of the total site area. Green space within the site increased from 13% to 23% of the total site area. Specific values for each category can be viewed in Appendix L.

The design proposal's stormwater management results reduced impervious surfaces to 66% and increased pervious surface area from about 13% to 34%. Existing impervious surface area is 87% and 67% of that impervious surface was dedicated for car use. The design proposal applied BMPs results in the following figures:

- **Bioretention:** 1% to 10% site area, 27% of all BMP area, 32% BMP volume
- **Lawn (grass):** 5% to 3% site area, 10% of all BMP area, 4% BMP volume
- **Green roof**: 0% to 1%, 4% of all BMP area, 1% BMP volume
- **Permeable paving**: 0% to 9% site area, 27% of all BMP area, 26% BMP volume
- **Silva Cells®:** not included in area as below grade, 3% BMP volume
- **Tree boxes/planting**: 10% site area, 31% of all BMP area, 35% BMP volume

Based on soil volume calculations the site can double the number of trees on site from 148 to 308 (Appendix M). If all trees were to have at least 30 ft tree canopies, then the total tree canopy area would be 44%, surpassing DC's 40% goal. Using iTree®, rough estimates over a 40-year time period indicate:

- nearly 7 million pounds of CO2 will be avoided
- Over 4.2 million pounds of CO2 will be sequestered
- Over 2.2 million pounds of electricity (kilowatt/hours) will be saved
- Over 31 million galls of stormwater will be intercepted
- Over 10 million gallons of stormwater runoff will be avoided

These numbers are based on selecting seven different tree types, the full table is available in Appendix N. This calculation does not include lower canopy and groundcover plantings.

Stormwater would be stored in cisterns to irrigate greenspaces and recharge groundwater. This method will ensure the site retains at least of stormwater runoff on site. Cisterns can be placed under tree pits and within the traffic circle park areas. Based on 50,000- and 15,000-gallon cisterns, the site would be need either 13 50,000-gallon cisterns or 44 15,000-gallon cisterns. The site's area can fit 62 50,000-gallon cisterns or 159 15,000-gallon cisterns, if buildings and no other limitations existed. Specific values for each category can be viewed in Appendix M.

Chapter 7: Considerations for Future Iterations

The overarching goal of this thesis was to demonstrate what an urban ROW can look like if sustainable mobility and urban water quality were prioritized over car-centric mobility. The purpose of this shift is to support urban livability. Two specific goals, through the application of Green Complete Streets, are:

1. Prioritize the pedestrian experience to support sustainable transportation (walking, transit, and micromobility), while providing space for planned and spontaneous engagement between people through:
    a. Increasing pedestrian space;
    b. Increasing public green space, and
    c. Improving safety for all ROW users by dedicating space for different mobility types.

2. Improve urban water quality by meeting DC's minimum of stormwater runoff requirements through the application of green infrastructure.

Both goals were achieved through the significant reduction of the amount of space within the site boundary dedicated to automobile mobility to enable sustainable transportation and green infrastructure to be accommodated by more appropriate spatial allocations. Pedestrians, micromobility, and public bus transit are allocated separated facilities with physical barriers to increase safety.

The additional space of pedestrian sidewalk can provide space for additional public amenities such as an assortment of public seating, water fountains and bathrooms, covered micromobility storage and charging areas, waste bins, postal service bins, street vendors, and informational kiosks. Additional suggestions of amenities and possible application can be found in Appendix I. Future designs should engage the community to identify public amenities to reclaim the sidewalk for their needs and move beyond the perception that sidewalks are for mobility.

The consideration of potential cost savings if this designed maintained DDOT's curb-side bus lanes were less of a priority than proposing a design that would better serve the community and safety of all roadway users. The consideration for reducing conflict between transit users and micromobility travelers could still be met through the application of design interventions that reduce micromobility speeds, such as raised crossings to transit islands. This orientation also permitted conflict-free mid-block curb access for micromobility users, which reduces wider curb zones and saves ROW space for other purposes, such as a wider concrete buffer between micromobility users and transit. This buffer increases safety for all micromobility users, especially for children as it will act as a physical barrier if swerving occurs. Shifting bus lanes to run within the center of the ROW saves 1 ft of ROW for other uses, reduces possible congestion caused by transit lane blockages caused by micromobility, and reduces potential conflicts between micromobility and transit.

Additional pedestrian safety and access is achieved through the application of raised crosswalks between the northern and southern blocks along the site. Though the ANC 4C Vision Zero Committee suggested raised crosswalks throughout the site, smaller speed bumps are placed where transit islands are located, as previously discussed. Raised crosswalks support connectivity, reduces strain on people with mobility limitations, and reduces vehicular speeds for all modes. Additionally, all transit islands will have accessible ramps from the crosswalk to provide another access point to the station. Though ten crosswalks were added within the site, the total area of all crosswalks reduced, indicating shorter distances pedestrians need to cross. Percentage of micromobility infrastructure would likely increase if calculations were made of all surface area dedicated for micromobility, such as parking areas, bikeshare locations, but travel lanes were only included in the above figure.

The second goal was to improve urban water quality by meeting DC’s minimum of stormwater runoff requirements. The design proposal meets DC’s stormwater management requirements for detaining volume of a 2-year storm for stream protection. In order for the site to meet 15-year storm volumes for flooding prevention, cisterns would be required. There is adequate space for cisterns but additional studies would be required for appropriate placement and model choice. It is recommended collected stormwater is used to irrigate planting beds and lawn to reduce water use and recharge groundwater supply.

Reflecting on the literature, design process, and results, a number of suggestions have been compiled for improvement and as possible considerations for future projects with similar intentions.

Hierarchy Considerations: Future Vehicle Sizes, Spatial Needs, and Establishing Priorities

This proposal is designing with the context of current vehicle dimensions in use. It would be interesting to design ROWs based on smaller sized vehicles including smaller buses, trucks, automobiles, and streetcars. Since ROWs are more constricted within urban areas, advocating and planning for smaller vehicles would permit both private and public automobiles within the ROW. However, larger micromobility vehicles are becoming more popular and are challenging the existing minimums. As noted in the Limitations' Literature section, unfortunately, NACTO's working paper *Designing for Small Things With Wheels* was not published until March 2023, far after new iterations of this final site plan was explored and established. Had this publication came out earlier, adjustments in criteria may have been made to accommodate wider micromobility widths. However, this poses a new question: how large will micromobility get and will they become threats to smaller micromobility users? NACTO's working paper argues these larger micromobility facilities are more inclusive of all ages and abilities as adaptive bicycles, like tricycles, can be wider but does not discuss the potential conflict between slower and faster micromobility riders beyond providing adequate space. It reads as though these design interventions will be implemented in spaces alongside automobiles – if no automobiles exist, or are significantly smaller in size, perhaps these larger micromobility vehicles will need separate facilities, or more significant separate, from standard bicycles.

Finally, with or without the change of vehicle sizes, this design could further improve by establishing a more defined hierarchy and prioritizing pedestrians above all other modes. Clearly defining a hierarchy will better validate design decisions. Future iterations can be improved by having more emphasis on understanding existing walkability and proposed impacts. For example, more public space can be created – such as sidewalks – if the hierarchy clearly defined people as the number one priority, which could result in deepening tree pits or using Silva Cell ® technology. Appendix O and Fig. 7.1 shows an example where more sidewalk can be gained if Silva Cells ® were used within tree buffers. Silva Cells® would maintain needed soil and stormwater volume needs. More investigation on impacts is recommended, involving the community in the design process to establish priorities will better influence design decisions.

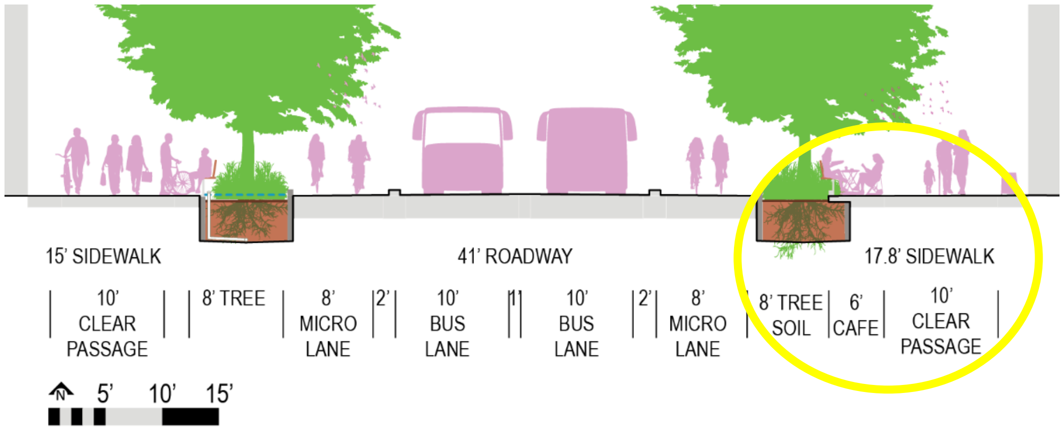


Fig. 7.1 Example of how Silva Cells can expand sidewalk area and maintain soil volume.

Green Infrastructure Expansion and Opportunities for Urban Agriculture

The choice of green infrastructure application and location, throughout the site, can be debated. However, the biggest opportunity for improvement for this specific proposal is the use of permeable paving throughout micromobility lanes and sidewalks. Though this project was not constricted by costs, it was not clear whether the application of permeable paving was a realistic use and poses opportunity for additional research and exploration. Converting all sidewalks and micromobility lanes would increase the site's stormwater storage volume to 6.44 acre-feet, or 65% permeable area, compared to 2.99 acre-feet and 34.5%, respectively, surpassing the 15-year storm runoff volume and no longer needing cisterns. However, as discussed in the literature review (Best Management Practices) permeable paving may not be as comfortable to ride, roll, or walk on, requires additional maintenance and is more expensive to install. Additional research is recommended to better evaluate outcomes. Monitoring of BMPs and TMDLs is also recommended to better quantify impacts on water quality.

Additionally, shifting the ROW to serve sustainable transportation and on-site stormwater management could pose an opportunity for urban agriculture. Feasibility studies and additional research is recommended but this project demonstrates the amount of vegetation the ROW can host. Why not have the vegetation be edible and improve local food access and overall resiliency? What other benefits can urban communities gain when the ROW is not solely dedicated for automobiles or mobility in general? This project begins to scratch the surface of benefits when the urban ROW prioritizes livability.

Community Engagement and Co-Design

Community engagement for this proposal was nonexistent beyond the one-hour conversation with the ANC 4C Vision Zero Committee. If a proposal was to be explored for this site, extensive community engagement is recommended. This will aid in designing spatial priorities. Co-design will direct programmatic needs. This is critical in reducing additional gentrification and displacement. (Nesbitt & Quinton, 2023)

Pollution Beyond Air & Water Emissions

Vehicular pollutants were limited in scope for this project, primarily focusing on air and water quality and related to only ICE vehicles. Focusing on other pollutants, such as noise or particulate matter, or larger scale impacts such as strain on infrastructure and the electric grid, could be another angle to approach this redesign. Results related to these impacts would be beneficial to quantify. Additionally, more research on the impacts of micromobility and public transit should be included.

Site Design and Microclimate Impacts

This proposal's scope did not include microclimate studies. Future iterations could explore how the surrounding architecture impacts plant selection and placement, which could expand into how the design impacts microclimate. For example, this proposed site plan uses a very linear arrangement for both street trees and the ROW. Inspired by the Krummholz design in West Loop Park in Chicago by Parkins and Will Architects, it would be interesting to consider how organic shapes impacts wind within the site. (VanderGoot, 2018)

Expand Scope for Holistic Impacts on Transportation System

This site proposal is limited in geographic scope and therefore does not begin to cover impacts of the transportation system in DC. Building on the design criteria and goals to DC's full geographic scope can uncover potential feasibility and resulting impacts to influence this type of aggressive ROW redesign.

Implementation Using Tactical Urbanism

A phased implementation plan was initially a part of this project's scope for two reasons. The first is that this thesis recognizes the radical changes existing conditions must have in order for this proposal could be feasible, it is one component of a longer-term strategic plan DC would need to adopt. The second is because communities can no longer wait for safety interventions, changes to the urban ROW are needed now. Using methods of tactical urbanism, this plan can be broken into phased buildouts to implement, test, and adapt suggested interventions for immediate and long-term impact with little risk and little cost. (Lydon & Garcia, 2015) However, this proposal would have greatly benefited from using tactical urbanism strategies to lead the design process and final proposal. (Wohl, 2018)

Chapter 8: Conclusion

In conclusion, this site is successful in meeting the initial design criteria to support sustainable transportation and urban water quality. Though there are several improvements and considerations for this proposal to be successful in application, the intention for this proposal is to demonstrate how the ROW can better serve people and the environment in urban communities. It demonstrates stormwater runoff requirements for DC's 2-year and 15-year volumes can be managed all within the public ROW. This thesis challenges the ROW to serve a purpose beyond mobility, reducing the total surface area dedicated to mobility from 60% to 30%. It demonstrates cities can reclaim this wide area of pavement to not only allow the movement of people and treat stormwater management, but to create space for community engagement. It is time for urban ROWs to prioritize people and ecology over the sole purpose of mobility.

Appendices

Appendix A Piney Branch TMDL

TMDL for organics and metals in Piney Branch, Rock Creek Tributary

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6.9 Piney Branch Loads and TMDL

Piney Branch loads are established for both inorganics and organics. For the District of Columbia storm water runoff sources, the following table shows the existing loads and allowable TMDLs for Piney Branch metals and organics that met the applicable WQS with a margin of safety of one percent. The total allowable loads for Piney Branch reflects the reductions needed in order to meet the following WQS: Class D criteria for Arsenic at 0.14 ug/L; Class C, CCC criteria for Copper at 12.31, Lead at 2.79, and Zinc at 113.29 ug/L; Class D criteria for Chlordane at 0.00059 ug/L; Class D criteria for DDD, DDE and DDT at 0.00059, respectively; Class D criteria for Dieldrin at 0.00014 ug/L; Class D criteria for Heptachlor Epoxide at 0.00011 ug/L; Class C-CCC for PAH 1 at 50 ug/L; and Class D for PAH2 and PAH2 at 0.031 ug/L, respectively. The allocable loads also meet Class C four-day average criteria for the constituents.

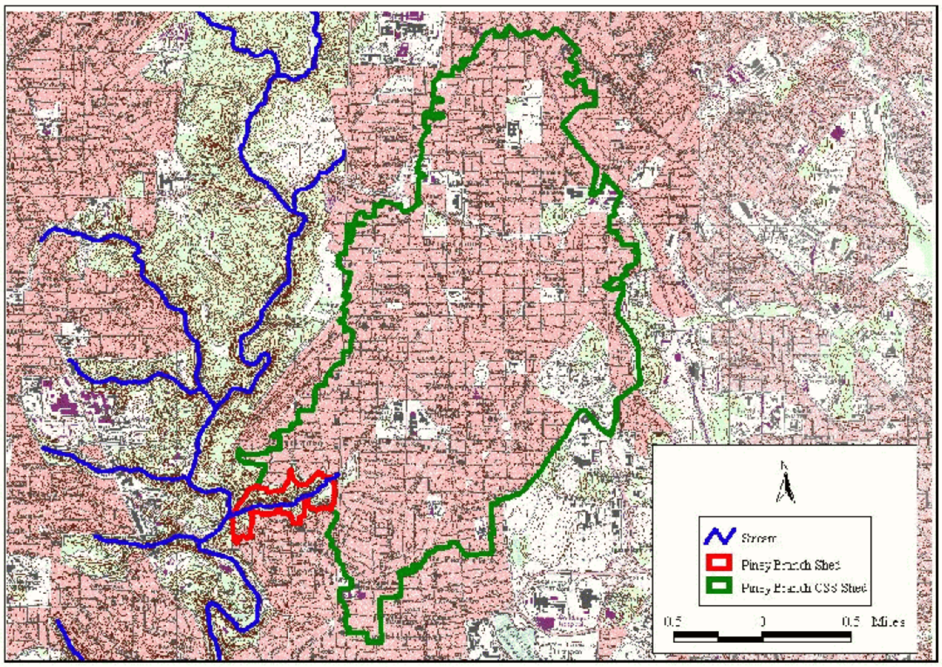
The following reductions were required for the District's storm water runoffs to meet these WQS: Total Arsenic at 65%; Total Copper at 65%; Total Lead at 75%; Total Zinc at 0%; Chlordane at 80%; DDD at 90%; DDE at 92%; DDT at 97%; Dieldrin at 80%; Heptachlor Epoxide at 85%; PAH 1 at 0%; PAH 2 at 98%; and PAH 3 at 96%. The reduction for CSOs is 96.5% for all constituents as the allocation scenario was run with the recommended plan for CSOs in the DCWASA LTCP (DCWASA, 2002). No margin of safety applied for the CSO loads, as there is implicit safety included in the analysis with first flush effects. The PCB issues are discussed in section 5.3. Although no loads are allocated for land-based sources, the reductions needed to meet water quality standards are 96.5 percent for CSOs and 99.9 percent for storm water loads, with sources of loads for both CSOs and storm water could be atmospheric and/or land-based. As shown below, the atmospheric loading contribution calculated is greater than the existing load; hence, no land-based allocation was made at this time. Therefore, the allocations shown below reflect the atmospheric loads and resulting allocations at this time.

Piney Branch Loads and TMDL – pounds/average year

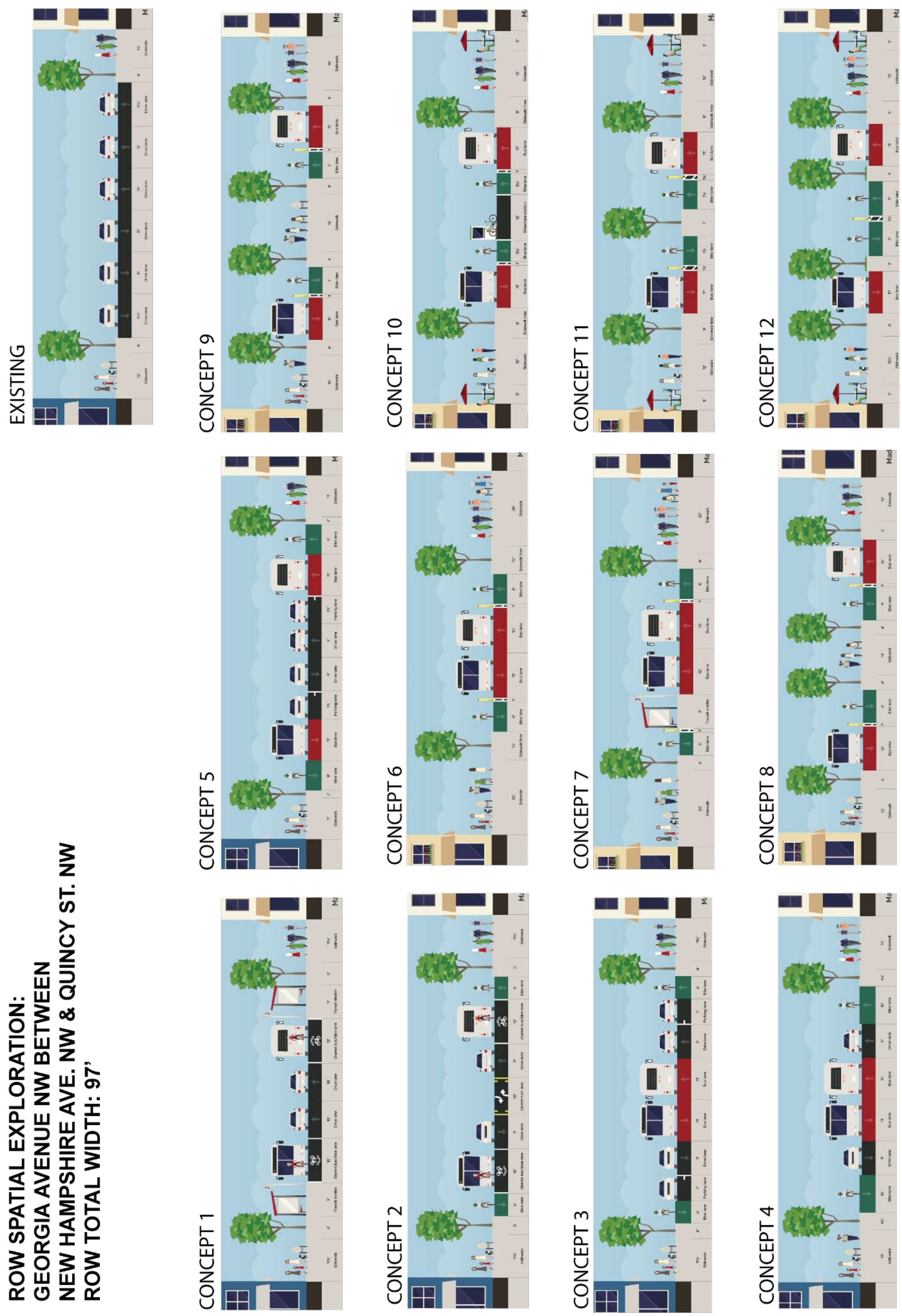
Constituent	Piney Branch Existing Load			TMDL	1% MOS	Storm Water and CSO	Direct Runoff
	SS Load	CSO Load	Total Load				
Arsenic (total)	1.236E-01	4.632E-01	5.868E-01	5.966E-02	4.324E-04	3.107E-02	2.816E-02
Copper (total)	4.297E+00	2.515E+01	2.944E+01	2.395E+00	1.504E-02	1.401E+00	9.793E-01
Lead (total)	2.000E+00	2.647E+01	2.847E+01	1.438E+00	4.999E-03	1.108E+00	3.255E-01
Zinc (total)	1.255E+01	7.047E+01	8.302E+01	1.505E+01	1.255E-01	6.750E+00	8.171E+00
Chlordane	7.978E-04	3.252E-03	4.050E-03	2.749E-04	1.596E-06	1.694E-04	1.039E-04
DDD	9.269E-04	9.926E-04	1.920E-03	1.279E-04	9.269E-07	6.659E-05	6.036E-05
DDE	1.495E-03	4.401E-03	5.895E-03	2.755E-04	1.196E-06	1.965E-04	7.785E-05
DDT	4.183E-03	1.132E-02	1.550E-02	5.266E-04	1.255E-06	4.436E-04	8.172E-05
Dieldrin	1.203E-04	9.595E-05	2.163E-04	2.746E-05	2.406E-07	1.156E-05	1.567E-05
Heptachlor Epoxide	1.641E-04	3.166E-04	4.808E-04	3.584E-05	2.462E-07	1.957E-05	1.603E-05
PAH1	5.629E-02	2.179E-01	2.742E-01	6.401E-02	5.629E-04	2.680E-02	3.665E-02
PAH2	3.078E-01	1.376E+00	1.684E+00	5.494E-02	6.156E-05	5.087E-02	4.009E-03
PAH3	1.930E-01	8.874E-01	1.080E+00	3.917E-02	7.720E-05	3.407E-02	5.027E-03

	SS Load	CSO Load	Total Load	Atmospheric Load	Total Allocable Load (Land-Based)
TPCB	7.111E-03	2.667E-02	3.378E-02	1.275E-01	0

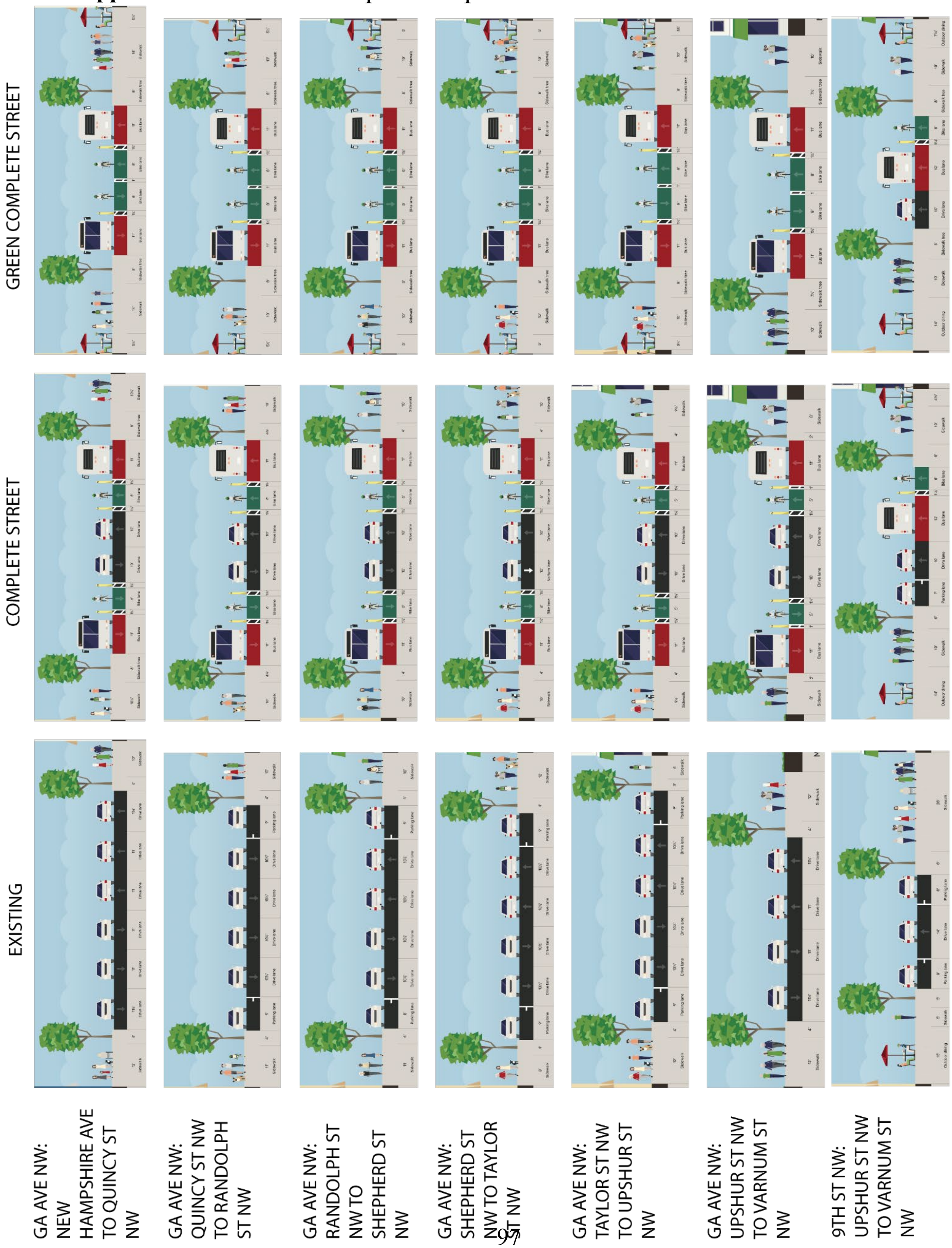
PINEY BRANCH



Appendix B Initial ROW Diagraming



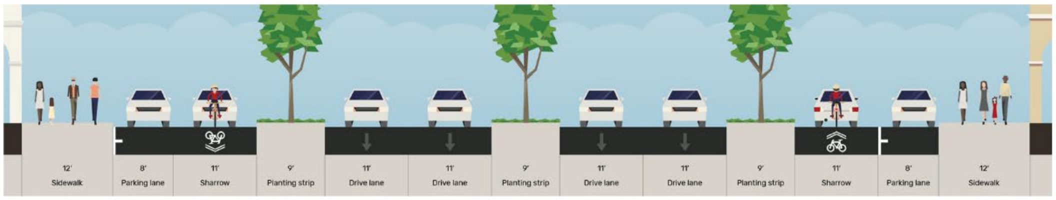
Appendix C ROW Concept I Comparison



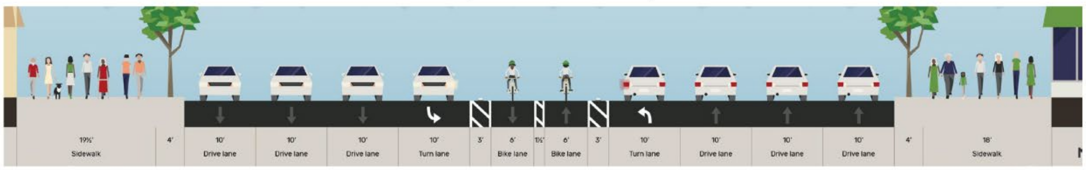
Appendix D ROW Precedents

The following precedents were observed to understand spatial priorities.

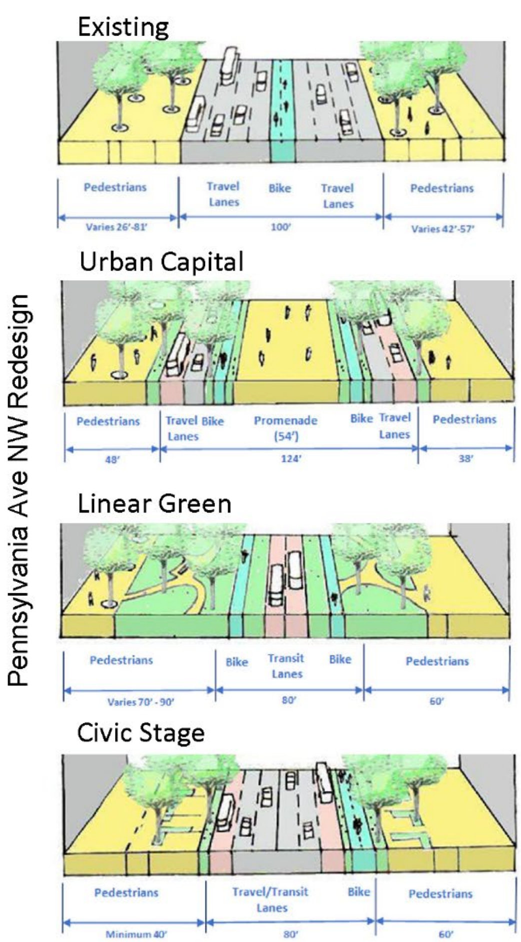
Octavia Blvd, SF

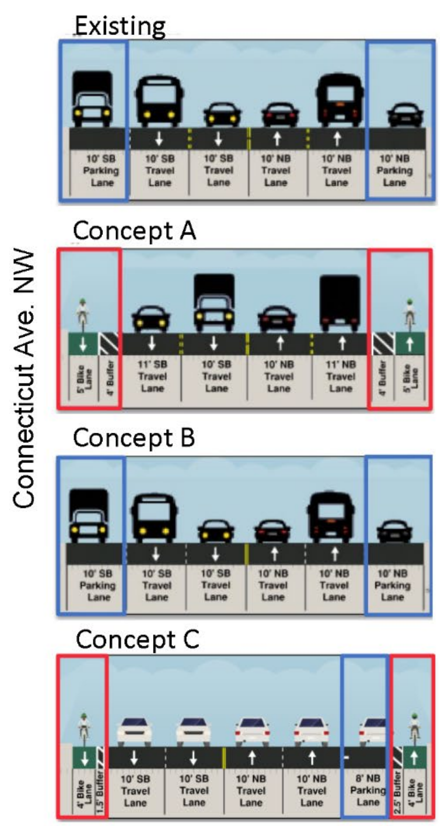


Pennsylvania Ave NW, DC



Pico Blvd,
LA

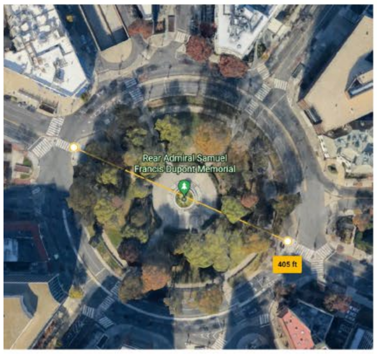




Appendix E Precedents of Traffic Circles

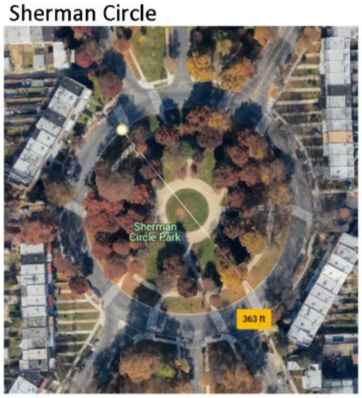
Traffic circles observed for dimensioning.

Dupont Circle

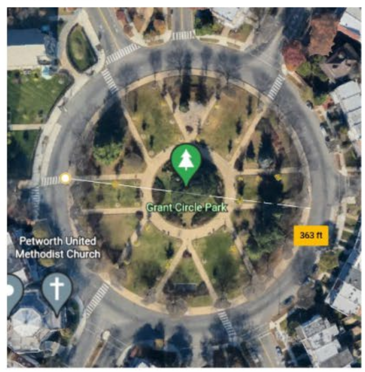


Logan Circle

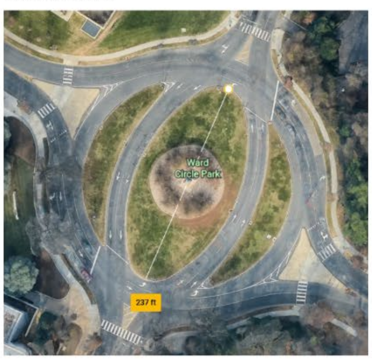
Sherman Circle



Grant Circle



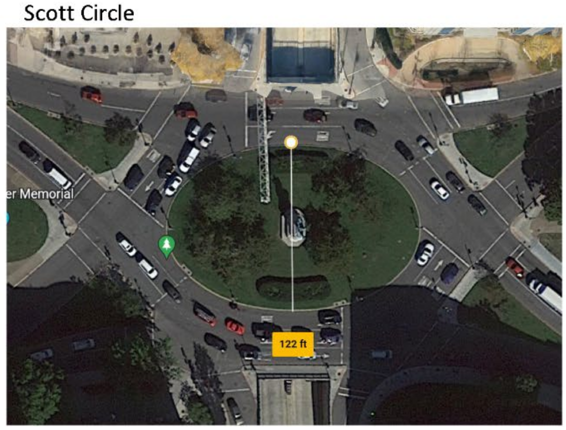
Ward Circle



Benjamin Banneker Park

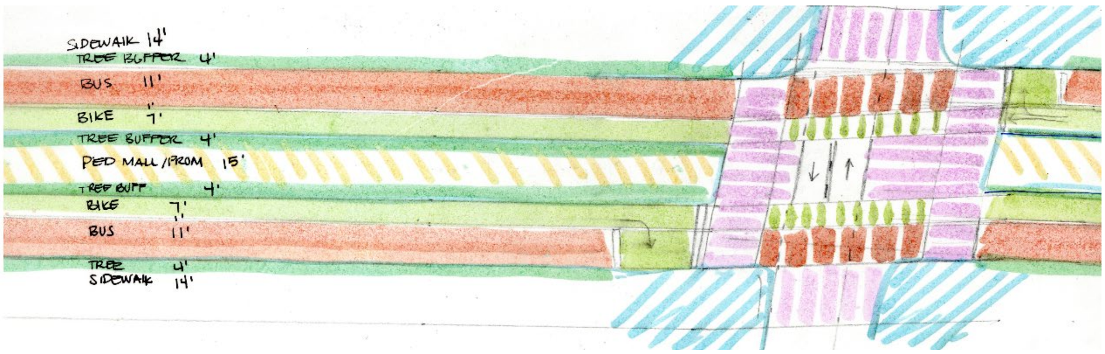
Thomas Circle

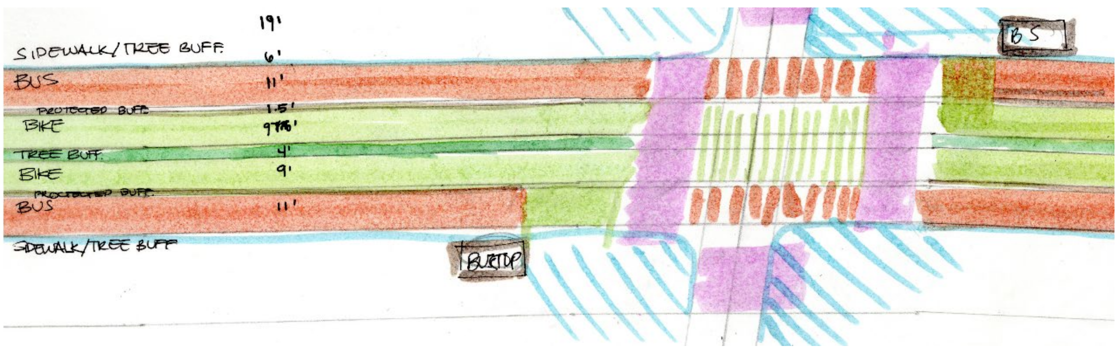
Scott Circle

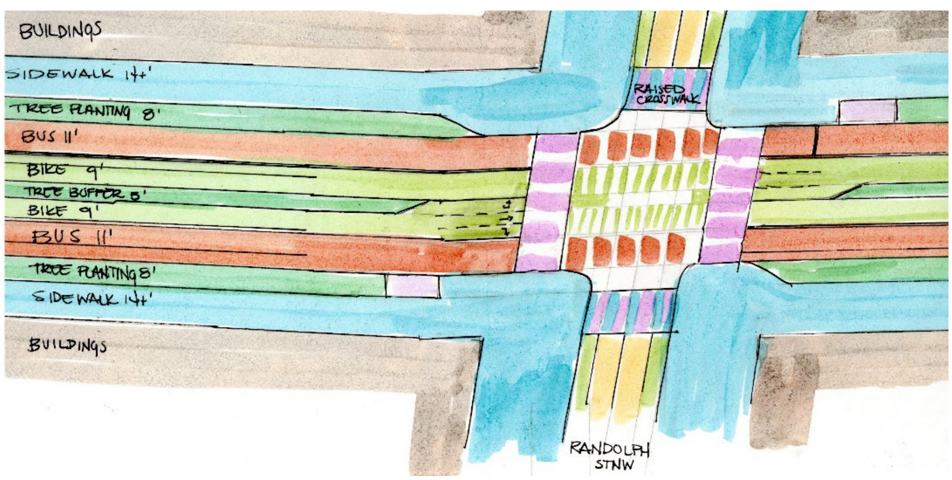


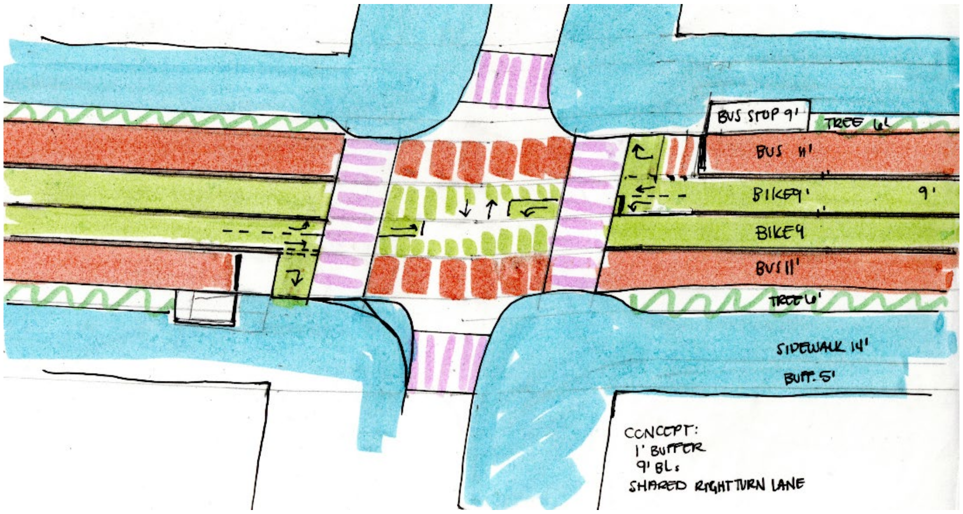
Appendix F Concepts of ROW Orientation In Plan

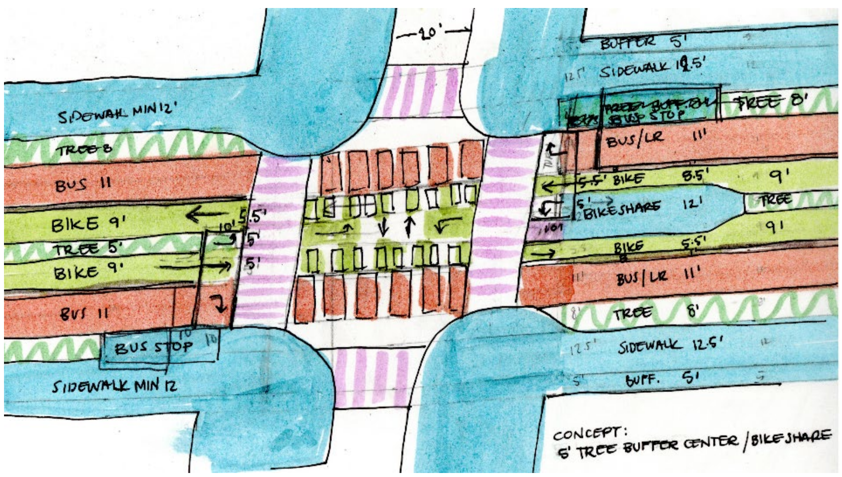
Sketches of ROW in plan view to explore layout and intersection design.

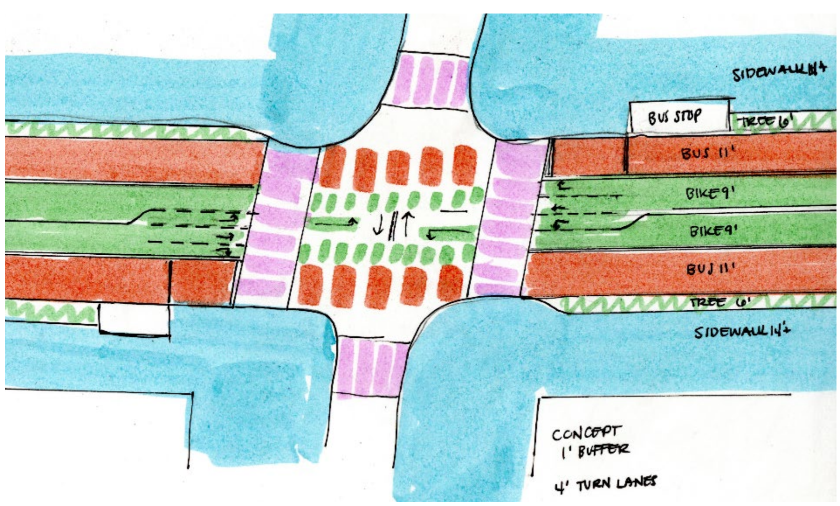







BUS STOP 9'
TREE 6'
BUS 11'
BIKE 9'
9'
BIKE 9
BUS 11'
TREE 6'
SIDEWALK 14'
BUFF. 5'
CONCEPT:
1' BUFFER
9' BLs
SHARED RIGHT TURN LANE

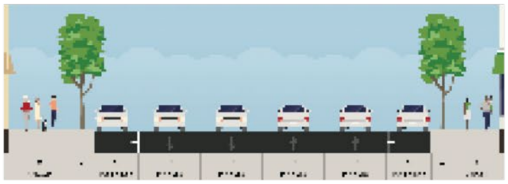

20'
BUFFER 5'
SIDEWALK 12.5'
SIDEWALK MIN 12'
TREE 8'
TREE 8
BUS 11
BUS/LR 11'
BIKE 9'
TREE 5'
BIKE 9'
BUS 11
BIKESHARE 12'
BIKE 5.5'
BUS/LR 11'
TREE 8'
BUS STOP
SIDEWALK 12.5'
SIDEWALK MIN 12
BUFF. 5'
CONCEPT:
5' TREE BUFFER CENTER / BIKESHARE

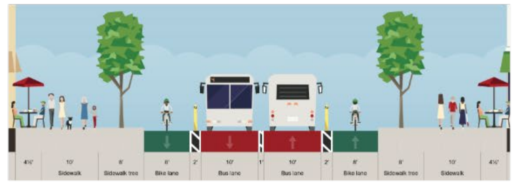

SIDEWALK 14'
BUS STOP
TREE 6'
BUS 11'
BIKE 9'
BIKE 9'
BUS 11'
TREE 6'
SIDEWALK 14'
CONCEPT
1' BUFFER
4' TURN LANES

Appendix G ROW Comparison – Existing & Proposed

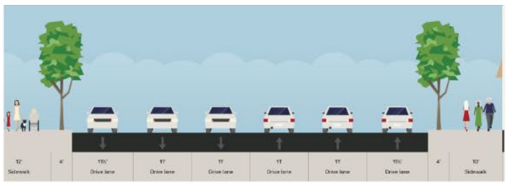
EXISTING | PROPOSED

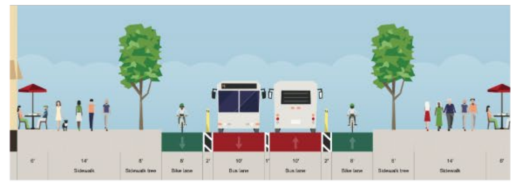
GA AVE NW: QUEBEC PL TO NEW HAMPSHIRE AVE



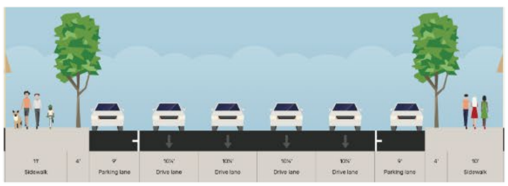


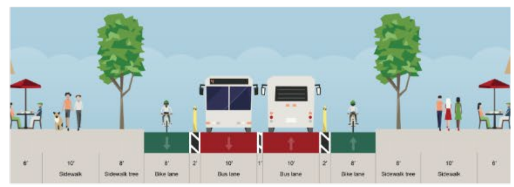
GA AVE NW: NEW HAMPSHIRE AVE TO QUINCY ST NW



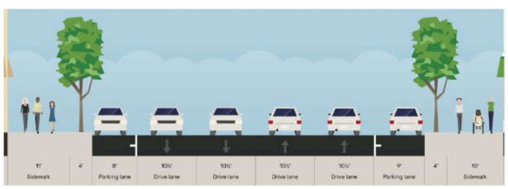


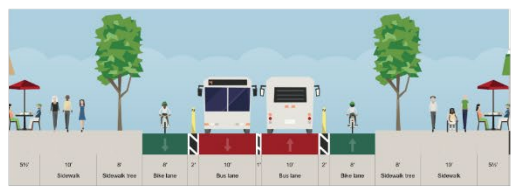
GA AVE NW: QUINCY ST NW TO RANDOLPH ST NW



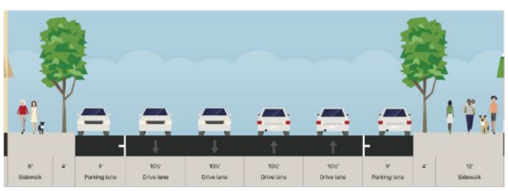


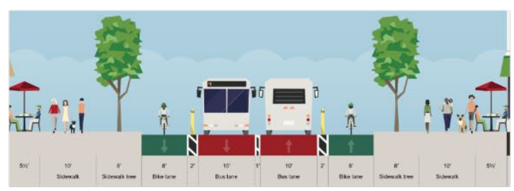
GA AVE NW: RANDOLPH ST NW TO SHEPHERD ST NW



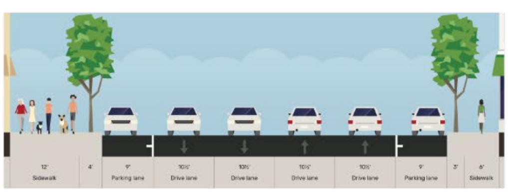


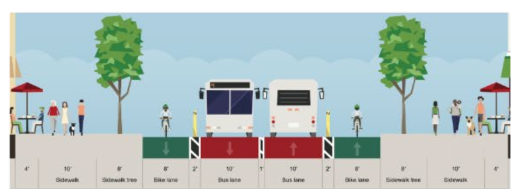
GA AVE NW: SHEPHERD ST NW TO TAYLOR ST NW



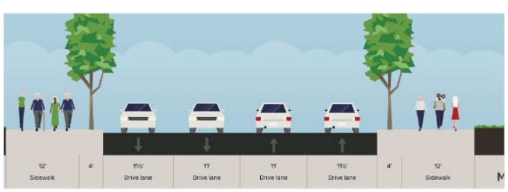


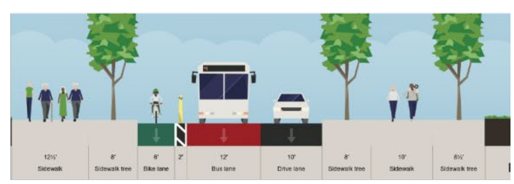
GA AVE NW: TAYLOR ST NW TO UPSHUR ST NW



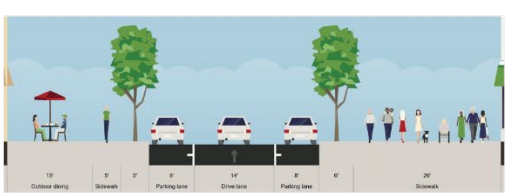


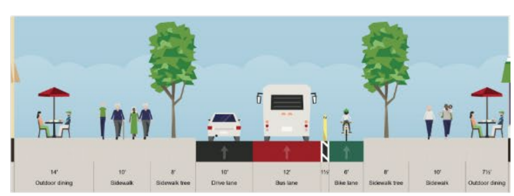
GA AVE NW: UPSHUR ST NW TO VARNUM ST NW





9TH ST NW: UPSHUR ST NW TO VARNUM ST NW





Appendix H ROW Spatial Documentation and Exploration

Table compares applications of different ROW configuration: existing, Complete Street (CS) with parking, Complete Street, and Hierarchy.

Right-of-way Spatial Documentation and Exploration

Block Segment	Application*	Total ROW	Number of Lanes	Width of Lanes	Parking Width	Buffer**	Bike	Bus	Tree Buffer	Sidewalk***
New Hampshire Avenue NW to Quincy St NW	Existing	97'	6	11-11.5'	-	-	-	-	4'-5'	12', 10'
	CS with Parking		2	10'	7.5'	1.5'	5'	11'	4'	8'
	Complete Street		2	10'	-	1.5', 1.5'	6'	11'	8'	10.5'
	Concept 1		-	-	-	1', 1.5'	8'	11'	8'	10', 4'
	Proposal		-	-	-	1', 2'	8'	10'	8'	14', 5.5'
Quincy to Randolph	Existing	89'	4	10.5'	9.5'	-	-	-	3'-6'	11', 10'
	CS with Parking		2	9'	7.5'	1.5'	5'	11'	.5-1'	8'
	Complete Street		2	10'	-	1.5', 1.5'	6'	11'	4.5'	10'
	Concept 1		-	-	-	1', 1.5'	8'	11'	8'	14', 5.5'
	Proposal		-	-	-	1', 2'	8'	10'	8'	10', 5.5'
Randolph to Shepherd	Existing	88'	4	10.5'	8'	-	-	-	3'-6'	11', 10'
	CS with Parking		2	9'	7'	1.5'	5'	11'	1'	8'
	Complete Street		2	10'	-	1.5', 1.5'	6'	11'	4'	10'
	Concept 1		-	-	-	1', 1.5'	8'	11'	8'	10', 5'
	Proposal		-	-	-	1', 2'	8'	10'	8'	10', 5.5'
Shepherd to Taylor	Existing	88'	4	10.5'	9'	-	-	-	5'-8'	8', 12'
	CS with Parking		2	9'	7'	1.5'	5'	11'	.5-1'	8'
	Complete Street		2	10'	-	1.5', 1.5'	6'	11'	4'	10'
	Concept 1		-	-	-	1', 1.5'	8'	11'	8'	10', 5'
	Proposal		-	-	-	1', 2'	8'	10'	8'	10', 5'
Taylor to Upshur	Existing	85'	4	10.5'	9'	-	-	-	5'-7'	12', 6'
	CS with Parking		2	9'	7'	1'	5'	11'	1'	7'
	Complete Street		2	10'	-	1.5', 1.5'	5'	11'	4'	9.5'
	Concept 1		-	-	-	1', 1.5'	8'	11'	8'	10', 3.5'
	Proposal		-	-	-	1', 2'	8'	10'	8'	10', 4'
Upshur to Varnum (Merging Upshur to Kansas and Kansas to Varnum)	Existing	77'	4	11-11.5'	-	-	-	-	2'-4'	12'
	CS with Parking		2	10'	-	1.5', 1'	5'	11'	2'	8'
	Complete Street		2	10'	-	1.5', 1'	5'	11'	2'	8'
	Concept 1		2	10'	-	1.5', 1'	5'	11'	2'	8'
	Proposal		1	10'	-	2'	6'	12'	8'	10'
9th St NW: Upshur to Varnum	Existing	87'	1	14'	8'	-	-	-	4'-6'	5', 26' (sidewalk)
	CS with Parking		1	10'	7'	1.5'	6'	12'	6'	10', 14', 4.5'
	Complete Street		1	10'	-	1.5'	6'	12'	8'	10', 14', 7.5'
	Concept 1		1	10'	-	1.5'	6'	12'	6'	10', 14', 7.5'
	Proposal		1	10'	-	1.5'	6'	12'	8'	10', 14', 7.5'

*CS = Complete Street

**One value: Buffer between bus lane and bicycle lane. Two values: buffer between bus lanes, buffer between bus lane and bike lanes.

***Existing measurements are "west, east." Proposed dimensions are total sidewalk width between building front and building-side treepit edge. Second value in proposed is additional space for businesses or public seating, or "frontage," if third value is provided the last two measurements reflect the west and east sides respectively.

[X] East sidewalk including frontage

Appendix I Possible Amenities and Features

The following lists are suggestions on possible public amenities and

Space

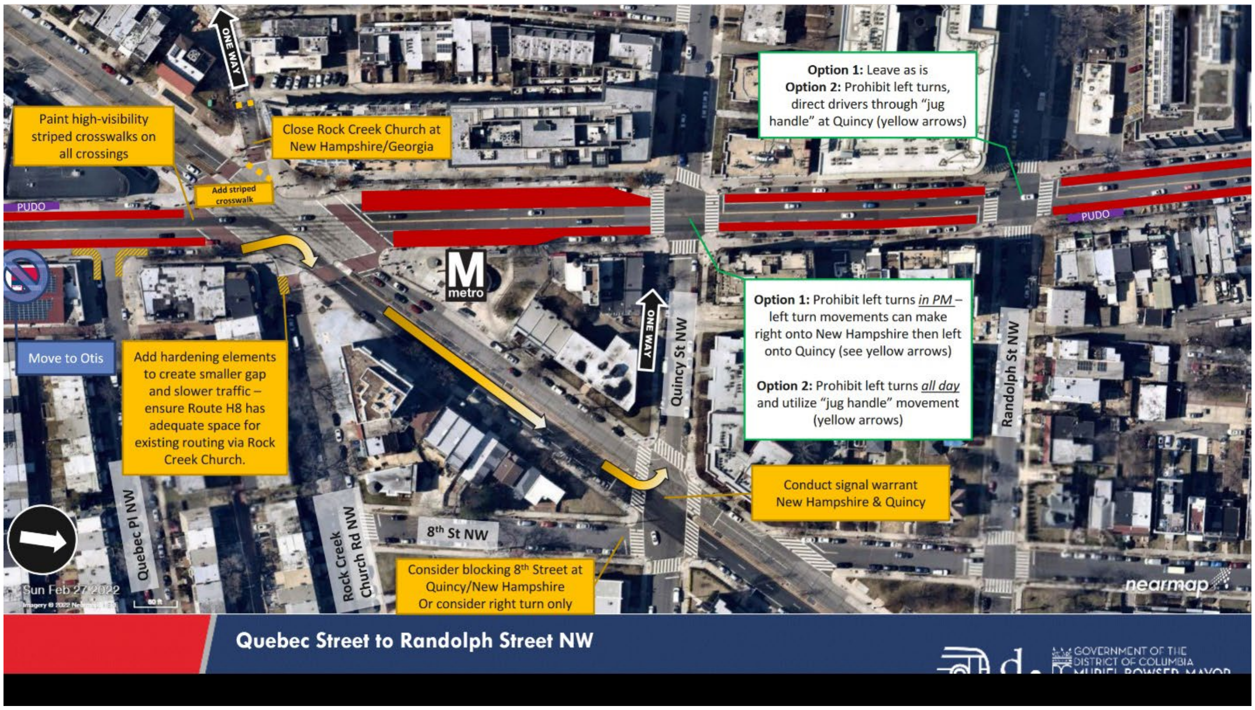
Library	1	Outdoor children's story time
	2	Outdoor history exhibits
	3	Outdoor art exhibits
	4	Benches
	5	Drinking fountains
	6	Public restroom
	7	Bike mainteance
	8	Stroller storage
	9	Covid/medical testing
	10	Voting/medical drop offs
	11	Tables
	12	Information/maps
	13	Outdoor wifi
Circles	1	Touchable water feature
	2	Play structure/games
	3	Farmers market/vendors
	4	Ice rink
	5	Art sculpture
	6	Stage
	7	Ample moveable seating
	8	Educational garden beds
	9	Music/audio
	10	Public kitchen
	11	Fire pits
Street	1	Variety of seating
	2	Comfortable bus shelters
	3	Shade
	4	Vendors
	5	Café seating
	6	Artful paving
	7	Sculptures
	8	Drinking fountains
	9	Restrooms
	10	Secure bike/stroller storage
	11	Wifi/electric outlets

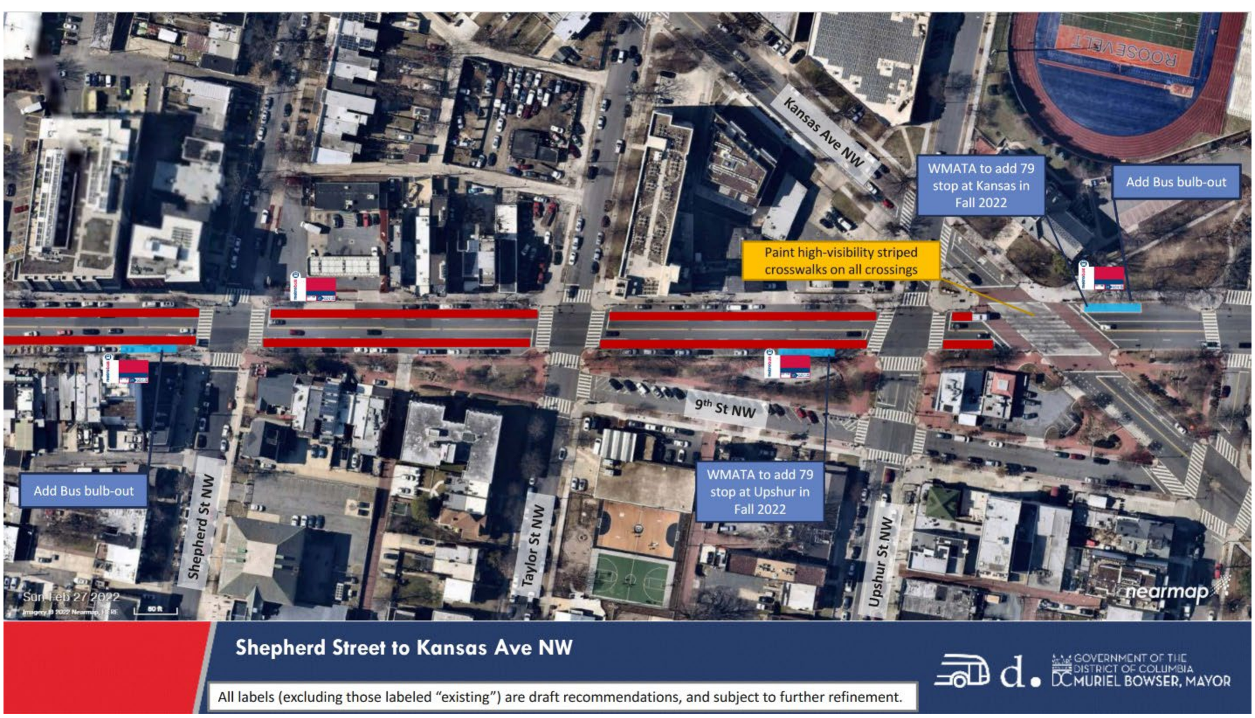
General Ammenities	1	Public charging (phone, laptop, bikes)
	2	Wifi
	3	Shade (trees/structures)
	4	Mist
	5	Variety and mobile seating
	6	Beautiful lighting
	7	Beautiful paving
	8	Sound buffering/sensitivity
	9	Restrooms
	10	Drinking fountains
	11	Stroller storage
	12	Bicycle maintenance
	13	Covered bicycle racks
	14	Vendors - food, drinks, goods
	15	Performers
	16	Art: 3d and 2D

features the site could support. This is not exhaustive.

Appendix J DDOT Bus Priority Project

These two images are from DDOT's Bus Priority Project proposed for Georgia Avenue NW between Barry Place NW to Kansas Avenue NW. (DDOT, 2022)





Appendix K ANC 4C Vision Zero Committee Meeting Attendees

The ANC 4C Vision Zero Committee Members that attended the one-hour video conference meeting to review the initial site plan were:

1. Avery Ash
2. Joshua Hertzberg
3. Hannah Sheehy, Chair

The meeting took place on January 25, 2023 from 6-7 pm EST over Zoom video conference.

Confirmation of members' role appointments can be found in the ANC 4C's September 2021 meeting minutes located here: https://www.anc4c.com/anc4c-meetings If no longer available on this site, please contact ANC 4C directly.

Appendix L Site Proposal Surface Area Calculations

The existing surface areas were obtained through DC Open Data GIS database. Note, the proposed surface area total is short 6% and is likely due to errors made in the computer-aided drafting software application used for the site

TOTAL SITE AREA (sqft)	494,194	
	Existing	Proposed
Impervious	430,793	295,621
Pervious	63,401	170,841

SURFACE AREA BY TYPE									
MOBILITY									
		Existing		Proposed		Existing		Proposed	
Category	Type	Area (sqft)	Type % of Category	Area (sqft)	Type % of Category	Type % of Total Site	Category % of Total Site Area	Type % of Total Site	Category % of Total Site Area
SOV	Road	223,994	89%	43,989	77%	45%	51%	9%	12%
	Parking Lot	23,915	10%	2,364	4%	5%		0%	
	Alley	1,201	0%	1,201	2%	0%		0%	
	Median	1,594	1%	9,414	17%	0%		2%	
	Sub total	**250,705**		**56,969**					
SUSTAINABLE TRANSPORTATION	Bus	0	0%	52,769	93%	0%	0%	11%	11%
	Bike	0	0%	3,479	6%	0%		1%	
	Sub total	**0**		**56,248**					
PEDESTRIANS	Crosswalks	37,790	23%	29,310	13%	8%	34%	6%	45%
	Sidewalk	129,556	77%	146,969	66%	26%		30%	
	Permeable paving	0	0%	45,571	21%	0%		9%	
	Sub total	**167,346**		**221,851**					
CATEGORY TOTAL		**418,050**		**278,819**			**85%**		**68%**
VEGETATION									
		Existing		Proposed		Existing		Proposed	
Category	Type	Area (sqft)	Type % of Category	Area (sqft)	Type % of Category	Type % of Total Site	Category % of Total Site Area	Type % of Total Site	Category % of Total Site Area
VEGETATION	Bioretention	3,449	5%	46,961	41%	1%	13%	10%	23%
	Grass	22,425	35%	16,505	14%	5%		3%	
	Tree Box	37,527	59%	51,707	45%	8%		10%	
	Sub total	**63,401**		**115,173**					
CATEGORY TOTAL		**63,401**		**115,173**			**13%**		**23%**
OTHER									
		Existing		Proposed		Existing		Proposed	
Category	Type	Area (sqft)	Type % of Category	Area (sqft)	Type % of Category	Type % of Total Site	Category % of Total Site Area	Type % of Total Site	Category % of Total Site Area
OTHER	Stairs	1,201	9%	1,201	9%	0%	3%	0%	3%
	Building	12,717	91%	12,717	91%	3%		3%	
	Sub total	**13,918**		**13,918**					
CATEGORY TOTAL		**13,918**		**13,918**			**3%**		**3%**
TOTAL							**100%**		**94%**

Additional Site Details

CROSSWALKS		
	Existing	Proposed
Number	40	50
Area (ft^2)	37,790	29,310

TREES		
	Existing	Proposed
Tree Count	148	308
Total Area		(707ft^2/tree)
	129,818	217756
Total Crown %	26%	44%
Tree mean DBH	9	n/a

Tree count for proposed is estimated by dividing the total cubic area of bioretention, tree pits, and silva cells (308,179 ft^3) by 1,000. (Casey Trees, 2013)

PUBLIC SPACE				
	Existing		Proposed	
Hardscape	*sidewalk*	26%	*sidewalk & permeable paving*	39%
Green space	*vegetation category*	13%	*vegetation category*	23%
Total of Site		**39%**		**62%**

Appendix M Stormwater Volume Calculations & Intervention Results

Full calculations on measuring stormwater runoff volume within the site (catchment area). The cistern dimensions were obtained from RainHarvest Systems LLC. (RainHarvest Systems LLC, n.d.)

Existing Surface Area & Stormwater Runoff Volumes

	Measured Drainage Area	**Percentage of Boundary**	**Total Drainage Area (A)**	**Rational method runoff coefficient (c)**	**Peak runoff 2-yr storm acre-feet/day**	**Peak runoff 15-yr storm acre-foot/day**
	sqft	*Measured Area/Boundary*	*(Area Measured)/43560', acre-foot*		*q=CiA*	*q=CiA*
Impervious	430,793.075	87%	9.890	0.900	2.366	3.857
Pervious	63,401.146	13%	1.455	0.250	0.097	0.158
Total	**494,194.222**		**11.345**		**2.463**	**4.015**
				50% Retention Volume	**1.231**	**2.007**

DC Storm Data

Rainfall Return Period (yr)	Rainfall intensity (i), inch/24-hour	Rainfall intensity (i), ft/24-hour
2	**3.19**	**0.266**
5	4.12	0.343
10	4.93	0.411
15	**5.2**	**0.433**
25	6.17	0.514
50	7.26	0.605
100	8.5	0.708
1	2.63	0.219

Proposed Detention Interventions & Volumes

BMP	**Void Percentage**	**Surface Area (ft^2)**	**Surface Area (acre)**	**Avg. Depth (ft)**	**Volume (ft^3)**	**Volume (acre-ft)**	**Storage volume (acre/foo** (Void Percentage) x (Volume)	**Percentage of Total BMP Surface Area**	**Percentage of Total Site Area**	**Percentage of Total BMP Volume (ft^3)**
Bioretention	0.25	46,960.72	1.07807	3.00	140,882.17	3.23421	0.80855	28%	10%	32%
Grass	0.25	16,504.77	0.37890	1.00	16,504.77	0.37890	0.09472	10%	3%	4%
Green Roof	0.40	6,617.77	0.15192	0.50	3,308.89	0.07596	0.03038	4%	1%	1%
Permeable paving	0.40	45,571.39	1.04618	2.50	113,928.47	2.61544	1.04618	27%	9%	26%
Silva cells	0.45	3,478.93	0.07987	3.50	12,176.24	0.27953	0.12579	2%	*below grade*	3%
Tree box	0.25	51,707.03	1.18703	3.00	155,121.08	3.56109	0.89027	31%	10%	35%
Total		167,361.68	3.84210	13.50	441,921.63	10.14512	**2.99590**	100%	**34%**	100%

Proposed Retention Interventions & Volumes

Volume		
Storm	**acre-feet**	**gallons**
2-year Retention	**1.231**	**401,123**
15-year Detention	**1.019**	**332,043**
15-year Retention	**2.007**	**653,984**
Cisterns		
	Model (Park)	**Model (ROW)**
Dimensions (w x l)	12' x 61.6'	8' x 40'9"
Volume Capacity	50,000	15,000
Footprint Area	739	326
Site Area Available	45,571	51,707
Site Maxium Cisterns	62	159
Cistern Count per Type		
	Model (Park)	**Model (ROW)**
2-year Retention	8	27
15-year Detention	7	22
15-year Retention	13	44

Existing			**Proposed**		
	Area (sqft)	**Percentage**		**Area (sqft)**	**Percentage**
Impervious	430793.08	87.17%	**Impervious**	326832.54	66.13%
Pervious	63401.15	12.83%	**Pervious**	167361.68	33.87%
Boundary (total)	494194.22	100.00%	**Boundary (total)**	494194.22	100.00%

Appendix N iTree® Planting Calculation Estimates

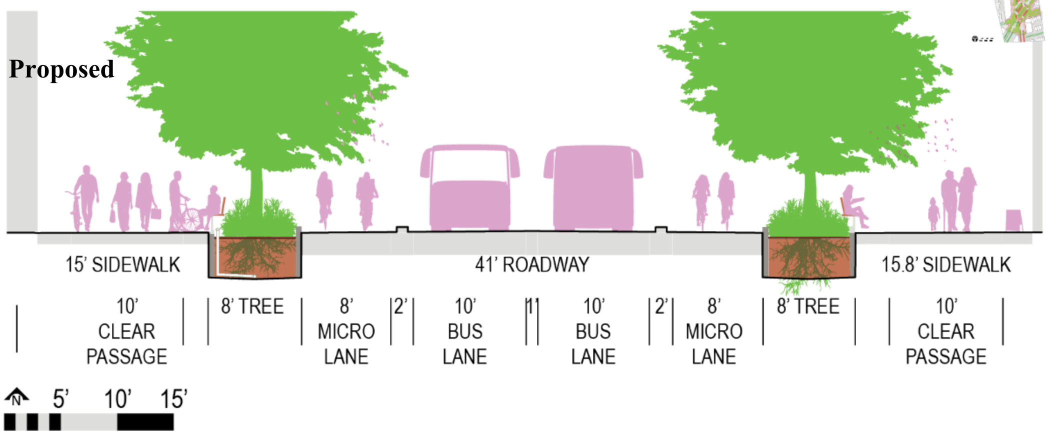
This data was produced from the i-Tree Planting Calculator version 2.4.1 for Washington; DC.
Location: Washington; DC 20001
Electricity Emissions Factor: 1127.04
Tree Mortality: 20%
Lifetime: 40
Fuel Emissions Factor: 73.73
Run Date: 4-13-2023

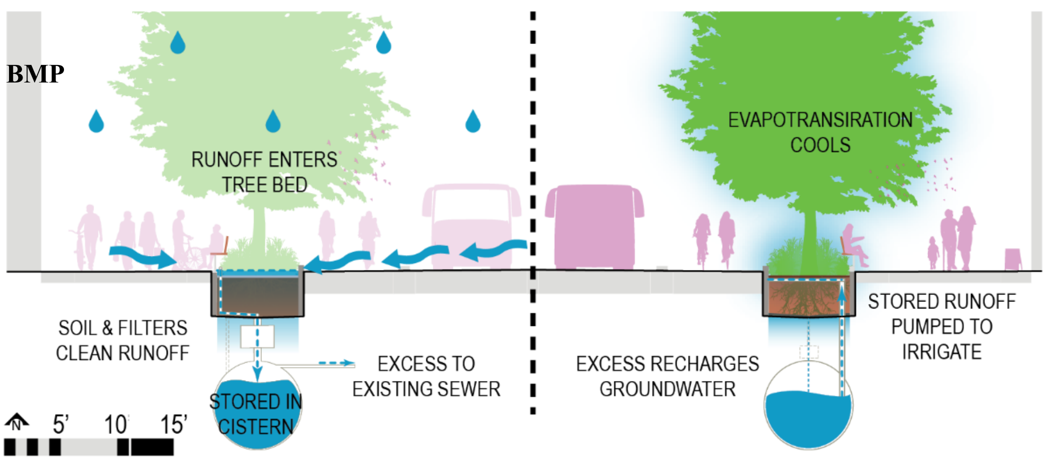
	Species	DBH (inches)	Distance to Building (feet)	Direction	Building Vintage	TreeCondition	CrownLightExposure	CO2 Avoided (pounds)	CO2 Avoided ($)	CO2 Sequestered (pounds)	CO2 Sequestered ($)	Electricity Saved (kWh)	Electricity Saved ($)	Fuel Saved (MMBtu)
1	Northern hackberry(Celtis occidentalis)	20	0-19	east	post-1980	excellent	partial sun	430,350.60	$10,008.63	27,825.20	$647.13	128,813.20	$12,456.24	558.8
2	American sycamore(Platanus occidentalis)	20	0-19	west	post-1980	excellent	full sun	558,325.10	$12,984.92	322,069.50	$7,490.34	190,745.10	$18,445.05	341.9
3	Swamp white oak(Quercus bicolor)	20	0-19	west	post-1980	excellent	full sun	558,325.10	$12,984.92	411,228.70	$9,563.91	190,745.10	$18,445.05	341.9
4	Southern red oak(Quercus falcata)	20	0-19	west	post-1980	excellent	full sun	558,325.10	$12,984.92	269,526.60	$6,268.36	190,745.10	$18,445.05	341.9
5	Willow oak(Quercus phellos)	20	0-19	west	post-1980	excellent	full sun	558,325.10	$12,984.92	520,528.60	$12,105.89	190,745.10	$18,445.05	341.9
6	American basswood(Tilia americana)	20	0-19	west	post-1980	excellent	full sun	558,325.10	$12,984.92	236,219.30	$5,493.73	190,745.10	$18,445.05	341.9
7	Sweetgum(Liquidambar styraciflua)	20	0-19	east	post-1980	excellent	full sun	430,350.60	$10,008.63	329,226.60	$7,656.80	128,813.20	$12,456.24	558.8
8	American sycamore(Platanus occidentalis)	20	0-19	east	post-1980	excellent	full sun	430,350.60	$10,008.63	322,069.50	$7,490.34	128,813.20	$12,456.24	558.8
9	Swamp white oak(Quercus bicolor)	20	0-19	east	post-1980	excellent	full sun	430,350.60	$10,008.63	411,228.70	$9,563.91	128,813.20	$12,456.24	558.8
#	Southern red oak(Quercus falcata)	20	0-19	east	post-1980	excellent	full sun	430,350.60	$10,008.63	269,526.60	$6,268.36	128,813.20	$12,456.24	558.8
#	Willow oak(Quercus phellos)	20	0-19	east	post-1980	excellent	full sun	430,350.60	$10,008.63	520,528.60	$12,105.89	128,813.20	$12,456.24	558.8
#	American basswood(Tilia americana)	20	0-19	east	post-1980	excellent	full sun	430,350.60	$10,008.63	236,219.30	$5,493.73	128,813.20	$12,456.24	558.8
#	Northern hackberry(Celtis occidentalis)	20	0-19	west	post-1980	excellent	full sun	558,325.10	$12,984.92	42,109.30	$979.33	190,745.10	$18,445.05	341.9
#	Sweetgum(Liquidambar styraciflua)	20	0-19	west	post-1980	excellent	full sun	558,325.10	$12,984.92	329,226.60	$7,656.80	190,745.10	$18,445.05	341.9
#								**6,920,730.10**	**$160,954.85**	**4,247,533.20**	**$98,784.53**	**2,236,908.20**	**$216,309.03**	**6,305.00**

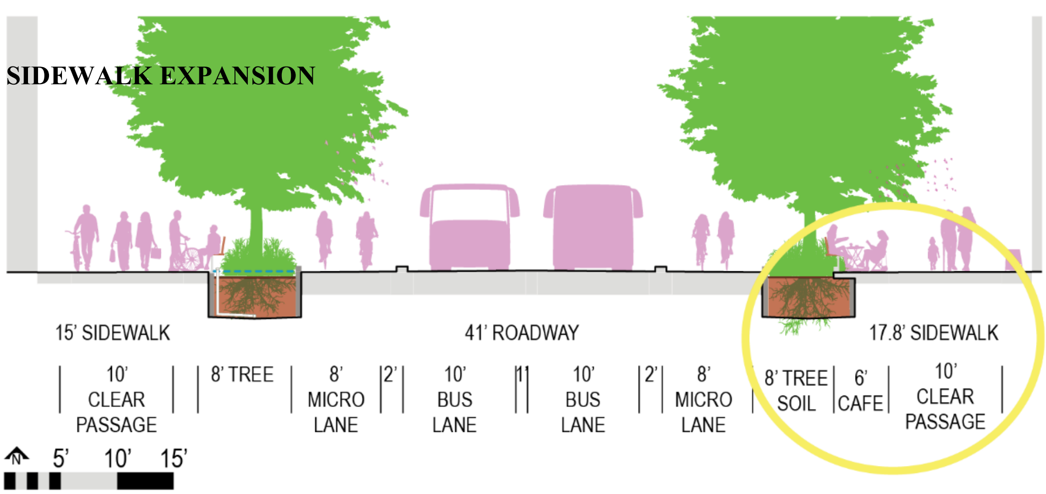
Fuel Saved ($)	Tree Biomass (short ton)	Rainfall Interception (gallons)	Avoided Runoff (gallons)	Avoided Runoff ($)	O3 Removed (pounds)	NO2 Avoided (pounds)	NO2 Removed (pounds)	SO2 Avoided (pounds)	SO2 Removed (pounds)	VOC Avoided (pounds)	PM2.5 Avoided (pounds)	PM2.5 Removed (pounds)	Avoided Value ($)	Removal Value ($)
$8,745.54	11.5	2,044,988.00	702,748.80	$6,279.76	1,627.32	158.97	239.08	3,215.50	61.87	12.57	28.4	100.72	$2,602.50	$28,281.98
$5,350.61	92	2,617,704.40	899,559.70	$8,038.47	2,240.82	206.24	334.03	4,171.67	84.72	15.99	41.46	150.04	$3,708.90	$41,493.53
$5,350.61	127	2,681,953.70	921,638.60	$8,235.76	1,635.91	206.24	228.36	4,171.67	63.46	15.99	41.46	77.39	$3,708.90	$23,147.04
$5,350.61	89.5	2,074,400.70	712,856.30	$6,370.09	1,491.18	206.24	214.71	4,171.67	57.14	15.99	41.46	82.84	$3,708.90	$23,805.72
$5,350.61	148.8	2,381,187.30	818,281.90	$7,312.17	2,125.34	206.24	319.53	4,171.67	80.09	15.99	41.46	149.14	$3,708.90	$40,902.64
$5,350.61	72.7	1,669,474.10	573,705.60	$5,126.63	1,338.95	206.24	197.06	4,171.67	50.87	15.99	41.46	83.75	$3,708.90	$23,468.49
$8,745.54	94.1	1,921,529.10	660,322.90	$5,900.65	1,277.25	158.97	181.65	3,215.50	49.19	12.57	28.4	67.29	$2,602.50	$19,597.07
$8,745.54	92	2,617,704.40	899,559.70	$8,038.47	2,240.82	158.97	334.03	3,215.50	84.72	12.57	28.4	150.04	$2,602.50	$41,493.53
$8,745.54	127	2,681,953.70	921,638.60	$8,235.76	1,635.91	158.97	228.36	3,215.50	63.46	12.57	28.4	77.39	$2,602.50	$23,147.04
$8,745.54	89.5	2,074,400.70	712,856.30	$6,370.09	1,491.18	158.97	214.71	3,215.50	57.14	12.57	28.4	82.84	$2,602.50	$23,805.72
$8,745.54	148.8	2,381,187.30	818,281.90	$7,312.17	2,125.34	158.97	319.53	3,215.50	80.09	12.57	28.4	149.14	$2,602.50	$40,902.64
$8,745.54	72.7	1,669,474.10	573,705.60	$5,126.63	1,338.95	158.97	197.06	3,215.50	50.87	12.57	28.4	83.75	$2,602.50	$23,468.49
$5,350.61	13.9	2,598,322.50	892,899.20	$7,978.95	1,809.12	206.24	259.23	4,171.67	69.47	15.99	41.46	98.52	$3,708.90	$28,454.15
$5,350.61	94.1	1,921,529.10	660,322.90	$5,900.65	1,277.25	206.24	181.65	4,171.67	49.19	15.99	41.46	67.29	$3,708.90	$19,597.07
$98,673.02	**1,273.70**	**31,335,809.20**	**10,768,377.80**	**$96,226.24**	**23,655.32**	**2,556.47**	**3,449.01**	**51,710.20**	**902.29**	**199.88**	**488.97**	**1,420.14**	**$44,179.83**	**$401,565.13**

Appendix O Section Comparison

Three sections between Quincy and Randolph St. NW to demonstrate proposed layout and application of Silva Cells to expand sidewalks.







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