



# National Mall, Washington DC Minimum Build-Out Study

National Park Service

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**Prepared for:**

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**Prepared by:**

Michael T. Cassell  
Global Wireless Co-leader  
M: 410 446 8888  
E: michael.cassell@aecom.com

AECOM  
4 North Park Drive  
Hunt Valley, MD 21030  
aecom.com

## Executive Summary

This report documents the methodology and results of the National Park Service (NPS) study of the mobile network coverage and capacity on the National Mall and surrounding areas. This analysis identifies potentially acceptable telecommunications infrastructure within the Project Area that is consistent with the cultural landscape, NPS' mission, enabling legislation, existing NPS management documents, and future planning considerations.

The study provides the NPS an independent engineering assessment and framework to guide the future construction and operation of communications infrastructure required to provide improved fourth- and fifth-generation (4G and 5G) cellular service coverage and capacity. The report outlines the minimum telecommunications buildout needed to provide an up to five times (400%) increase in capacity for current wireless carriers while minimizing impacts on the viewsheds and resources of the landscape.

Specifically, this planning analysis looked at NPS lands including and surrounding the National Mall to identify potential sites and types of equipment needed to accomplish the telecommunications buildout. For the purposes of the analysis, the Project Area is divided into five sub-areas as shown in Figure ES-1.

The specific focus of the study was the potential addition of small cell and/or neutral host sites and required fiber infrastructure to support them. The project team worked closely with the NPS, Cybersecurity and Infrastructure Security Agency (CISA), mobile network operators (MNOs), and third-party operators (3POs) to ensure that all parties agreed with the technical methodologies.

## Analyzed Solutions

Four different base configurations ("Topologies") were analyzed and are described below: stand-alone small cell (SASC); dual-Multiple Network Operator (MNO) Distributed Radio Access Network (DRAN) small cell (DRAN-2); four-MNO DRAN small cell (DRAN-4); and four-MNO Neutral Host. A particular Topology will be utilized exclusively at an individual location but may be combined with other Topologies in any given area.

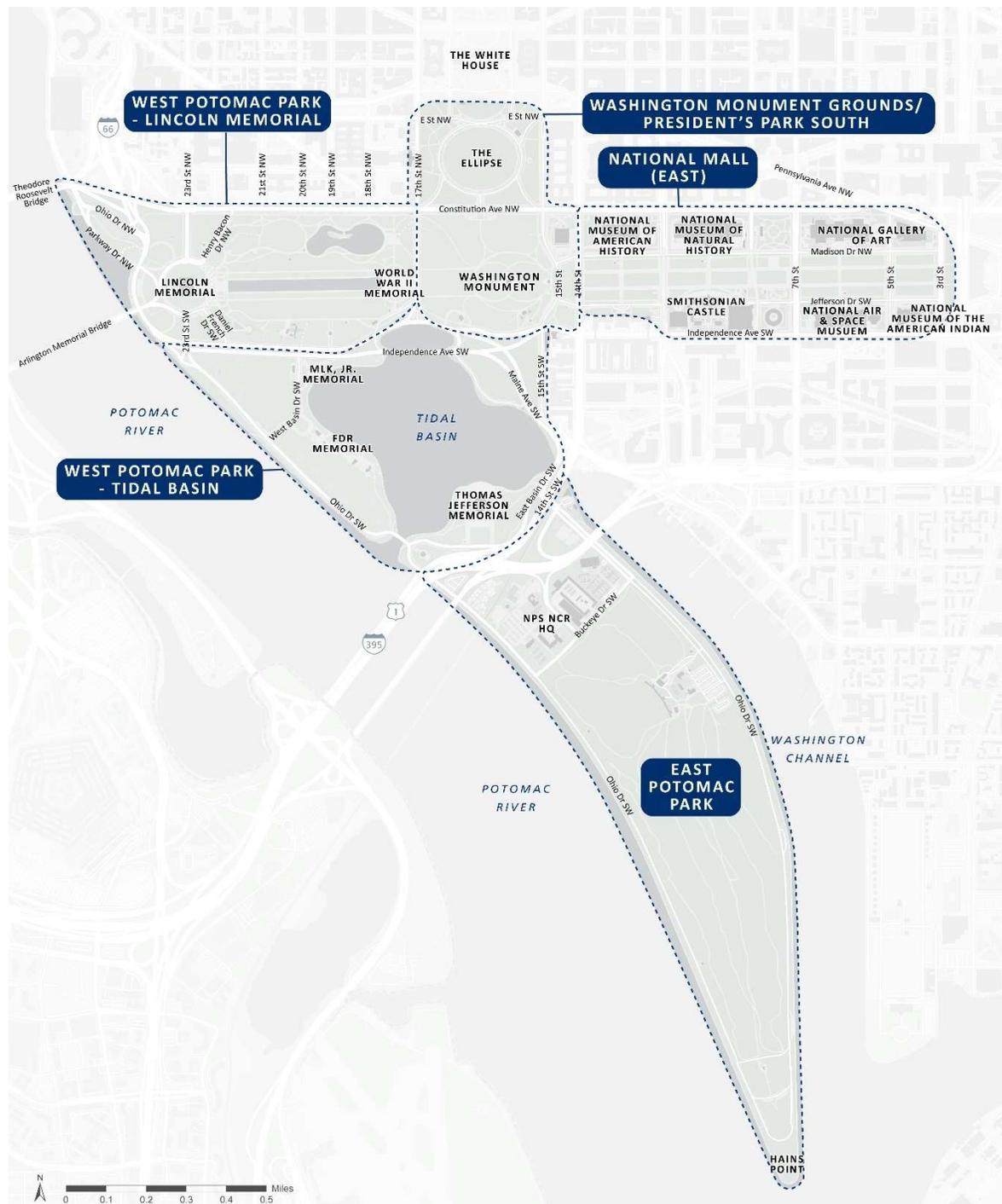
For each Topology, a standard site contains an antenna that would be mounted on a light pole, pylon, or similar vertical structure and associated ground-based infrastructure (equipment) that would be housed in a separate enclosure.

Below is a brief description of each Topology.

- **Stand-alone Small Cell (SASC):** The SASC Topology is a single-MNO Topology feeding a dedicated Multiple Input Multiple Output (MIMO) antenna on a light pole, pylon, or similar vertical structure.
- **Dual-MNO DRAN (DRAN-2):** The DRAN-2 small cell Topology consists of two MNOs providing independent equipment, each feeding a single dedicated antenna on a light pole, pylon, or similar vertical structure. DRAN-2 equipment could not be housed in the base of the pole because it would require a space approximately twice the size of the recently approved DC Department of Transportation (DDOT) standalone pole.
- **Four-MNO DRAN (DRAN-4):** The DRAN-4 small cell Topology is identical to DRAN-2 except that four MNOs would be sharing the site. A corresponding increase in equipment housing space would be required. There would also be a slight decrease in coverage radius for each MNO.
- **Neutral Host:** The Neutral Host Topology also supports four MNOs at each site but has less coverage and capacity versus DRAN-4 (due to power output and shared radios). The size of the associated outdoor distributed antenna system (oDAS) equipment footprint per site is like the DRAN-2 Topology but the antenna is much smaller. The Neutral Host Topology does require a system "head-end" where MNO equipment would be housed and be interfaced to a fiber-based Neutral Host distribution network.

Table ES-1 shows a summary of the characteristics of each Topologies relative to the other Topologies analyzed in this report.

**Figure ES-1: Project Sub-Areas**



**Table ES-1: Characteristics of Base Topologies (Estimated)**

Characteristic	SASC	DRAN-2	DRAN-4	Neutral Host
<b>Approximate Coverage Radius</b> <i>(C-Band / 2.5 GHz, vs SASC)</i>	100%	95%	75%	60%
<b>Approximate Equip. Housing Volume</b> <i>(Cubic Feet / vs SASC)</i>	45 / 100%	73 / 160%	130 / 290%	45 / 100%
<b>Approximate HVAC Requirements</b> <i>(vs SASC)</i>	100%	200%	400%	130%
<b>Approximate Power Requirements</b> <i>(per MNO, vs SASC)</i>	100%	200%	400%	150%
<b>Approximate Site Count</b> <i>(vs SASC)</i>	100%	50-55%	30-35%	35-40%
<b>MNOs per Site</b>	1	2	4	
<b>Approximate Capacity</b> <i>(per MNO, vs SASC)</i>	100%			70%
<b>Antenna Size</b> <i>(Height x Diameter)</i>	23.6" x 7.9"			21" x 1.6"
<b>"Hoteling" Required?</b>	No			Yes

### Existing Architectural Features

The Project Area includes existing architectural features that could be used to mount equipment. Features include light poles, memorial lighting (stanchions), wayfinding pylons, various structures, and small-scale features. Within each category of architectural features, numerous varieties are present, as shown in Table ES-2.

**Table ES-2: Existing Architectural Features**

Light Pole Types	Stanchion Types	Wayfinding Pylons	Structures	Small-scale Features
Twin Washington Globe	Lincoln Memorial	Small	Comfort Stations (existing)	Benches
Washington Globe	Washington Monument	Large	Comfort Stations (new)	Trash Cans
Olmsted	Jefferson Memorial		Concessions Kiosks	Recycling Cans
Lincoln Cobra				
Cobra				
Bega Lantern				
Saratoga				

### Criteria

The following represents the criteria applied to potential solutions:

- **Minimize impacts on cultural resources.** Multiple existing views and vistas are contributing features within the Project Area, including some of the country's most iconic view corridors, such as the view west from the U.S. Capitol to the Lincoln Memorial.
- **Use existing non-contributing architectural features when possible.** The Project Area contains multiple architectural features, ranging from kiosks and restrooms to light poles.
- **Reduce maintenance requirements.** To the extent practicable, the solutions should simplify the variety of materials (e.g., poles) in a way that minimizes potential NPS maintenance.

- **Consider the number of sites.** While fewer sites are often better, other factors in this section may lead to the selection of a design with more sites.

### Recommended Solutions

Due to their unique character, each of the five sub-areas require specific context-specific solutions. Separate designs were engineered for each Topology and compared for their efficacy. In some cases, a hybrid solution (mixture of Topologies within a given sub-area) is utilized allowing for the most efficient use of resources (e.g., utilizing lighting stanchions to provide service) and maximizing capacity near the locations where the densest crowds are expected (e.g., near the primary Memorials). While the solutions below reference light poles to be adapted or replaced, these could also be potential locations of standalone poles. A summary of the preferred solutions is provided in Table ES-3 below:

**Table ES-3: Summary of Preferred Solutions**

Sub-Area	Recommended Topology	Details
<b>National Mall East</b>	DRAN-2	<ul style="list-style-type: none"> <li>➤ 14 sites</li> <li>➤ Sites integrated with existing light poles along turf panels, with equipment enclosures concealed adjacent to poles</li> <li>➤ Ideal combination of capacity and size</li> </ul>
<b>Washington Monument Grounds and President’s Park South</b>	Hybrid (DRAN4 and Neutral Host)	<ul style="list-style-type: none"> <li>➤ 7 sites (4x DRAN-4, 3x Neutral Host)</li> <li>➤ Four DRAN-4 sites on existing Washington Monument stanchions</li> <li>➤ One Neutral Host site on the screening facility and 2 sites on poles at President’s Park South</li> <li>➤ Best combination of capacity, coverage, and concealment</li> </ul>
<b>West Potomac Park – Lincoln Memorial</b>	Hybrid (DRAN-4 and Neutral Host)	<ul style="list-style-type: none"> <li>➤ 11 sites (2x DRAN-4, 9x Neutral Host)</li> <li>➤ Two DRAN-4 on existing Memorial stanchions</li> <li>➤ Nine Neutral Host sites on light poles</li> <li>➤ Best combination of capacity, coverage, and concealment</li> </ul>
<b>West Potomac Park – Tidal Basin</b>	Hybrid (DRAN4 and Neutral Host)	<ul style="list-style-type: none"> <li>➤ 12 sites (4x DRAN-4, 8x Neutral Host)</li> <li>➤ Three DRAN-4 on lighting stanchions</li> <li>➤ One DRAN-4 on existing pole</li> <li>➤ Eight Neutral Host on poles spread throughout sub-area</li> <li>➤ Best combination of capacity, coverage, and concealment</li> </ul>
<b>East Potomac Park</b>	Neutral Host	<ul style="list-style-type: none"> <li>➤ 13 sites</li> <li>➤ Sites integrated in new, taller light poles with identical luminaires and easy-to-conceal equipment enclosures</li> <li>➤ Small site footprint with sufficient coverage and capacity</li> </ul>

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## Acronyms and Abbreviations

3PO	Third-party operator
4G-LTE	Fourth Generation – Long-Term Evolution
5G-NR	Fifth Generation – New Radio
AWS	Advanced Wireless Services
BAWA	Baltimore-Washington
CINR	Carrier to Interference and Noise Ratio
CISA	Cybersecurity and Infrastructure Security Agency
COLT	Cell On Light Truck
COW	Cell On Wheels
DAS	Distributed Antenna System
DDOT	DC Department of Transportation
DRAN	Distributed Radio Access Network
FDR	Franklin Delano Roosevelt
HVAC	Heating, Ventilation, and Air Conditioning
MIMO	Multiple Input Multiple Output
MLK	Martin Luther King
MNO	Mobile Network Operator
NAMA	National Mall and Memorial Parks
NCR	National Capital Region
NMNH	National Museum of Natural History
NMAAHC	National Museum of African American History and Culture
NPS	National Park Service
NRHP	National Register of Historic Places
oDAS	Outdoor Distributed Antenna System
RAN	Radio Access Network
RF	Radio Frequency
SASC	Stand-Alone Small Cell
SNOW	Small Node on Wheels
WCS	Wireless Communications Services

## Glossary of Terms

**3GPP:** 3rd Generation Partnership Project. An umbrella term for several standards organizations which develop protocols for mobile telecommunications including 4G-LTE and 5G-NR.

**4G-LTE:** Fourth Generation – Long-Term Evolution. A standard for wireless broadband communication for mobile devices and data terminals, based on the GSM/EDGE and UMTS/HSPA standards.

**5G-NR:** Fifth Generation – New Radio. A standard for wireless broadband communications developed by the 3rd Generation Partnership Project (3GPP) for the 5G (fifth generation) mobile networks. 5G-NR builds on the 4G-LTE standard.

**AWS:** Advanced Wireless Services. A family of frequency bands designated and licensed by the FCC. This band is comprised of three blocks including AWS-1 (1710 to 1755 MHz for uplink, and from 2110 to 2155 MHz), AWS-2 (1915-1920 MHz and 1995-2000 MHz), and AWS-3 (1695-1710 MHz, 1755-1780 MHz and 2155-2180 MHz).

**C-Band:** Federal Communications Commission-defined licensed spectrum band from 3.7 to 3.98 GHz; one of the bands used by Verizon Wireless and AT&T for 5G service. T-Mobile uses the 2.5 GHz band.

**CINR:** Carrier to Interference and Noise Ratio. A measurement defined in the 4G and 5G specifications as the ratio of the strength of a wanted carrier (signal) to the unwanted signal and noise at a given time and location. Closely related to Signal to Interference and Noise (SINR). Measured in dB.

**COLT:** Cell On Light Truck; see COW

**COW:** Cell On Wheels; a category of cell site that is built on a wheeled platform that can be quickly and temporarily relocated to provide temporary coverage and capacity for a specific mobile network. A COW requires highspeed data backhaul (usually in the form of fiber to a provider) to connect to the service providers network and power, which can be locally provided, generator powered, or both for redundancy. Special types of COWs include COLT (Cell On Light Truck) and SNOW (Small Node On Wheels, a special COW which is based on small cell equipment).

**dB:** a logarithmic unit that measures the relative power of two signals.

**dBm:** a logarithmic unit that measures the power of a signal relative to one watt.

**DRAN:** Distributed Radio Access Network. A shared network site Topology where multiple MNOs provide independent network electronics, typically small cells, which are then combined via RF connections into a single antenna. The number of MNOs sharing a DRAN site is often notated as an attached number, e.g., DRAN-2 refers to a site hosting two MNOs.

**Fiber Infrastructure:** the fiber-optic systems required to be installed to support the backhaul requirements of a site or a collection of sites. This would include the fiber itself, conduit, pull-boxes, patch panels, and other related infrastructure. For this project most of this infrastructure would be installed underground running between the various equipment housing enclosures and would have interconnection points in or near the Project Area to tie into commercial fiber networks. For the Neutral Host Topology, the fiber would terminate at the “head-end”.

**Head-End:** a central location where MNO equipment is housed and interfaced to a separate fiber-based distribution system that delivers signals to and from a Neutral Host site. The Neutral Host sites in the Project Area may be supported by one or multiple head-ends.

**HVAC:** Heating, Ventilation, Air Conditioning. Equipment required to maintain temperature and humidity within equipment housing.

**Macro:** the collection of cell sites in a network providing the primary coverage and capacity for an MNO.

**Macro Site:** high power network sites typically with larger antenna systems placed well above ground level on buildings, towers, or other similar structures.

**MIMO:** Multiple Input Multiple Output. MNOs use MIMO antenna technology to provide more capacity for a site by increasing the efficiency of the communications.

**Massive MIMO:** configuration that uses many MIMO antennas working together (frequently designed into a single enclosure) to create extremely efficient sites with extremely high capacity.

**Millimeter-Wave:** (mmWave) is a high frequency band, greater than 30 gigahertz, sometimes used for 5G. This band does not propagate well and is easily blocked by physical obstructions, but because of the extremely high bandwidths available can produce remarkably high throughput in wireless systems.

**MNO:** Mobile Network Operator. One of the licensed mobile telephony service providers which include AT&T, Verizon Wireless, T-Mobile, and Dish.

**Neutral Host:** also referred to as a Distributed Antenna System, or DAS. A network Topology where the MNO site electronics are housed at a central “hotel”. The sites for each MNO are interfaced to a separate “neutral” layer of electronics which combines and distributes all MNO services to remote transceivers (“remotes”) via fiber. The remotes in each location feed small, multi-band antennas via RF connections; the antennas are typically not MIMO and are smaller than the antennas used in small cell applications. The remotes can feed multiple antennas via RF connections, but for this study the assumption is that only a single antenna (pole) will be fed by each remote. A single set of site electronics can feed multiple remotes, a configuration that is used where capacity needs are not critical.

**oDAS:** Outdoor Distributed Antenna System. See “Neutral Host”.

**Shroud:** a covering, usually ABS or similar plastic, over an antenna on a pole or building to help conceal the antenna and better visually blend it in with the structure.

**Small Cell:** lower power network cell sites typically with small antennas placed near the ground, often on streetlamps, small structures, or dedicated poles.

**Stand Alone Small Cell:** a small cell site supporting a single MNO.

**Spectral Efficiency:** a measurement of the efficiency of a technology to create data throughput from a given frequency spectrum, measured in bits per second per hertz. This is a function of the underlying technology (e.g., 4G-LTE), the antenna system, interference, noise, environmental conditions, and other factors.

**SNOW:** Small Node on Wheels; see COW.

**Throughput:** Rate of data transmission, usually measured in Mbps for mobile wireless links.

**WCS:** Wireless Communications Services. A family of frequency bands designated and licensed by the FCC. This band is comprised of four blocks including A Block (2305–2310 and 2350–2355 MHz), B Block (2310–2315 and 2355–2360 MHz), C Block (2315–2320 MHz), and D Block (2345–2350 MHz).

## 1. Introduction

AECOM, under contract to the National Park Service (NPS), conducted a study to assess the existing commercial mobile network coverage and capacity on the National Mall in Washington, DC. This report, titled “National Mall Minimum Build-Out Study” (MBOS), presents AECOM’s analysis of the NPS’ mobile telecommunications build-out study for the National Mall area. It includes an overview of the Project Area, analysis of the existing mobile networks, potential network infrastructure types, existing architectural features, network build-out options, and AECOM’s recommendations.

The MBOS aims to provide the NPS with a framework and guidance for the future expansion and management of communications infrastructure. It documents the methodology used and the outcomes from the study of the mobile network coverage and capacity on the National Mall and surrounding areas. This analysis seeks to identify feasible telecommunications infrastructure solutions within the Project Area that respects the cultural landscape while adhering to the NPS mission and management policies.

A primary outcome of the MBOS is to outline the minimum telecommunications build-out within the Project Area necessary to achieve a potential fivefold (“5x” or 400%) increase in capacity for each current Mobile Network Operator (MNO), while minimizing impacts to the viewsheds and resources of the cultural landscape.

This technical report serves as a planning document estimating the minimum build-out required to provide improved fourth- and fifth-generation (4G-LTE and 5G-NR) mobile network service. The study targets locations and outlines potential solutions providing the required infrastructure types for each current MNO. AECOM’s assessment was conducted in collaboration with Cybersecurity and Infrastructure Security Agency (CISA), the MNOs, and the NPS.

The minimal buildout study will serve as the basis for a proposed action to be evaluated through the environmental and historic preservation compliance processes. The Environmental Assessment will evaluate the environmental impacts of the proposed buildout. The NPS will also conduct historic preservation review through the Section 106 process to evaluate potential adverse effects on historic properties due to the undertaking.

## 2. Project Area

The Project Area is shown in Figure 1.

This study splits the Project Area into five sub-areas to make the analysis easier to understand. These five sub-areas are the National Mall East, the Washington Monument Grounds and Presidents Park South, West Potomac Park – Lincoln Memorial, West Potomac Park – Tidal Basin, and East Potomac Park and are shown in Figure 1.

### 2.1 NPS Parks Units within the Project Area

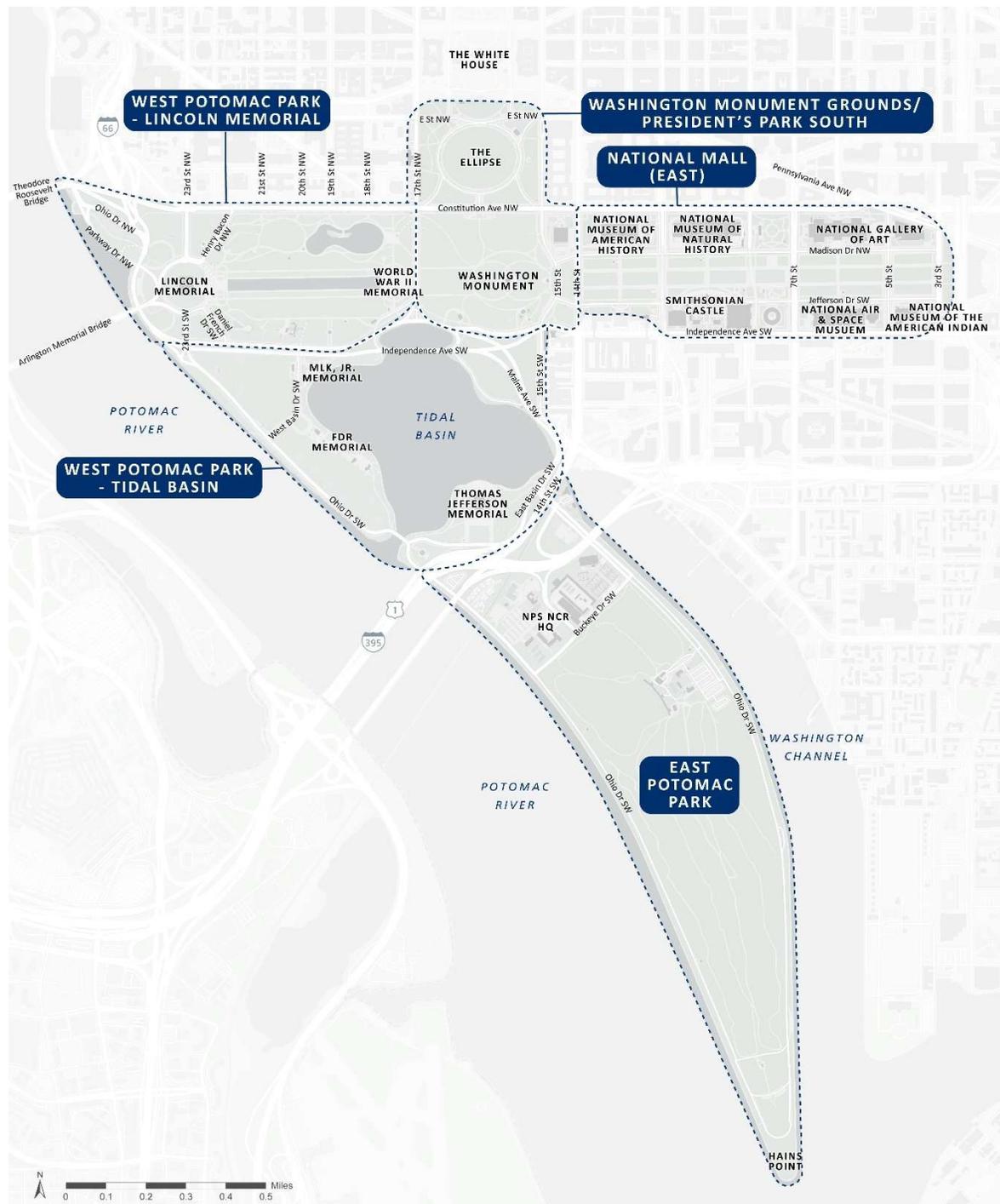
The Project Area encompasses two NPS units, the National Mall and Memorial Parks (NAMA) and the White House and President's Park.

#### 2.1.1 The National Mall and Memorial Parks

NAMA administers more than 1,000 acres of park land within the District of Columbia, including 13 units of the NPS park system, including the National Mall, Washington Monument Grounds, and East and West Potomac Parks as shown in Figure 1: Project Area

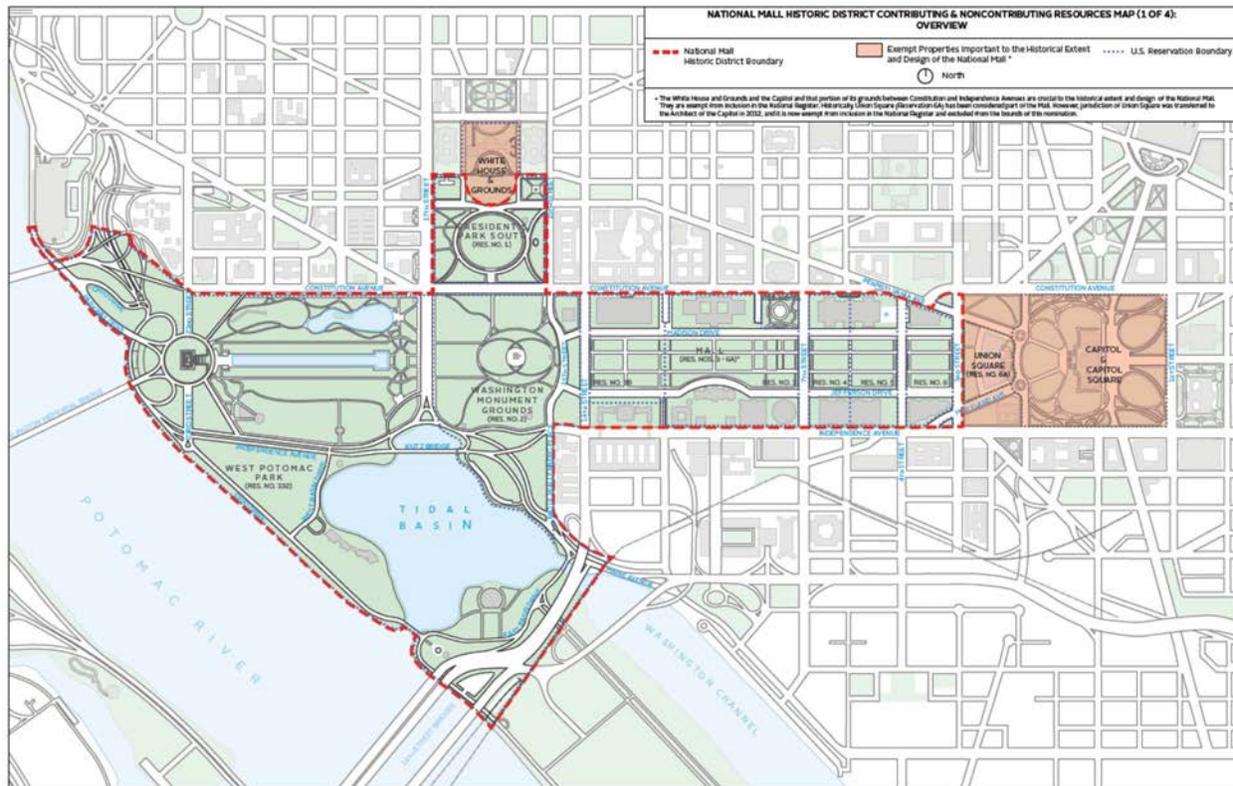
The purpose of the NAMA is to preserve, protect, and interpret symbolic, monumental, and dignified civic spaces and commemorative works in the center of the nation's capital that honor American ideals and values, distinguished public figures, events, and military and civilian sacrifices and contributions. The NAMA serves as a public park and open space for First Amendment gatherings, national celebrations, active civic and cultural engagement, recreation, and public enjoyment.

Figure 1: Project Area



**National Mall (Historic District)**

The National Mall, which is listed in the National Register of Historic Places (NRHP) as an historic district, extends west from the U.S. Capitol grounds to the Potomac River and south from Constitution Avenue NW to Independence Avenue SW and west of 15th Street around the Tidal Basin to the 14th Street Bridge (see Figure 2). The National Mall also includes the Washington Monument Grounds and West Potomac Park.

**Figure 2: National Mall National Register Historic District boundary (dashed red line) as approved in 2016**

### Washington Monument Grounds

The Washington Monument Grounds, part of the National Mall, is located near the center of the National Mall and is listed in the NRHP at the level of national significance.

### East and West Potomac Parks

The East and West Potomac Parks are listed together in the NRHP (see Figure 3).

East Potomac Park is one of the largest recreational spaces in the Washington, DC core, occupying most of Hains Point between the Washington Channel and the Potomac River. It is almost 330 acres in size and extends southeast of West Potomac Park. East Potomac Park has been primarily developed for active recreation purposes. This park currently has a golf course with food service, one of the country's oldest miniature golf courses, and a tennis facility. The area's roads are well-used by cyclists. Visitor services also include picnic facilities, restrooms, and a playground.

West Potomac Park provides the setting for such nationally recognized memorials and landscape features as the Lincoln Memorial and Reflecting Pool, Thomas Jefferson Memorial, Franklin Delano Roosevelt (FDR) Memorial, Vietnam Veterans Memorial, Korean War Veterans Memorial, World War II Memorial, Martin Luther King, Jr. (MLK) Memorial, Constitution Gardens and the 56 Signers of the Declaration of Independence Memorial, and several other memorials or features. West Potomac Park encompasses the Tidal Basin, with its three memorials, views, and spectacular Japanese flowering cherry trees, and features public parking, floral library, seasonal concession stand, and recreation rentals.

Figure 3: Map of East and West Potomac Parks



Office of Planning – June 8, 2018  
Government of the District of Columbia  
This map was created for planning purposes from a variety of sources. It is neither a survey nor a legal document. Information provided by other agencies should be verified with them where appropriate.

### East and West Potomac Parks Historic District



### 2.1.2 The White House and President's Park

Also, part of the National Mall historic district, located north of the NAMA, is the White House and President's Park. President's Park South includes the area bounded by State Place, South Executive Avenue, and Alexander Hamilton Place on the north, 15th Street N.W. on the east, Constitution Avenue N.W. on the south, and 17th Street N.W. on the west.

The White House and President's Park is listed in the National Registry of Historic Places (NRHP). The Project Area is the oldest federal reservation in the nation, and it is a nationally significant historic landscape that continues to reflect the design principles of Pierre Charles L'Enfant in 1791, Andrew Jackson Downing in 1851, and the Olmsted brothers in the 1930s — design principles that have withstood the test of time. President's Park is integral to the historic layout of the city, which was initially designed to physically represent the functional relationships of the three branches of our government. Memorials that have been incorporated into the historic landscape design commemorate noteworthy events and individuals in the nation's history.

## 2.2 Character and Significance

Multiple physical attributes—both viewsheds and the natural and built characteristics—contribute to the character and significance of the Project Area.

### 2.2.1 Viewsheds

One of the key features of the National Mall is the visual relationships established as part of the original plan and expanded and embellished in subsequent plans and efforts. These include, described as key resources in the 2016 NRHP nomination for the National Mall, planned vistas along the principal north-south and east-west axes of the National Mall, reciprocal views between major memorial sites, extended views along contributing streets and avenues, multidirectional views across open expanses, and periodic views of resources from circulation routes.

Views and their related spaces help organize the landscape and create visual and thematic relationships between important governmental and commemorative features in the landscape. The 1791 L'Enfant Plan of the City of Washington and the 1902 McMillan Plan (collectively referred to as the L'Enfant Plan) established many significant views within the Project Area. The views within the Project Area listed in the L'Enfant Plan NRHP nomination (1994) are shown in Table 1.

**Table 1: Views Listed in L'Enfant NRHP Nomination**

Primary Views	Other Views
<p>View west from the U.S. Capitol to the Lincoln Memorial and the western horizon</p> <p>View south from the White House to the Jefferson Memorial and the southern horizon</p>	<p>Reciprocal view east from the Washington Monument to Union Square and the Capitol</p> <p>View radiating from Virginia Avenue, including the Washington Monument</p> <p>North-south views along 4th Street, SW, and 4½ Street, NW, toward Judiciary Square</p> <p>View along 6th Street NW, toward the National Gallery of Art</p> <p>View along 8th Street NW-SW, toward the National Archives</p> <p>View along 10th Street, NW-SW, toward the National Museum of Natural History (NMNH) and the Smithsonian Institution Building.</p> <p>View along 23rd Street</p> <p>Views to the elms and the buildings along the National Mall from its walks and grass panels</p>

The National Mall NRHP nomination (2016) included multiple contributing buildings and sites that incorporate views in the Project Area as part of the visual experience of the National Mall in addition to those identified in the L'Enfant Plan, listed in Table 2.

**Table 2: Views Listed in the National Mall NRHP Nomination**

Washington Monument	Lincoln Memorial	Constitution Gardens	Tidal Basin Cluster
<p>Reciprocal views to the Lincoln Memorial, White House, Thomas Jefferson Memorial, and the U.S. Capitol</p> <p>Views of the Washington Monument from the city and surrounding region</p>	<p>Views between the memorial and the radial roads from Lincoln Circle</p> <p>Views between the memorial and the Ericsson Monument</p> <p>Views between the memorial and Constitution Avenue along 23rd Street NW</p>	<p>Views east to the Washington Monument</p> <p>Views from within the Project Area to the Vietnam Veterans Memorial</p> <p>Views from the Vietnam Veterans Memorial to the Washington Monument</p> <p>Views to the Lincoln Memorial and the Lincoln Memorial Reflecting Pool area</p> <p>Views to the District of Columbia War Memorial</p> <p>Internal views of the pond and the 56 Signers Memorial and from the overlook terrace</p>	<p>Reciprocal views between the memorials, such as the views between the Thomas Jefferson Memorial and the Martin Luther King, Jr. Memorial, among others</p> <p>Periodic views from various locations along the Tidal Basin's path of the surrounding Japanese cherry trees and nearby memorials</p>

The Project Area includes other views not specifically identified in the L'Enfant Plan or National Mall NRHP nominations as historically significant but are part of the viewer experience within the National Mall. For example, the view of Ohio Drive along the Potomac River in West Potomac Park includes roadways, sidewalks, and trails that access open recreation areas with fencing and a maintenance route, flanked by the open water of the river.

## **2.2.2 Visual Character**

The overall visual character of the Project Area presents a cohesive design with multiple qualities. The site is an entirely designed and constructed landscape, and therefore functions as a cultural landscape. For the purposes of this analysis, the natural and cultural visual environments are treated as a single combined visual environment. Many types of built features within the Project Area help define the landscape's views: distinctive landform, vegetation, buildings, infrastructure, structures, and other artifacts and art. These are described in the visual inventory below.

### **Primary East-West and North-South Views**

The primary east-west and north-south views have few intrusions or interruptions. The corridor edges maintain consistent lines, reinforced by buildings, structures, linear pathways, and vegetation. The views' key anchoring features (Lincoln Memorial, Washington Monument, U.S. Capitol, Jefferson Memorial, and White House) are built of light-colored stone, placed at slightly higher elevations, and are the most prominent visual elements within the Project Area.

### **Land (Topography)**

The designed environment of the Project Area consists of flat turf panels bordered by trees. The topography has been modified with subtle elevation changes at locations, such as the Vietnam Veterans Memorial, Constitution Gardens, levees along the east-west axis of the National Mall, and gentle slopes toward the Tidal Basin and Potomac River.

### **Spatial Organization**

Spatial organization is the three-dimensional organization of physical forms and visual associations in a landscape, including the articulation of ground, vertical, and overhead planes that define and create spaces. The National Mall includes a greensward of turf panels framed on either side by lines of elm trees. Facades of the imposing monumental museum buildings reinforce this line. The overall spatial organization of West Potomac Park is defined by the Potomac River, by the centrally located Tidal Basin, by the locations of major memorials, and by the recreational fields. The morphological characteristics of a human-made landform situated between the Virginia and the Washington Channels of the Potomac River remain the primary characteristic of the East Potomac Park's spatial organization. Other specific spatial organizations include Constitution Gardens, Tidal Basin, and others.

### **Water**

The Potomac River is a wide tidally influenced river, with both natural and constructed stream banks.

### **Vegetation**

The land has a large amount of vegetation within the built environment. Vegetation reinforces the designed cultural landscape within the Project Area. The Lincoln Memorial to U.S. Capitol axis features open turf panels flanked by parallel rows of trees that reinforce the visual corridor. Other landscaped vegetation includes deciduous trees, turf fields, and memorial-specific designs. The view corridor between the White House and Jefferson Memorial is intended to be 150 feet wide, although mature trees have grown into the space.

## **Structures**

The Project Area contains multiple structures, ranging from national memorials to levees and seawalls. The most prominent structures within the Project Area are the Lincoln Memorial, the Washington Monument, and the Jefferson Memorial, which are large-scale iconic, nationally significant structures of white stone. Other memorials—which range in materials, color, form, and scale—are placed to avoid interruption of the primary axial views; however, these memorials often provide additional visual and thematic connections to the landscape’s primary axis points. The Tidal Basin and its associated seawall, bridges, and other features cover a large area but are located at a low elevation.

## **Buildings**

The Project Area contains an extensive collection of buildings that represent a diverse range of styles and characters. In addition to the National Mall’s iconic memorials and view corridors, the museum complex of the Smithsonian Institution and National Gallery of Art lining the National Mall’s central greensward form a consistent visual line, although the buildings range in height, color, and materials. The Project Area also includes utilitarian buildings, such as concession stands and comfort stations that support the needs of visitors.

## **Circulation Features and Systems**

Many of the orthogonal streets and diagonal avenues that characterize the L’Enfant Plan for Washington intersect with and cross the Project Area. In addition to these road corridors, other historic circulation features include elements such as the Ellipse road and its associated walks and the rectilinear system of pedestrian paths along the National Mall.

## **Constructed Water Features**

Constructed water features are built features and elements that utilize water for aesthetic or utilitarian functions in the landscape. Contributing constructed water features include Constitution Gardens Lake, Reflecting Pool, Tidal Basin, and others.

## **Small Scale Features**

The National Mall has only a few types of small-scale features. Contributing features include benches and streetlights. Non-contributing small-scale features include drinking fountains, fire hydrants, post-and-chain barriers, trash receptacles, and bike racks.

### 3. Mobile Phone Networks Analysis

The mobile phone networks – operated by AT&T, Dish, T-Mobile, and Verizon Wireless – play a crucial role in the experience of visitors to the National Mall and its surrounding areas. Many park visitors frequently experience degraded service across the Project Area, especially during peak crowd times. This study establishes a baseline for the current performance of these networks, focusing on their capacity defined by the total available throughput (rate of data transmission) available on each MNO. It is important to note that this study focuses on the day-to-day capacity of these networks and does not consider temporary network assets often deployed by the MNOs near the National Mall grounds during special events.

Following the establishment of the current performance baseline, AECOM assessed potential future scenarios, including:

- Changes to the existing macro (tower, building façade and rooftop, and other larger footprint) cellular sites
- Addition of new macro sites
- Construction of smaller footprint sites, including “small cell” (dedicated active equipment for each supported MNO) and “neutral host” (specialized infrastructure supporting multiple MNOs) sites. (Refer to Section 4 for additional information.)

It is important to recognize that the total available network capacity at any given location cannot be directly measured in any practical way. Instead, AECOM estimated this value through a combination of calculations and statistical analyses. The datasets used to perform these calculations were limited due to the proprietary nature of MNO network data, which restricted full data sharing. Nevertheless, this report provides a reliable methodology for estimating the 5x increase in network capacity. This section will describe both the methodology employed and the results of the network analyses.

#### 3.1 Capacity Calculation Methodology

As part of this study, the NPS consulted with CISA to develop a methodology for using data, collected using standard network testing methods<sup>1</sup>, to estimate network throughput for each MNO. As the methodology and algorithm were developed, the MNOs were regularly consulted and many of the final details of the algorithm were adjusted based on their input and experience. In addition, both Extenet and Crown Castle (each of whom provide neutral host networks) also provided input during the process. The resulting methodology is summarized here, and a white paper describing the methodology in detail is included in Appendix B.

#### 3.2 Existing Network Conditions

To establish the baseline, a thorough network test was performed between July 20, 2023, and July 24, 2023, collecting data for the four MNOs in the Project Area. As described in Section 2, the Project Area was broken into five sub-areas for the purpose of evaluating existing network conditions (see Figure 1, page A-3):

- National Mall East
- Washington Monument Grounds and President’s Park South
- West Potomac Park – Lincoln Memorial
- West Potomac Park – Tidal Basin

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<sup>1</sup> Network testing involves a specialized scanning receiver, which is used to simultaneously collect signal data from each of the networks. The receiver can be used in a vehicle, on foot, or even – as in this case – on an electric scooter. For more information refer to Appendix B.

- East Potomac Park

The Radio Frequency (RF) signal survey data was collected using the digital scanner that captured data from the 600 MHz band through the C-Band (3.7 to 3.98 GHz). The data collected is for all known bands/channels for each of the MNOs, excluding millimeter-wave (above 30 GHz) band which was determined to be inactive for all MNOs, to help determine the capacity that an MNO can provide to its users in a giving area. The data also identifies from which site the signal originates, which helps with identifying the coverage from each site and some insight into current capacity. The survey data helps identify the quality of signal, which in turn provides an insight into the coverage and capacity each band can provide to the users. A thorough description of the testing process is included in Appendix B.

The RF survey collected key information for the active carriers for each MNO in the subject area. Results showed active service in the following bands for each MNO, as shown in Table 3. AWS: Advanced Wireless Services (AWS) and Wireless Communication Services (WCS) are specific FCC-defined frequency bands.

**Table 3: Active Bands by MNO**

	Band										
	600	700	800	1900	2100	1900 Ext	2100 Ext	AWS-3	WCS	2.5 GHz	C-Band
Verizon		✓	✓	✓	✓	✓	✓	✓			
AT&T		✓	✓	✓	✓	✓	✓	✓	✓		
T-Mobile	✓	✓		✓	✓	✓	✓	✓		✓	
Dish								✓			

### 3.2.1 Overview of Existing MNO Network Capacity

By performing a data analysis of the drive test results, the existing capacity of each network was estimated based on the capacity calculation methodology. One of the most important discussions leading up to the study was the use of CINR (Carrier to Interference and Noise Ratio) in the calculations to determine a practical estimate of spectral density versus using an “up-to spectral density” of 4.5 bps/m<sup>2</sup> (this is discussed in detail in the capacity density white paper in Appendix C). This study uses the average CINR and the 3GPP (3rd Generation Partnership Project) spectral density curves to estimate spectral density. For insight into the impact, the CINR average and resulting spectral density calculation results are shown in Table 4 and Table 5.

For CINR, there is some data variation within each area, significant at times, which could provide additional refinement within the sub-areas but is beyond the scope of this study. Each MNO, using their more precise network data, would better be able to target specific needs and better identify specific site locations to maximize effectiveness. However, the results of this study provide an accurate, demonstrable, and effective treatment of the capacity analysis and the results should be close to individual MNO analyses. The average CINR as measured during testing is summarized in Table 4, and the resultant spectral density calculated using this data is listed in Table 5.

**Table 4: Average CINR by MNO**

	National Mall East	Washington Monument Grounds and President's Park South	West Potomac Park - Lincoln Memorial Area	West Potomac Park - Tidal Basin	East Potomac Park
AT&T, 4G	1.34	1.88	1.73	-1.15	-2.84
Dish, 4G	--	--	--	--	--
T-Mobile, 4G	-1.04	1.82	1.11	0.78	0.67
Verizon, 4G	5.43	2.65	-0.35	-0.13	-1.58
AT&T, 5G	0.97	-1.02	-2.80	2.17	2.90
Dish, 5G	11.43	12.59	12.62	3.78	1.84
T-Mobile, 5G	1.31	4.57	2.16	3.46	2.02
Verizon, 5G	--	--	--	--	--
AT&T, 4G + 5G	1.16	0.43	-0.53	0.51	0.03
Dish, 4G + 5G	11.43	12.59	12.62	3.78	1.84
T-Mobile, 4G + 5G	0.13	3.19	1.64	2.12	1.35
Verizon, 4G + 5G	5.43	2.65	-0.35	-0.13	-1.58

**Table 5: Average Spectral Density (bps/m2) by MNO**

	National Mall East	Washington Monument Grounds and President's Park South	West Potomac Park - Lincoln Memorial Area	West Potomac Park - Tidal Basin	East Potomac Park
AT&T, 4G	0.93	1.01	0.99	0.62	0.45
Dish, 4G	--	--	--	--	--
T-Mobile, 4G	0.92	1.46	1.05	1.27	1.03
Verizon, 4G	1.63	1.13	0.71	0.73	0.57
AT&T, 5G	0.88	0.63	0.46	1.05	1.17
Dish, 5G	2.92	3.19	3.20	1.32	1.00
T-Mobile, 5G	1.55	2.46	1.95	2.12	1.87
Verizon, 5G	--	--	--	--	--
AT&T, 4G + 5G	0.90	0.82	0.72	0.84	0.81
Dish, 4G + 5G	2.92	3.19	3.20	1.32	1.00
T-Mobile, 4G + 5G	1.24	1.96	1.50	1.69	1.45
Verizon, 4G + 5G	1.63	1.13	0.71	0.73	0.57

For this study, each carrier for each MNO was analyzed independently, using the average test CINR results for each individual carrier and the carrier bandwidth to calculate spectral density. These results were then totaled for the MNO to calculate the overall 1x capacity results for each area. These are summarized in Table 6 and are shown in Mbps.

**Table 6: Total Capacity (Mbps) by MNO**

	National Mall East	Washington Monument Grounds and President's Park South	West Potomac Park - Lincoln Memorial Area	West Potomac Park - Tidal Basin	East Potomac Park
AT&T, 4G	52	32	27	32	33
Dish, 4G	N/A	N/A	N/A	N/A	N/A
T-Mobile, 4G	36	57	38	57	89
Verizon, 4G	74	44	23	36	24
AT&T, 5G	22	13	6	30	31
Dish, 5G	8	18	13	11	41
T-Mobile, 5G	39	40	27	31	55
Verizon, 5G	N/A	N/A	N/A	N/A	N/A
AT&T, 4G + 5G	73	45	33	62	64
Dish, 4G + 5G	8	18	13	11	41
T-Mobile, 4G + 5G	75	97	65	89	143
Verizon, 4G + 5G	74	44	23	36	24

Finally, the area (in m<sup>2</sup>) was used to calculate the capacity density of each sub-area (to be better able to compare the sub-areas with other sub-areas). These results are shown in Table 7 under column "1x".

### 3.2.2 Future MNO Network Capacity Targets

With the established goal of 5x capacity density, the objective for each MNO in each of the five sub-areas can be determined by multiplying the 1x results. The objective capacity density results are shown in Table 7 under the column "5x". By showing the "1x" and "5x" results, this table provides a picture of the "before and after" capacity for the Project Area.

**Table 7: 5x Capacity Density (bps/m2) by MNO**

	National Mall East		Washington Monument Grounds and President's Park South		West Potomac Park - Lincoln Memorial		West Potomac Park - Tidal Basin		East Potomac Park	
	"1x"	"5x"	"1x"	"5x"	"1x"	"5x"	"1x"	"5x"	"1x"	"5x"
AT&T, 4G	1,060	5,302	399	1,995	323	1,615	199	996	92	462
Dish, 4G	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T-Mobile, 4G	737	3,686	710	3,552	449	2,245	362	1,810	252	1,260
Verizon, 4G	1,523	7,613	550	2,752	271	1,353	229	1,144	69	346
AT&T, 5G	446	2,231	163	813	66	332	190	948	88	441
Dish, 5G	165	825	220	1,099	155	776	69	343	116	581
T-Mobile, 5G	796	3,982	503	2,517	319	1,594	197	986	155	776
Verizon, 5G	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AT&T, 4G + 5G	1,507	7,533	561	2,807	389	1,947	389	1,944	181	903
Dish, 4G + 5G	165	825	220	1,099	155	776	69	343	116	581
T-Mobile, 4G + 5G	1,534	7,668	1,214	6,068	768	3,840	559	2,797	407	2,037
Verizon, 4G + 5G	1,523	7,613	550	2,752	271	1,353	229	1,144	69	346

### 3.3 Contribution of Macro Additions and Changes to Future Capacity

Increasing the coverage and capacity within the Project Area would require the installation of new small-cell or neutral host sites close to pedestrian circulation within the Project Area. As a result, most new site capacity would be utilized by park-related user traffic. Also, because the proposed small cell/neutral host solution is based on the higher frequency bands (particularly C-Band), it would provide targeted capacity and coverage while providing dominant service over the macro sites for the grounds. This dominance (ensuring all mobile data traffic is served by the small cell/neutral host sites) ensures that the total throughput available in the Project Area will be maximized.

Optimizing the network in the Project Area, and achieving the target capacity levels, will be achieved via three key components: (1) more occupied frequency bandwidth particularly in the broader bands above 2.5 GHz, (2) introducing more serving sectors, and (3) creating networks with optimal CINR. Increasing the frequency bandwidth for an MNO directly increases the theoretical throughput for the network, and likewise adding more sectors to a given area will increase the throughput by a similar factor. The third element, CINR, affects how efficiently a given carrier (frequency band) can carry traffic; as CINR increases, throughput increases exponentially. Because of this exponential quality, a single sector with excellent CINR will provide more throughput than multiple sectors with mediocre CINR serving the same area. This latter point is a large reason a design in the Project Area that provides significantly stronger coverage than the macro is preferred. As a result of this, most current macro sites would provide little practical contribution to network capacity.

However, in specific locations and circumstances, macro sites could have a positive effect on capacity. Based on the information shared by the MNOs, a few such locations appear likely to be deployed within the next five years. The two most likely locations are the rooftop site at the National Museum of African American History and Culture (NMAAHC) and the tower site on the NPS headquarters. For the MNOs that deploy macro sites that specifically target areas of the Project Area, the net effect would be to reduce the small cell site count by three, or the neutral host site count by five, for a typical site. For sites with more extensive MIMO<sup>2</sup>, the reduction in small cell site counts depends on many site construction and configuration issues exist with individual MNOs). Although these sites are not certain, and are treated as possibilities, it would be beneficial if key neighboring structures were prioritized. The potential impacts of these sites are discussed in the sections where applicable.

### 3.4 Contributions of Temporary Network Resources

Special planned and unplanned events, such as a Presidential Inauguration or July 4<sup>th</sup> celebration, create unusually high volumes of pedestrian circulation. In response, the MNOs frequently add temporary network resources, including short-term changes to existing macro sites and the addition of temporary sites. Configurations of temporary sites include mobile cell sites – e.g. Cell on Wheels (COW) and Cell on Light Truck (COLT) as shown in Figure 4 – that are comparable to fully dimension macro sites with higher capacity than temporary small cells. In some cases, the temporary sites are fitted with large “massive MIMO” antennas which can provide the equivalent capacity of many macro sites.

To deploy these temporary resources, the MNOs require power for the site electronics and fiber for data. While some locations exist where this infrastructure is readily available, this is often not the case. The MNOs are left to identify practical solutions and provide temporary (e.g., generator) power. This can leave the sites exposed to disruption and requires higher levels of security and maintenance. When this infrastructure can be provided in a permanent demarcation, the MNOs can deploy these sites more quickly (and with less interruption to the Project Area), with less notice, and at lower cost.

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<sup>2</sup> Multiple Input Multiple Output (MIMO) provides redundant RF paths that serve to increase the effective CINR of a transmission, often resulting in an increase in effective throughput by 50% or more.

The capacity evaluation in this report does not consider the capacity effects of these temporary sites but instead provides a foundation of consistent network capacity on which the MNOs can more accurately place temporary network resources to meet the needs of special planned events.

**Figure 4: Temporary COW within the Project Area**



## 4. Potential Mobile Network Topologies

Four Topology options have been considered for this project to enhance coverage and capacity within the Project Area for each of the MNOs. These options vary in equipment Topologies and site location designs, yet they all aim to achieve the goal of a 5x increase in capacity.

Each of the four Topologies proposed in this report will consist of: (1) an antenna integrated into a feature (e.g., light pole luminaire or wayfinding pylon) via custom concealment design<sup>3</sup> and (2) an adjacent equipment enclosure within eight feet of the pole to house the necessary electronics, power and fiber connections, as detailed below.

Any network design solution that may be implemented in the Project Area is likely to include a mix of site Topologies selected from the options described in this section.

### 4.1 Stand-Alone Small Cell

The Stand-Alone Small Cell (SASC) Topology is a single-MNO Topology feeding a dedicated antenna on a light pole, pylon, or similar vertical structure. The SASC Topology requires the greatest number of antenna sites (because each MNO requires their own pole for coverage) but requires the smallest individual equipment housing in comparison with the other Topologies. It is not anticipated that equipment housings will be incorporated into the base of the poles, but this is certainly a possibility.

The qualities of the SASC relative to the other Topologies presented in this report are shown in Table 8, page A-17.

### 4.2 Distributed Radio Access Network Topologies

Distributed Radio Access Network (DRAN) refers to the use of a common antenna fed by radio frequency (RF) equipment that is independently connected to each MNO's Radio Access Network (RAN), allowing multiple MNOs to share a single pole. The DRAN Topology is commonly used in many markets, particularly the Baltimore-Washington (BAWA) market, to share vertical assets during deployment.

The analysis for this project considered two options that use this topology: the DRAN two-operator small cell Topology (DRAN-2) and the DRAN four-operator small cell Topology (DRAN-4).

#### 4.2.1 DRAN-2

The DRAN-2 consists of two MNOs providing independent equipment, all feeding a single dedicated antenna on a light pole, pylon, or similar vertical structure. Because each node is shared by two MNOs, the DRAN-2 Topology requires fewer sites than the SASC Topology (50% to 60% of SASC node count) but requires a larger equipment footprint per site. This Topology provides slightly less coverage per site. DRAN-2 equipment would not be housed in the base of the pole as it would require twice the equipment of the recently approved DC Department of Transportation (DDOT) standalone pole and would therefore be very conspicuous in the landscape of the Project Area.

The qualities of the DRAN-2 Topology relative to the other Topologies presented in this report are shown in Table 8, page A-17.

#### 4.2.2 DRAN-4

The DRAN-4 Topology uses independent equipment from each of the four MNOs, all feeding a single dedicated antenna on a light pole, pylon, or similar vertical structure. Because each node is shared by all four MNOs, this Topology would require the fewest total number of nodes of any of the three small cell

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<sup>3</sup> The antennas that will be integrated into the luminaires differ between the small cell and neutral host solutions, with the small cell antennas being larger. E.g., the size of the Olmsted luminaire should be able to accommodate either antenna, the Washington Globe luminaire will need to be enlarged to accommodate the small cell antennas but not the neutral host antenna, and some light poles will require a separate antenna enclosure on the pole apart from the luminaire. See Table 9 for more information on antenna sizing.

Topologies (25% to 35% of SASC nodes) but would have the smallest coverage area of any of the small cell Topologies. The equipment enclosure will be the largest of any of the four Topologies and would be difficult to design to fit well within the landscape. Because this Topology provides service for all MNOs from one site (like the Neutral Host) but has better capacity per site (due to the MIMO configuration) and better coverage than Neutral Host, it provides the greatest overall capacity of any Topology.

The qualities of the DRAN-4 Topology relative to the other Topologies presented in this report are shown in Table 8, page A-17.

### 4.3 Neutral Host

The Neutral Host Topology has all four operators on every site being fed by an outdoor distributed antenna system ("oDAS") equipment. The oDAS remote at each site is fed by a fiber link to a central location ("hotel") equipment housing the "head-end equipment which interfaces to the MNO equipment.

The size of the oDAS equipment footprint per site would be like the DRAN-2 Topology. This Topology is likely to use a smaller antenna than the small cell Topologies and could therefore be more easily designed into a custom pole or other feature. In addition, this Topology is perfect for larger areas that require less capacity as individual MNO sectors can be shared across multiple sites by sharing oDAS remotes from the head end; however, we anticipate that most deployments of this Topology would be a single sector per MNO per site.

This Topology would require more overall sites versus DRAN-4 but less than the DRAN-2 or SASC Topologies (two-thirds less sites than SASC). It is not anticipated that equipment housings will be incorporated into the base of the poles, but this is a possibility.

The qualities of the Neutral Host Topology in comparison to the other Topologies presented in this report are shown in Table 8.

**Table 8: Comparison of Network Topologies**

	<b>SASC</b>	<b>DRAN-2</b>	<b>DRAN-4</b>	<b>Neutral Host</b>
Approximate Coverage Radius (C-Band / 2.5 GHz, vs SASC)	100%	95%	75%	60%
Approximate Equip. Housing Volume (Cubic Feet / vs SASC)	45 / 100%	73 / 160%	130 / 290%	45 / 100%
Approximate HVAC Requirements (vs SASC)	100%	200%	400%	130%
Approximate Power Requirements (per MNO, vs SASC)	100%	200%	400%	150%
Approximate Site Count (vs SASC)	100%	50-55%	30-35%	35-40%
MNOs per Site	1	2	4	
Approximate Capacity (per MNO, vs SASC)	100%			70%
Antenna Size (Height x Diameter)	23.6" x 7.9"			21" x 1.6"
"Hoteling" Required?	No			Yes

## 4.4 Fiber and Electrical Infrastructure

To meet the goal of a 5x increase in network capacity, both the fiber optic and power infrastructures need to be carefully planned. As part of this study, fiber and power pathways were evaluated to ensure sites located in the project area could be supported by the existing infrastructure or extension of that infrastructure. While this initial evaluation showed ample flexibility to meet the network needs, more detailed planning will need to take place prior to the final planning stages for each site.

Coordinating the installation of fiberoptic and power infrastructure is key to minimizing disruptions. Ideally, both should be installed at the same time to ensure they work together seamlessly. Planning for the future is also important, with designs that allow for expansion without needing major new construction. This means including extra conduit capacity and power lines that can support future network upgrades without impacting current services.

Heat management is another consideration. Vaults housing power equipment should be equipped with cooling systems or ventilation to prevent overheating, which could cause failures. The network should also use energy-efficient technologies to reduce overall power consumption, which is particularly important in areas with limited power availability.

Finally, all installations must comply with local, state, and federal regulations to ensure they are safe and legally compliant. By carefully planning and integrating these components, the network infrastructure will be strong and adaptable, ready to handle growing demands, while being flexible enough to expand in the future.

### 4.4.1 Fiber Optic Infrastructure

The fiber optic infrastructure must be capable of handling much higher data traffic, which requires using high-capacity, multi-strand fiber cables. High strand-count single-mode fiber cables are used, allowing multiple MNOs to share a single cable. Using this type of fiber cable not only makes efficient use of the underground pathways but also leaves room for future expansion. In areas with high data demand, higher strand-count cables may be beneficial to ensure the network can scale up as needed.

To keep the network reliable, it is important to have redundant fiber pathways; if one pathway fails, traffic can be quickly rerouted through another. This is particularly critical during large events that cause spikes in network usage. The fiber network should also include direct, high-capacity links between nodes and the core network to minimize delays and improve overall performance.

During this study, the fiber pathways were evaluated, and it was determined that the site locations chosen can be supported by an extension of the infrastructure.

### 4.4.2 Electrical Distribution

The power demands of the network are also challenging. Nodes, especially those using advanced setups like DRAN-4 or Neutral Host, require a reliable power supply. To meet this need, dedicated underground power lines may be necessary, and these should be laid alongside the fiber optic conduits to keep the installation process efficient and minimize potential disruptions.

Backup power is another essential aspect to consider. Systems like battery backups or generators should be integrated to keep the network running during outages, particularly in high-traffic or critical areas. Power-conditioning systems will also be needed to ensure that the power supplied to the nodes is stable and does not damage the equipment.

During this study, the electrical infrastructure was evaluated and found to be sufficient to support an expansion to power this build-out.

## 4.5 Constraints

The Project Area presents multiple challenges for increasing commercial mobile network coverage and capacity. The following represent constraints identified.

- **Tree canopy.** To provide effective mobile network coverage and capacity, the areas between the sites and primary service area should have as few trees as possible. The existing tree canopy within the Project Area limits the locations that could potentially place sites because the trees would block signals. For instance, locations along Madison and Jefferson Drives would not provide the required signal levels in the center of the National Mall lawn panels due to the allées of trees.
- **Cultural resources.** As noted in Section 2, the Project Area contains a dense fabric of cultural resources. As a result, locations that could be most effective in achieving the technical requirements of the project would not be appropriate.
- **Low scale existing buildings without network sites.** One option for locating sites is to use existing buildings found within the Project Area, such as information kiosks and comfort stations. In addition to these buildings being in areas with dense tree canopy, these buildings are low in scale and therefore, are unable to provide the necessary signal within the Project Area.
- **Existing macros are located on buildings.** Macros are already located on multiple buildings within or adjacent to the Project Area, such as the Smithsonian Institution museums. The MNOs have been working to upgrade these macro sites to better serve the Project Area but have been limited by the owners due to aesthetic concerns. Additionally, suitable buildings adjacent to the Project Area have been approached, but the MNOs have been unable to obtain site leases.
- **Below-grade infrastructure limitations.** Much of the Project Area has a high water-table that limits the widespread use of below-grade vaults for infrastructure. Similarly, portions of the Project Area are within the floodplain, further limiting below-grade infrastructure.
- **Physical Site Properties.** The network facilities have technical and physical requirements.
  - *Antenna Size:* Depending on the pole design, small cell antennas may require larger antenna shrouds (coverings) and therefore, may not be able to be visually integrated as well as a neutral host antenna.
  - *Housing Size:* Each Topology has a unique required equipment housing size. Some of the housing sizes can be better visually integrated into some areas than others, which is a consideration for the Topology selection for a site.
  - *Antenna Mounting:* The ability to integrate a site design visually has a substantial impact on selection. Where it is believed antennas can be integrated in a way that closely mimics the existing architecture of the area, the visual impact of the site is anticipated to be minimal. Where sites need to be stray from the existing architecture (e.g., luminaires enlarged to house antennas), some visual impact is anticipated. Where poles (with or without a luminaire) have independent shrouds for the antenna, a greater visual impact is anticipated.
- **Site Coverage.** Because some topologies have a smaller coverage radius per site, the efficiency of the design for that topology may be reduced<sup>4</sup> (e.g., a DRAN-2 design may have more than twice as many sites per MNO as an SASC design). The relative visual impact of the extra site(s) is considered in the selection process.

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<sup>4</sup> In some cases, designs are “coverage limited” meaning the number of sites need to meet the coverage requirements is larger than the number of sites need to meet the capacity requirements. (Conversely, “capacity limited” means that the number of sites to meet the capacity goal is higher than the number of sites required to meet the coverage requirements.) Coverage limited designs can increase the ratio of sites required between the topologies (e.g., five sites per MNO (ten sites total) may be required for DRAN-2 where four sites per MNO (16 total) is required for SASC). In capacity limited designs, the ratio of sites will closely match the ratios shown in Table 9.

## 4.6 Topology Selection Criteria

The goal in the design selection process is to achieve the capacity and coverage objectives within the Project Area. The following represents the criteria applied to potential solutions:

- **Minimize impacts on cultural resources.** Multiple existing views and vistas are contributing features within the Project Area, including some of the country's most iconic view corridors, such as the view west from the U.S. Capitol to the Lincoln Memorial.
- **Use existing non-contributing architectural features when possible.** The Project Area contains multiple architectural features, ranging from kiosks and restrooms to light poles.
- **Reduce maintenance requirements.** To the extent practicable, the solutions should simplify the variety of materials (e.g., poles) in a way that minimizes potential NPS maintenance.
- **Consider the number of sites.** While fewer sites are often better, other factors in this section may lead to the selection of a design with more sites.

Other factors could be considered, such as power requirements, HVAC (heating, ventilation, and air conditioning) requirements, operational efficiencies, and the amount of fiber infrastructure needed to support a site. However, during the selection process, these factors emerged as such minor variances that they would not provide meaningful differentiation between the topologies.

Section 6 summarizes the designs and recommendations for each sub-area based on the application of these criteria.

## 5. Project Area Infrastructure and Features

Due to the high sensitivity of the viewsheds associated within the Project Area, this study places considerable weight on using the existing architectural features. AECOM's analysis focuses on solutions that maintain the aesthetic nature during prospective build-out scenarios based on information provided by the NPS and other agencies, field surveys performed by AECOM, and publicly available information.

The typical small cell designs use strategies to disguise infrastructure, including appending large antenna shrouds or incorporating equipment housings into the bases of light poles, would not be acceptable in the Project Area. The approach in this study focuses on adapting, replicating existing features, designing new features that closely resemble and carry the architectural cues of existing features, or providing stealthing treatments to existing features to hide equipment.

### 5.1 Existing Architectural Features

Within each category of architectural feature, numerous varieties are present. The locations of these items, except for small-scale site features, is depicted in Table 9.

#### 5.1.1 Light Poles

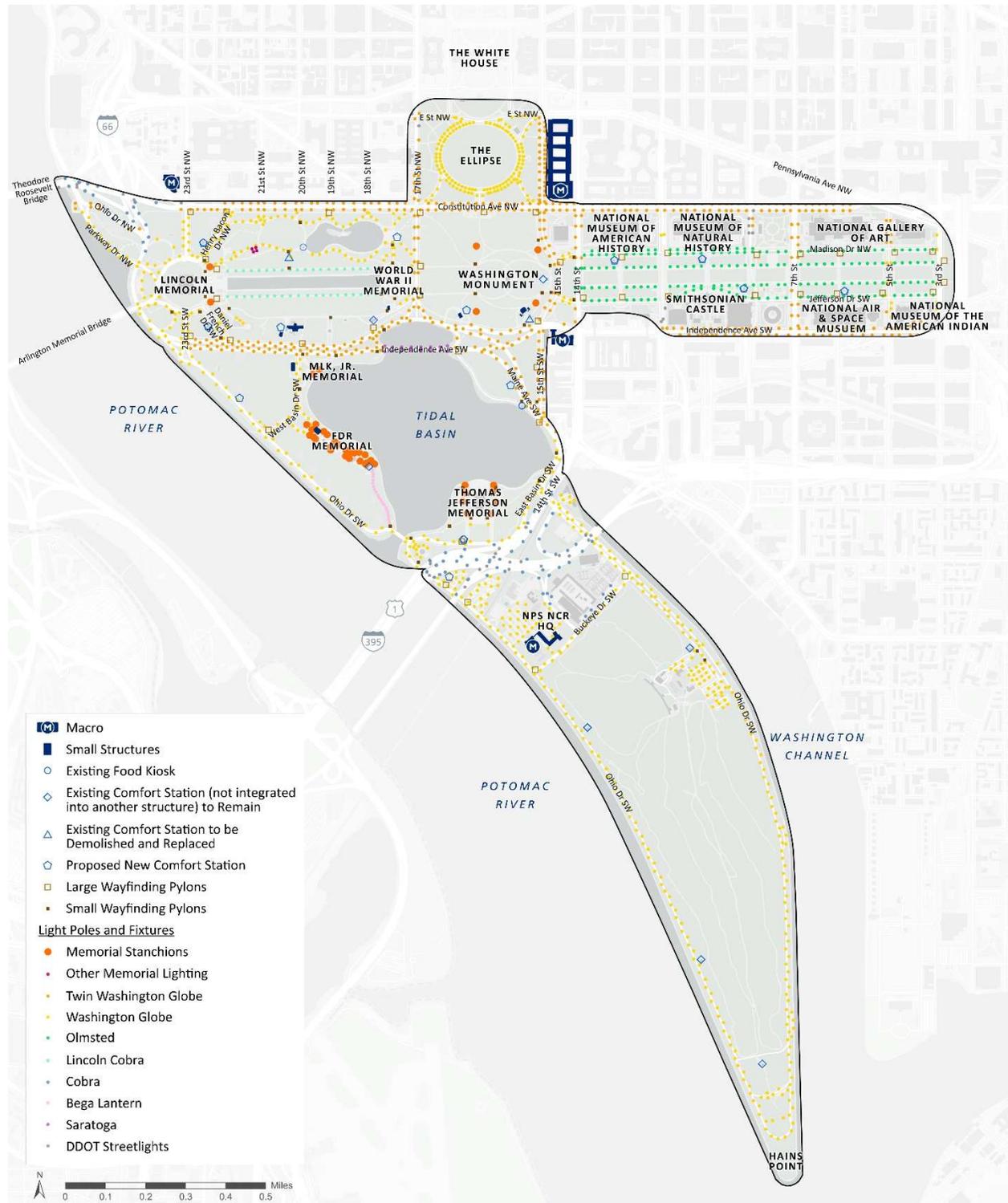
The Project Area has eight distinct types of light poles. The three most common light pole types are the Washington Globe (766 fixtures), Twin Washington Globe (310 fixtures), and Olmsted (191 fixtures). Washington Globe and Twin Washington Globe lights are primarily found in East and West Potomac Parks. Olmsted lights are found along the pathways of the eastern portions of the National Mall. The Lincoln Cobra lights frame the tree allées of the Lincoln Memorial Reflecting Pool. Other light fixtures, including Bega Lantern and Saratoga lights, are clustered in specific areas around the Project Area. Except for Cobra lights along roadways, light poles are intended to illuminate pedestrian areas and are contributing features of historic properties. Cobra lights are located primary near major roadways, such as access roads to I-395 and I-66 (Figure 6, page A-23 and Figure 7, page A-24).

**Table 9: Light Pole Types within Project Area**

Pole Type	Count
Memorial Stanchions	14
Other Memorial Lighting (includes, but not limited to, tall lighting at FDR Memorial and MLK Jr. Memorial <sup>5</sup> )	31
Twin Washington Globe	310
Washington Globe	766
Olmsted	191
Lincoln Cobra	40
Cobra	80
Bega Lantern	22
Saratoga	16

<sup>5</sup> FDR = Franklin Delano Roosevelt; MLK = Martin Luther King

Figure 5: Existing Architectural Features



**Figure 6: Light Poles (1)**



**Washington Globe Lighting**



**Twin Washington Globe Lighting**



**Olmsted Lighting**



**Lincoln Cobra Lighting**

**Figure 7: Light Poles (2)**



**Bega Lanterns Lighting**



**Saratoga Lighting**



**Cobra Lighting**

### 5.1.2 Memorial Light Stanchions

Many of the memorials within the Project Area feature special lighting fixtures to illuminate them at night. Three commemorative works contain such lighting stanchions: the Lincoln Memorial, Jefferson Memorial, and the Washington Monument (Figure 8). These lighting stanchions are not contributing features of historic properties.

Figure 8: Memorial Lighting



### 5.1.3 Wayfinding Pylons

The Project Area contains 93 way-finding pylons, which are not contributing features of historic properties. These pylons, which are found in two sizes, direct visitors to points of interest and amenities within the Project Area (Figure 9).

Figure 9: Wayfinding Pylons



Small Wayfinding Pylon



Large Wayfinding Pylon



Large Wayfinding Pylon

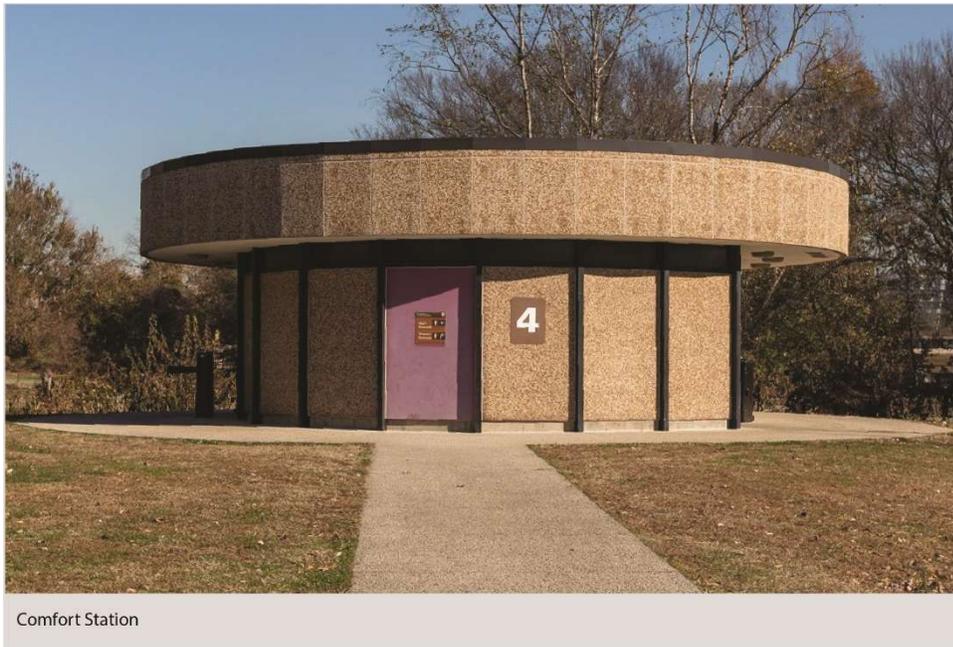


Large Wayfinding Pylon

### 5.1.4 Buildings

The Project Area contains multiple types of buildings based on the variety of NPS facilities and their operations. Currently, the Project Area contains nine stand-alone comfort stations (non-contributing). Of these, most are circular “Benjis.” The NPS is currently advancing a plan to replace or add 15 comfort stations and kiosks with new, expanded facilities. Additionally, the Project Area contains multiple food, information, and souvenir kiosks. Most feature a consistent design style (Figure 10, Figure 11, and Figure 12).

**Figure 10: Buildings: Existing Comfort Station**



Comfort Station

**Figure 11: Example of Proposed Comfort Station**



Comfort Station (Future)

**Figure 12: Buildings: Kiosk**



Concessions Kiosk

### 5.1.5 Small Scale Site Features

Small scale site features throughout the Project Area provide amenities to visitors and facilitate operations. These features include park benches (which may be contributing features, depending on type and location), trash and recycling cans (non-contributing features), and post-and chain barriers (non-contributing features). Figure 13 shows examples.

**Figure 13: Site Furnishings Features**



Benches



Benches



Trash/Recycling Cans



Trash/Recycling Cans

## 5.2 Application of Existing Vertical Architectural Features

As part of the minimum build-out study, the study considered existing architectural features as part of analyzing the number and placement of nodes needed within the Project Area. The architectural features were reviewed to determine whether the required antenna infrastructure could be housed in those features by adapting the features and if not, whether visually similar features could be created to house the required equipment. AECOM's study did not include design of the necessary infrastructure; design would be required to validate some of the assumed infrastructure deployment strategies used in the study.

The vertical architectural features (i.e., features that have or could have sufficient height to support an antenna) currently in place on NPS property can be classified into four categories:

1. Light poles (pedestrian)
2. Memorial lighting stanchions
3. Wayfinding pylons
4. Buildings

Each of these categories would also include the potential for adding identical or similar new features (using a "familial standards" concept where a new pole design incorporates many of the design features of an existing feature to minimize the visual impact). Table 10 lists the existing identified vertical features (or assets), and how they could be used. In such cases, the new asset would replace an existing asset.

**Table 10: Existing Vertical Infrastructure Assets**

No.	Classification/Asset	Potential Use(s)
<b>1</b>	<b>Pedestrian Lighting Poles</b>	
a	Olmsted	Replace existing or add new poles
b	Washington Globe	Replace existing or add new poles
c	Twin Washington Globe	Replace existing or add new poles
d	Lincoln Cobra	Modify existing or add new poles
e	Cobra	Modify existing or add new poles
f	Other Light Poles	Modify existing or add new poles
g	New Familial Poles	Add new poles
<b>2</b>	<b>Memorial Lighting Stanchions</b>	
a	Lincoln	Redesign existing stanchions
b	Washington	Redesign existing stanchions
c	Jefferson	Redesign existing stanchions
d	Other Stanchions	Redesign existing stanchions
e	New Stanchions	Add new stanchions
<b>3</b>	<b>Wayfinding Pylons (existing)</b>	
a	Large Pylons	Redesign existing pylons
b	Small Pylons	Replace with redesigned large pylons
c	New Pylons	Add new pylons

<b>4</b>	<b>Buildings</b>	
a	Existing Comfort Stations	Add asset to or near existing building
b	Planned Comfort Stations	Add asset to or near building
c	Food Kiosk	Add asset to or near building
d	Other Buildings	Add asset to or near building

AECOM's design sought to place the required nodes in locations where architectural features are currently located (e.g., light pole replacement) or in new locations consistent with existing infrastructure (e.g., new light poles in line with existing poles). This approach could potentially allow the deployment of effective systems while minimizing the visual impact on cultural resources. The October 2024 District of Columbia's Draft Small Cell Design Guidelines (Version 4) states that small-cell infrastructure is not to be permitted or installed on Twin-Twenty and Washington Globe lighting.

### 5.2.1 Architectural Features and Technical Limitations

With each of these architectural feature categories, and even specific architectural features, there are anticipated preferences between them when considering using each in a design. No telecommunications facilities were designed as part of this report. The new telecommunication facilities, such as light poles and stanchions, are only illustrative. However, the illustrative examples reflect telecommunications industry standards and subject matter expertise of the project team.

It is anticipated that new nodes would be designed to support a wide range of uses, including the deployment of commercial wireless networks, Wi-Fi networks, security cameras, electrical hook-ups, network and fiber drops, security call boxes, and other uses that may be beneficial to NPS visitors.

The vertical architectural features shown in Table 10 indicates how each architectural feature may be incorporated in node designs and are further described below.

#### 5.2.1.1 Light Poles

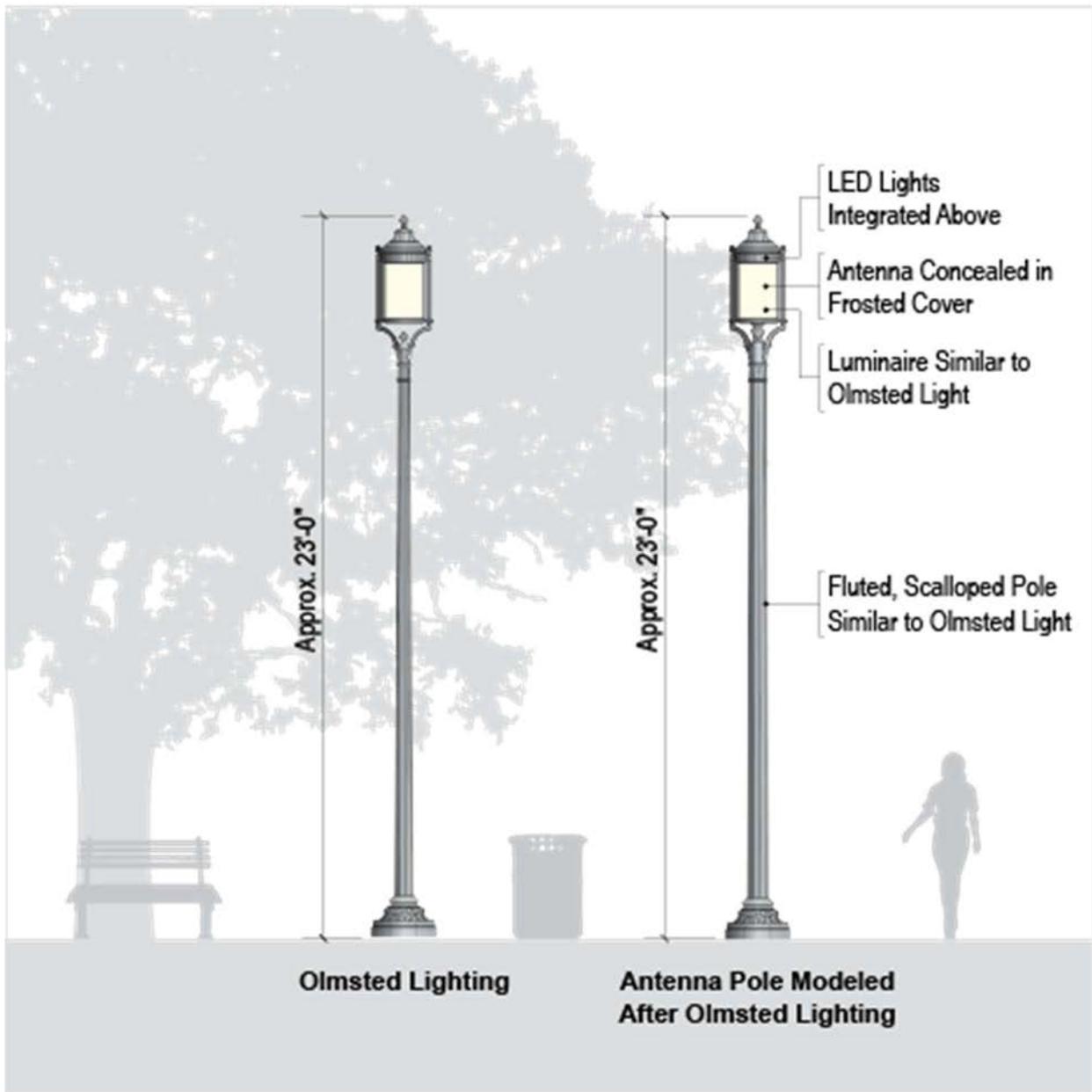
The Project Area includes multiple light pole types that could be adapted to support network infrastructure. The following describes the types of changes that could occur if adapting light poles.

- Olmsted lights could be adapted to integrate antennas into the globe while retaining the overall appearance to closely match the existing poles.
  - Replace existing Olmsted light poles with new light poles that are designed to closely resemble existing lights or install new Olmsted lights between the existing line of lights (Figure 14, page A-32).
  - The Olmsted luminaires are large enough to incorporate either the small cell or neutral host antenna without needing to be enlarged.
- Washington Globe and Washington Twin Globe lights could be adapted for use, though some would need to be replaced, and some new poles would be needed between existing light poles. Also, adding lights to new locations could meet coverage requirements (Figure 15, page A-33 and Figure 16, page A-34).
  - A Washington Globe luminaire would need to be enlarged to incorporate the small cell antenna used in this study; the neutral host antenna would fit within the existing luminaire size.
- Lincoln Cobra and Cobra lights use a familial pole that adds a shrouded antenna in addition to and above the light (Figure 17, page A-35). These new poles may be deployed in line with existing light poles or in new locations. The poles would be consistent with existing light poles of the areas of deployment in the new locations.

- In areas where lighting is not needed, Olmsted, Washington Globe, Washington Twin Globe, Lincoln Cobra, and Cobra lights would use a newly created familial stand-alone pole that would have a shrouded antenna at the top, typically without a light fixture. These poles may be the same size or a taller than the existing versions of the pole.
- Other pole types may be needed where existing poles cannot be modified or replaced, or where poles do not currently exist. Design and use of any new light poles would follow similar techniques as described above.

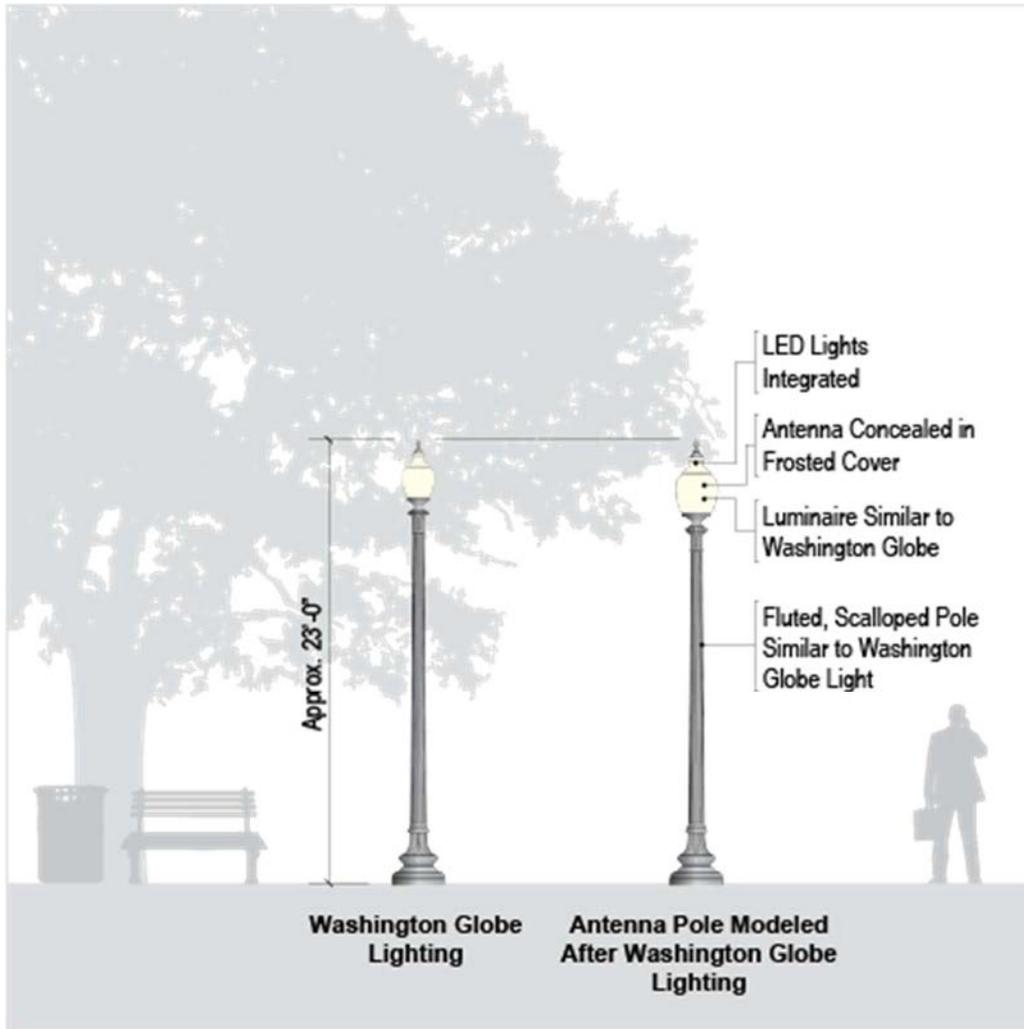
The treatment of light poles would have limited variation between the potential solutions (SASC, DRAN-2, DRAN-4, and Neutral Host).

**Figure 14: Elevation Diagram of Olmsted Lighting with Network Infrastructure**



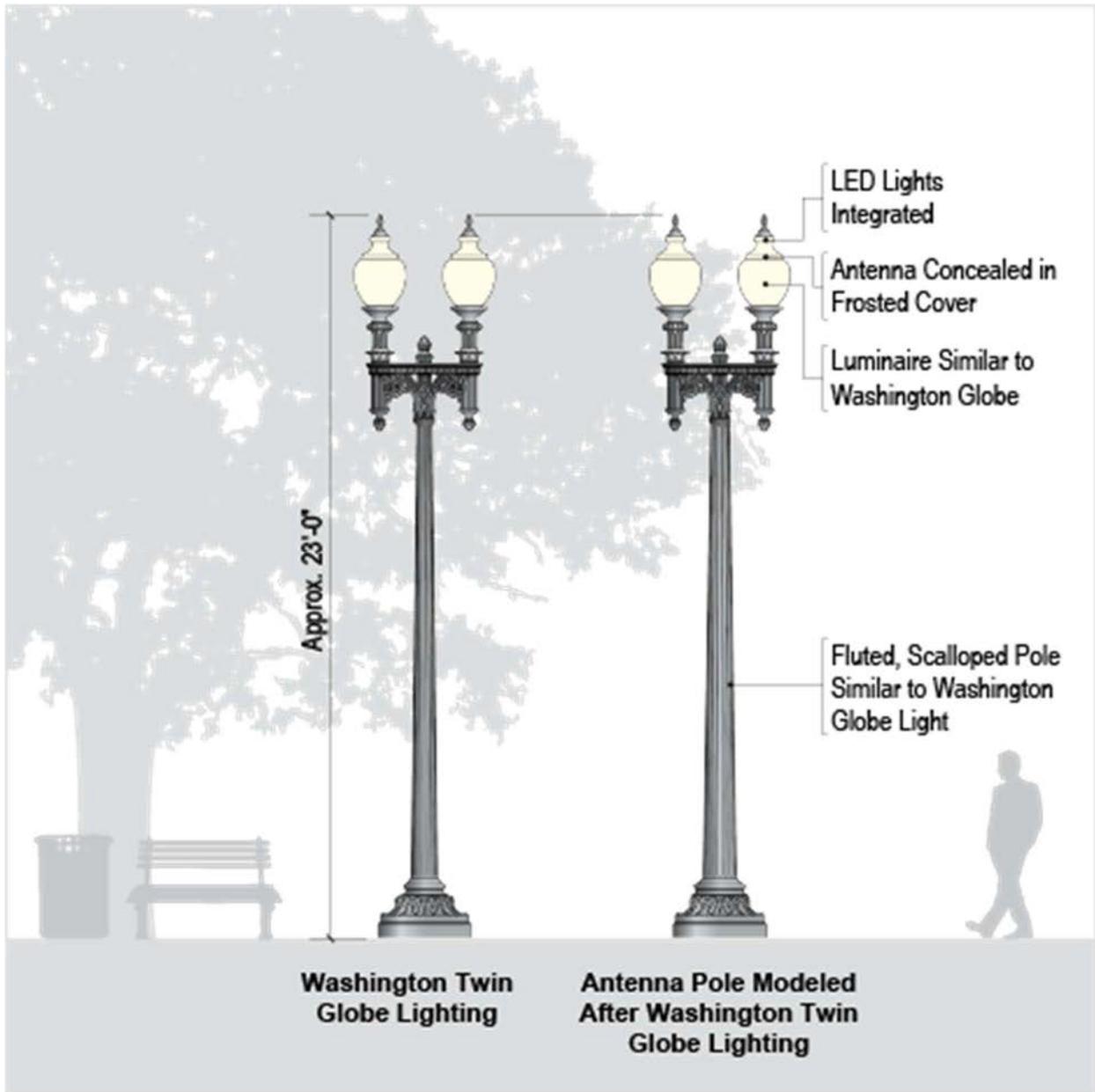
*Note: Diagram is for illustrative purposes only*

**Figure 15: Elevation Diagram of Washington Globe Lighting with Network Infrastructure**

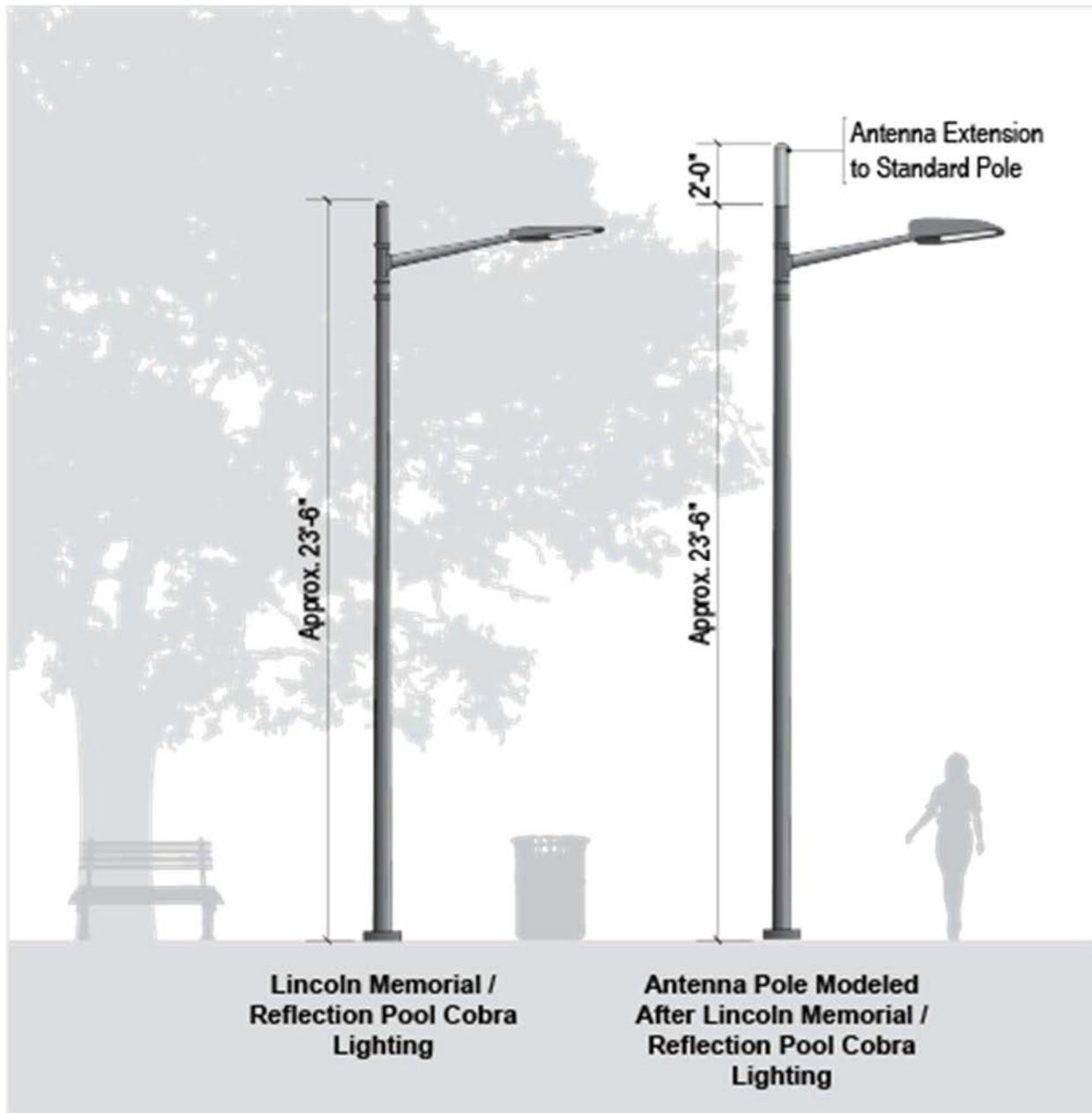


*Note: Diagram is for illustrative purposes only*

**Figure 16: Elevation Diagram of Washington Twin Globe Lighting with Network Infrastructure**



*Note: Diagram is for illustrative purposes only*

**Figure 17: Elevation Diagram of Lincoln Cobra Lighting with Network Infrastructure**

*Note: Diagram is for illustrative purposes only*

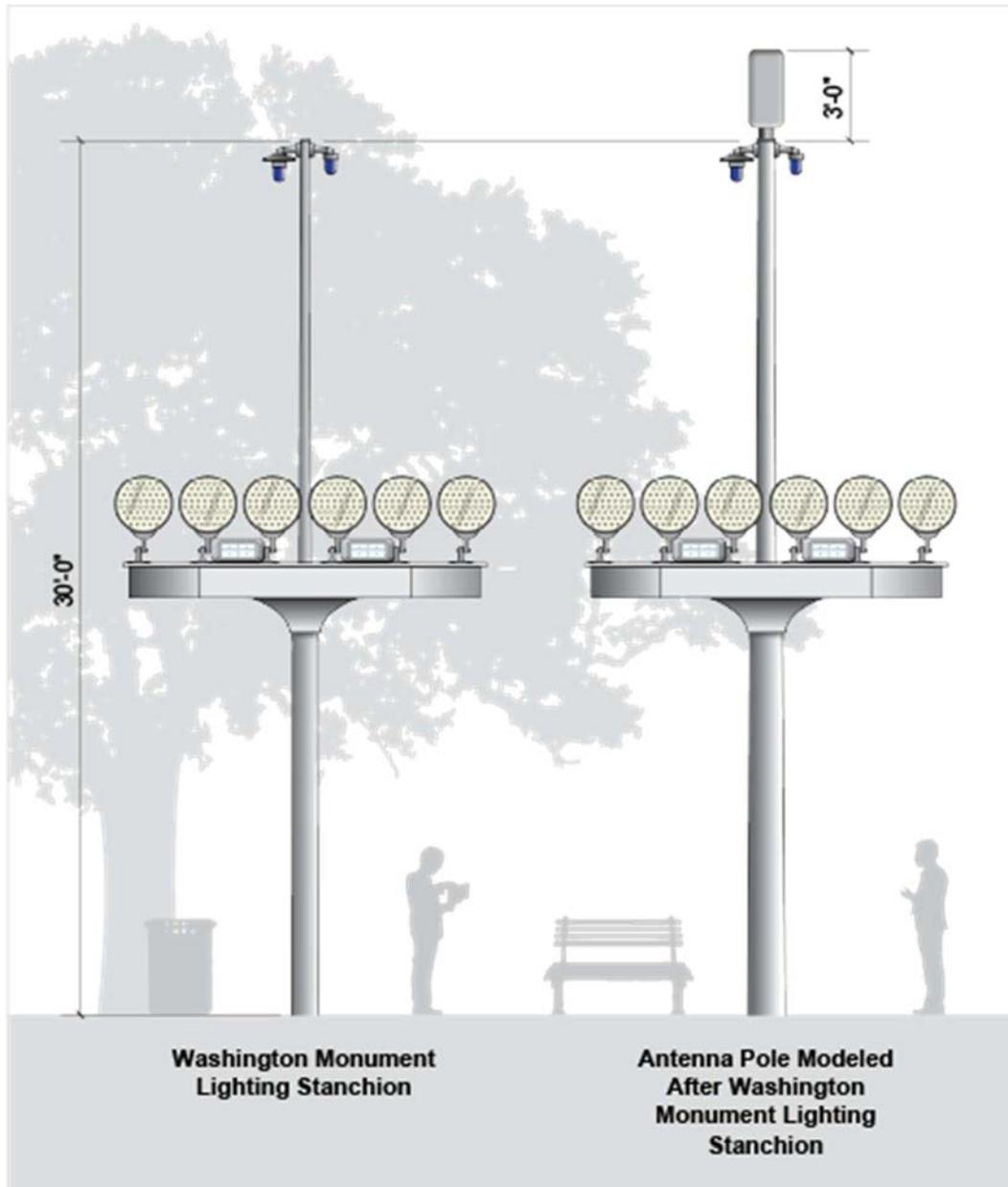
### 5.2.1.2 Memorial Lighting Stanchions

In addition to the pole lighting that illuminates pedestrian and vehicular uses, memorial lighting stanchions are used to illuminate memorials. While stanchions styles vary among memorials, the Lincoln and Jefferson Memorials are close in style and appearance. For the purposes of the visual illustrations in this analysis, the stanchions at the Washington Monument and Jefferson Memorial are used to convey the approximate concepts.

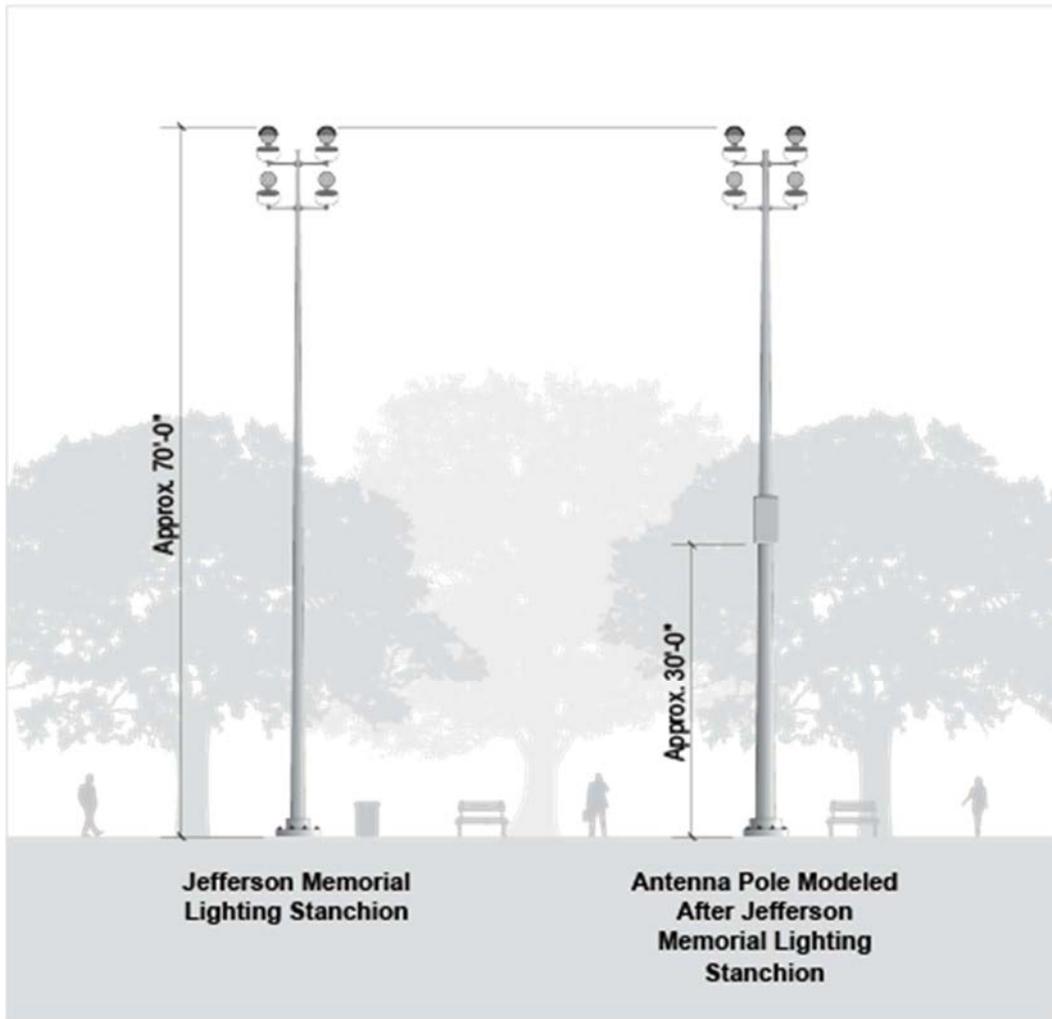
- The four Washington Memorial lighting stanchions would be redesigned to incorporate all existing functionality as well as house the infrastructure needed to deploy a DRAN-4 (for minimizing visual impact) or four collocated SASC topologies (to maximize performance). The redesigned stanchions would be similar in visual character to those in place today (Figure 18, page A-36).

- The two existing Lincoln Memorial lighting stanchions (northeast and southeast of the memorial) would be redesigned to incorporate either a DRAN-4 or four collocated SASC topologies. Redesigning these stanchions would offer the opportunity to better incorporate, and thus camouflage, the existing security camera.
- Four of the Jefferson Memorial lighting stanchions (northeast, northwest, southeast, and southwest) would be redesigned to incorporate all existing functionality as well as house infrastructure needed to deploy a DRAN-4 or four collocated SASC topologies. The redesigned stanchions would be similar in visual character to those in place today (Figure 19, page A-37).

**Figure 18: Elevation Diagram of Washington Monument Lighting Stanchions with Network Infrastructure**



*Note: Diagram is for illustrative purposes only*

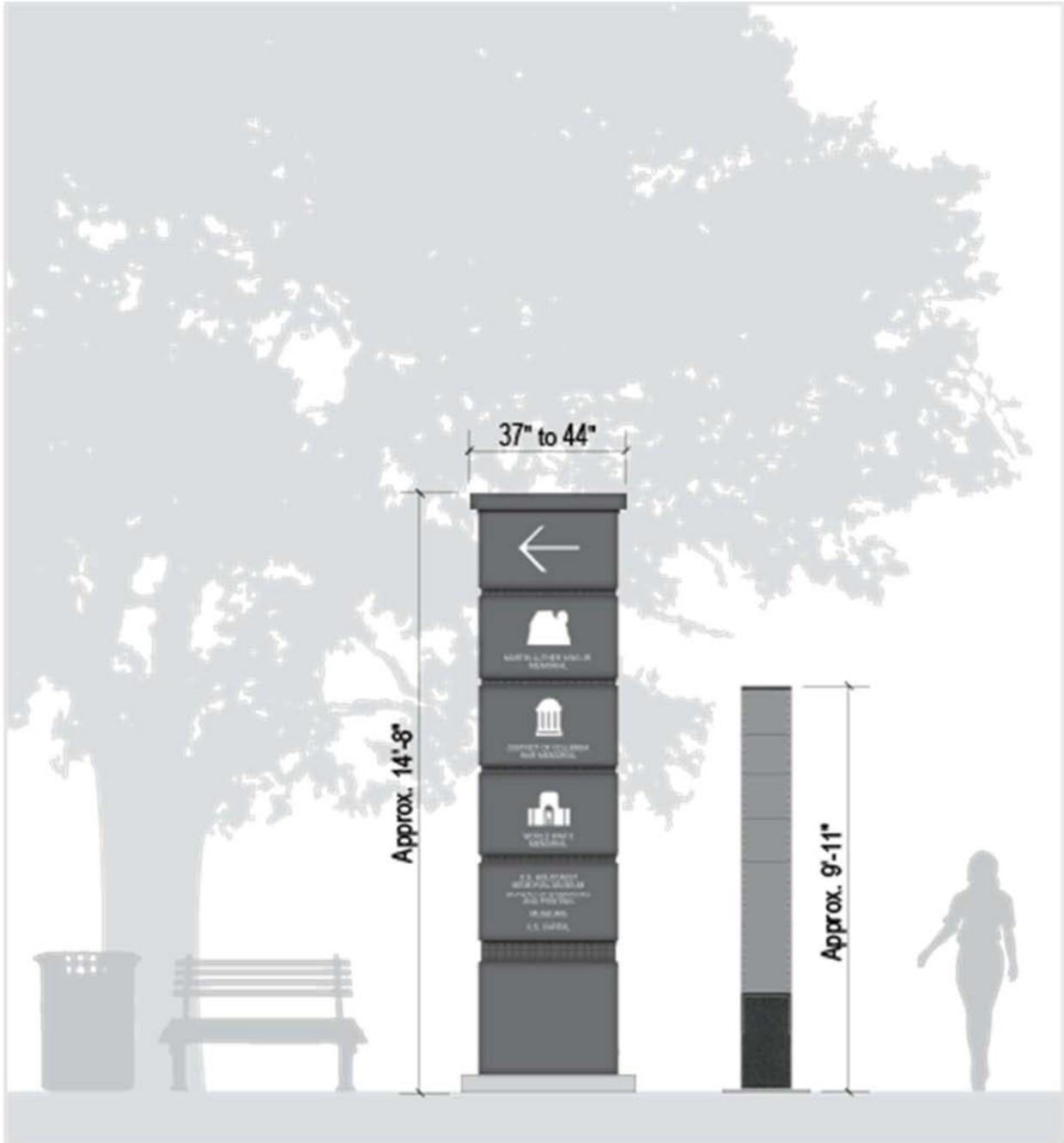
**Figure 19: Illustrative Elevation of Jefferson Memorial Lighting Stanchions with Network Infrastructure**

*Note: Diagram is for illustrative purposes only*

### 5.2.1.3 Wayfinding Pylons

Existing pylons could be modified to incorporate the infrastructure needed for the small cell deployment. Modification would be needed to incorporate the antenna(s) at a sufficient height. The modified pylons would closely match the existing pylons in all other capacities besides the height, with the notable exception of potentially needing to have an increased footprint to incorporate the equipment housing for the node (Figure 20, page A-38).

Figure 20: Elevation Diagram of Wayfinding Pylon with Network Infrastructure



Note: Diagram is for illustrative purposes only

### 5.2.1.4 Buildings

The Project Area contains multiple types of buildings, including concession kiosks and comfort stations. These buildings offer the opportunity to collocate communications infrastructure (Figure 21, page A-39).

- Buildings in the Project Area would be considered on a case-by-case basis as needed within the context of providing the desired coverage. Antennas could be incorporated behind fabricated stealthing applications, shrouds (resembling smokestacks) could be added to the building's roof, or poles could be added adjacent to the building using a familial design to fit the area.
- Ground-based infrastructure would be incorporated into the existing building or, more likely, added to the existing building in a way that creates little or no visual impact.

**Figure 21: Diagram of Potential Configuration of Comfort Station to Support Network Infrastructure**



*Note: Diagram is for illustrative purposes only*

### 5.2.1.5 Summary of Use

Most, but not all, types of architectural features which are currently existing within the Project Area can be used to support the telecommunications network. Light poles would need to be replaced or reconfigured. The existing memorial lighting stanchions and wayfinding pylons could be modified, as existing buildings could be modified. Stand-alone poles, which could be designed to resemble an existing light pole design (and referred to here as familial poles) could also be included. Table 11 summarizes the information.

**Table 11: Potential Use of Existing Architectural Features for Deploying Infrastructure Configurations**

Potential for Adapting Feature	Light Poles	Memorial Lighting Stanchions	Wayfinding Pylons	Buildings
Modification of Existing Feature Possible	No	Yes	Yes	Yes
Replacement (Identical) of Existing Feature Possible	Yes	No	No	No
Replacement (Modified Design) Needed	Yes	Yes	Yes	No
Familial Pole	Yes	No	No	No

### 5.2.2 Small-Scale Site Features

Each node will require a set of ground-based infrastructure within approximately six feet of the pole including radios, combiners, electrical panels, fiber panels, fans, and other related items. While the size of this infrastructure varies by deployment category (SASC, DRAN-2, DRAN-4, and Neutral Host; see Section 4 for details), each location will require some variation of equipment housing to protect and maintain the infrastructure (Table 12, Figure 22, Figure 23, Figure 24, and Figure 25).

**Table 12: Size of Equipment Housing by Deployment Category**

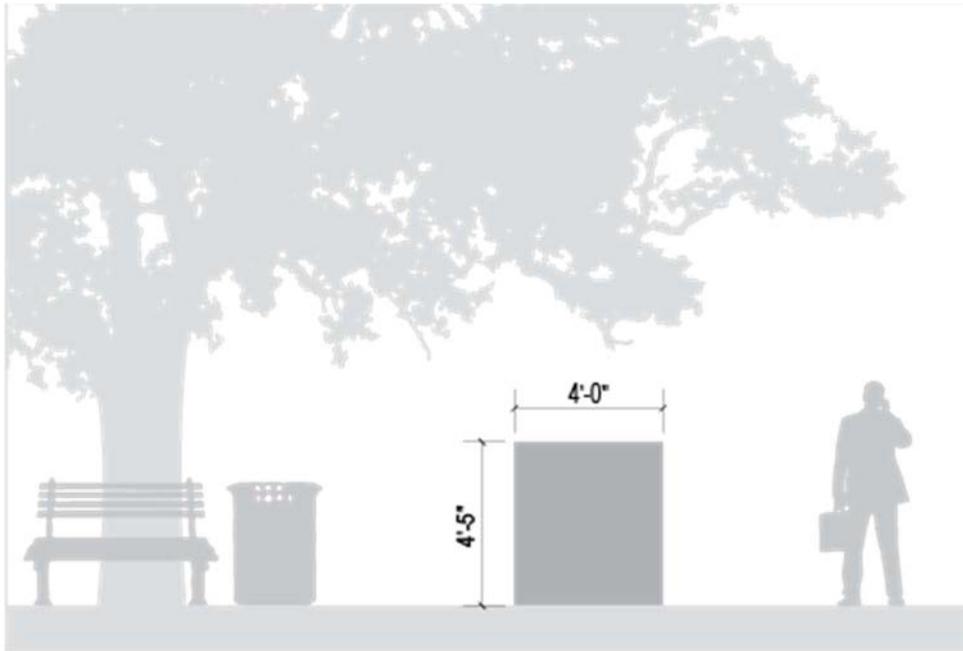
Deployment Category	Width (ft)	Height (ft)
Stand-Alone Small Cell	4	4.5
DRAN-2	6	4.5
DRAN-4	10	5.8
Neutral Host	4	6

Creative solutions would be required to house infrastructure while minimizing visual impact around the node. While creative solutions are likely to be added to this list, equipment housing types are expected to include enclosures that are incorporated or integrated into the following park ground-based infrastructure (either existing or new):

- Park bench with enclosed base
- Trash and recycling center
- Wayfinding pylon
- Existing adjacent structure
- Pole
- Industrial enclosures (especially adjacent to lighting stanchions) consistent with existing enclosures

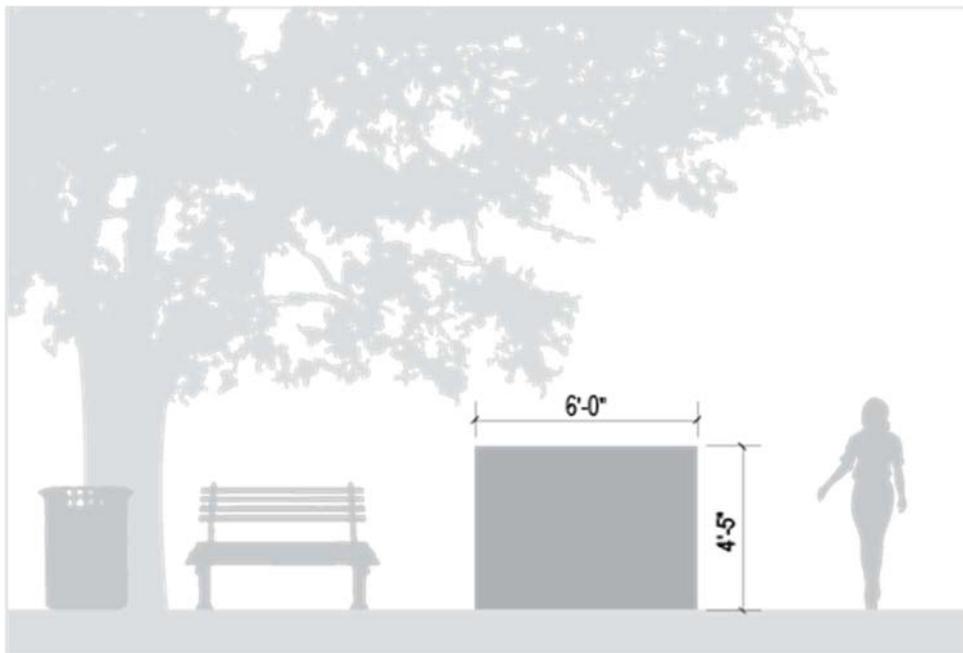
For the purposes of this study, it is assumed that suitable ground-based housing infrastructure can be designed for, and placed adjacent to, each site. In addition, it is assumed that below-grade vault enclosures will not be viable in flood-prone areas but could be considered in other areas as technology and circumstances allow.

**Figure 22: Scale Elevation Diagram of Ground-Level Infrastructure for SASC Deployment**



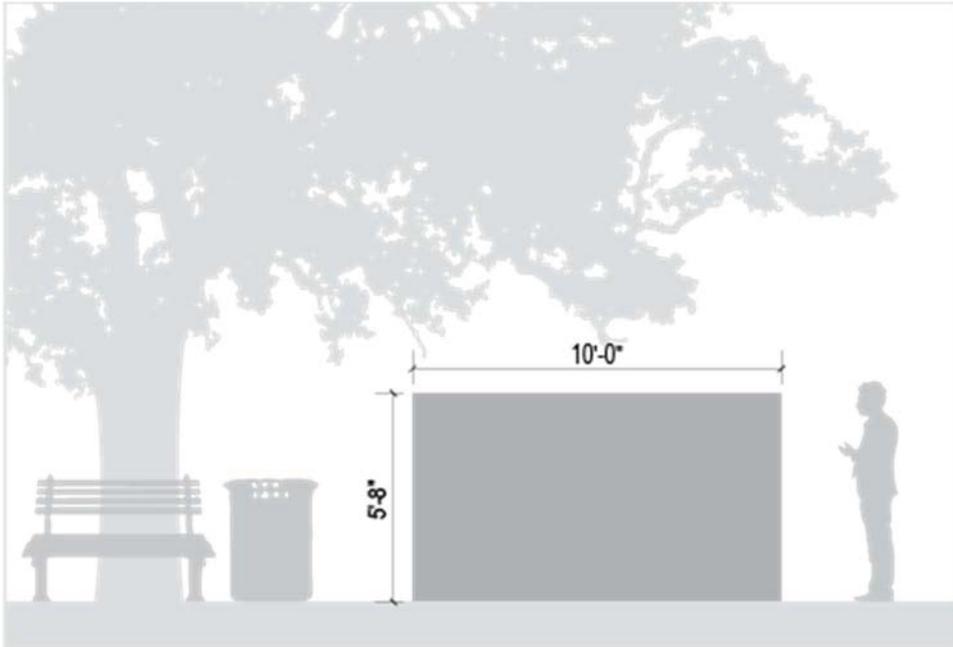
*Note: Diagram is for illustrative purposes only*

**Figure 23: Scale Elevation Diagram of Ground-Level Infrastructure for DRAN-2 Deployment**



*Note: Diagram is for illustrative purposes only*

**Figure 24: Scale Elevation Diagram of Ground-Level Infrastructure for DRAN-4 Deployment**



*Note: Diagram is for illustrative purposes only*

**Figure 25: Scale Elevation Diagram of Ground-Level Infrastructure for Neutral Host Deployment**



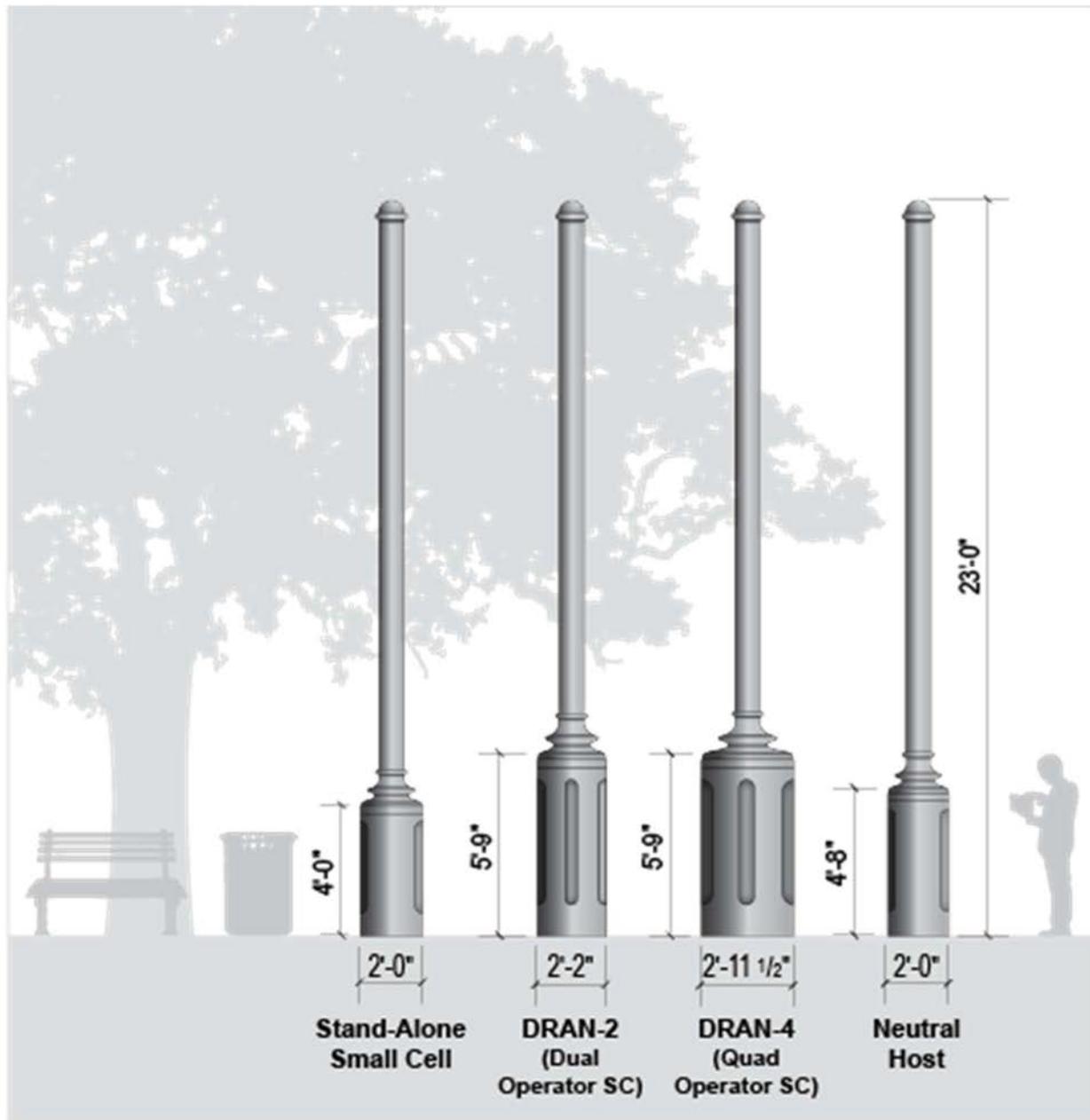
*Note: Diagram is for illustrative purposes only*

### 5.3 New Standalone and Integrated Architectural Features

Sections 5.1 and 5.2 describe existing architectural features within the Project Area and how they could be adapted to increase the network capacity. In addition to these existing locations, standalone features could also be included. These would entail the installation of poles in areas adjacent to existing lighting features or in areas that contain no or limited architectural features.

For the purposes of this analysis, the standalone poles shown illustrated the poles in a way that would not include cabinetry and have integrated all the equipment into the pole (see Figure 26).

**Figure 26: Standalone Poles with Various Deployments Diagram**



*Note: Diagram is for illustrative purposes only*

## 6. Network Analysis and Recommendations

The sections below outline each sub-area, with the study results summarized for each network topology (refer to Section 5 for an explanation of the topologies). After designs for each of the Topologies were developed, optimized, and compared, recommended system topologies for the sub-area and potentially acceptable alternative(s) were identified. This selection is documented in each subsection below.

While this report breaks the Project Area into smaller sub-areas, no physical, geographic, or practical boundaries exist between the sub-areas. The independent treatment of the sub-areas is strictly for the purposes of calculating results and illustrating conceptual designs. The designs were then compared to the criteria. Care has been taken to ensure that preferred designs in adjacent sub-areas provide seamless performance when combined.

For those areas using existing light poles, changes to the light poles would not vary significantly between the four solutions (SASC, DRAN-2, DRAN-4, Neutral Host). The primary difference between solutions would be the size of the ground-based infrastructure, although in some cases (e.g., Washington Globe lights) luminaires may need to be enlarged to house small cell antennas. If determined through the planning process that standalone poles are preferred, they can be installed at similar locations to those outlined in the topology solutions.

### 6.1 National Mall East

The National Mall East area is an open pedestrian area, with trees along the north and south buffer areas adjacent to Madison and Jefferson Drives. This area frequently attracts heavy crowds and would require a high-density network to minimize site count. For this reason, the conceptual design should primarily draw from small cell topologies to ensure that maximum network capacity is achieved from each site location.

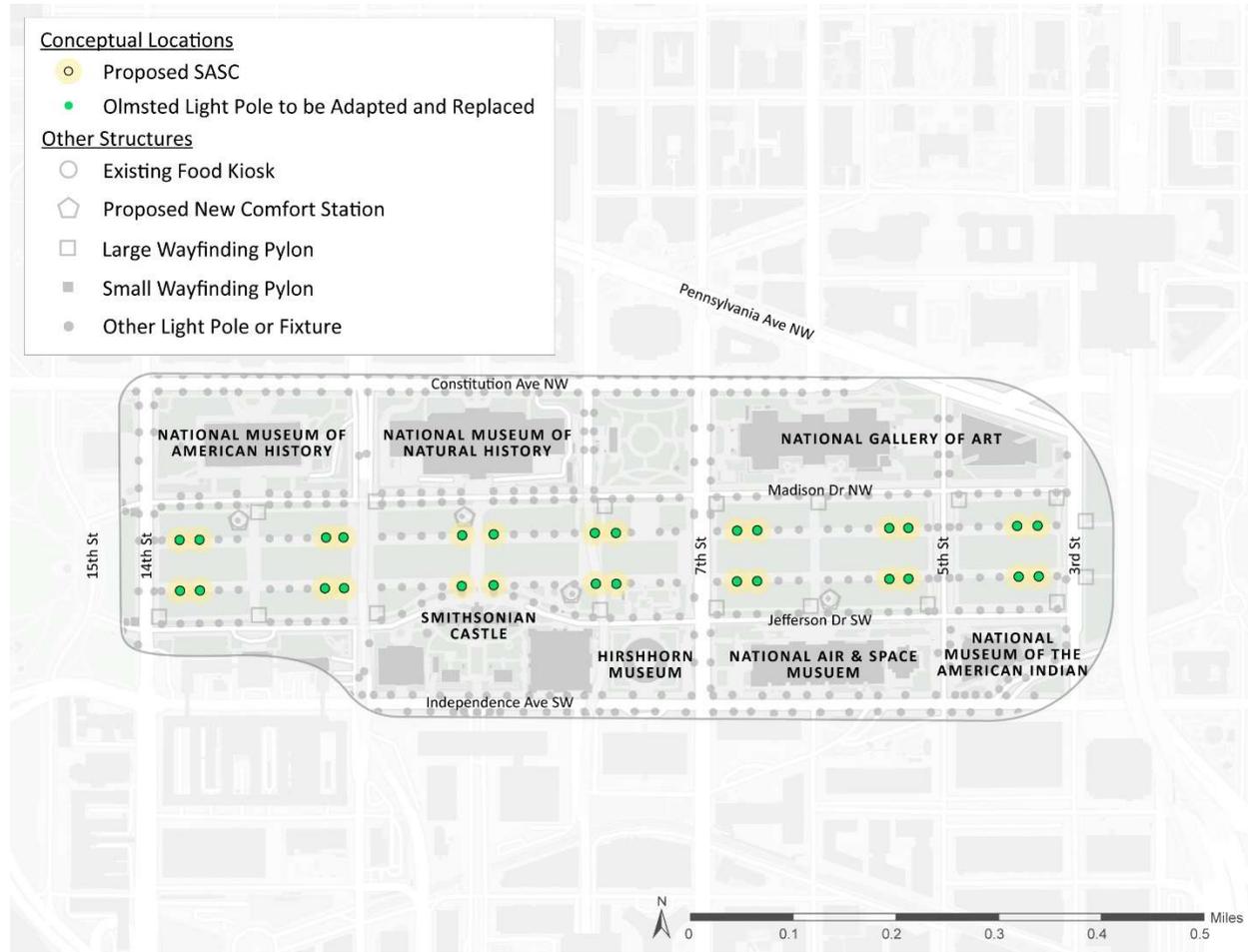
Due to the limited existing features, the sensitive cultural landscape of this area, and the allée of trees that limit signal propagation, the antenna poles should be aligned with the Olmsted light poles and be designed to limit their visual impact. Aligning with the poles also ensures the best possible performance in both the open and tree-lined areas. This approach would utilize the tree-lined areas to buffer the system from the macro network sites, improving CINR and therefore network performance (see Section 3.3 for more details). Equipment enclosures would be immediately adjacent to the antenna poles and, due the openness of the area, should be limited in size. While the maps identify Olmsted lights to be adapted or replaced, these could also be potential locations of standalone poles. Tree canopy and the low height of existing structures are constraints to locating resources outside of primary corridors.

#### 6.1.1 SASC Topology

A SASC design for this area would consist of a total of 28 sites (seven for each MNO) spread evenly along the two lines of Olmsted lights. The antenna poles for the sites could replace existing poles or be added between the pole; the ultimate selection is beyond the scope of this study. Each antenna pole would have a small adjacent equipment enclosure that could be disguised as a bench or trash receptacle.

A conceptual map of the locations and a scale elevation of ground-level infrastructure for a SASC deployment is shown in Figure 27.

Figure 27: SASC Deployment for National Mall East

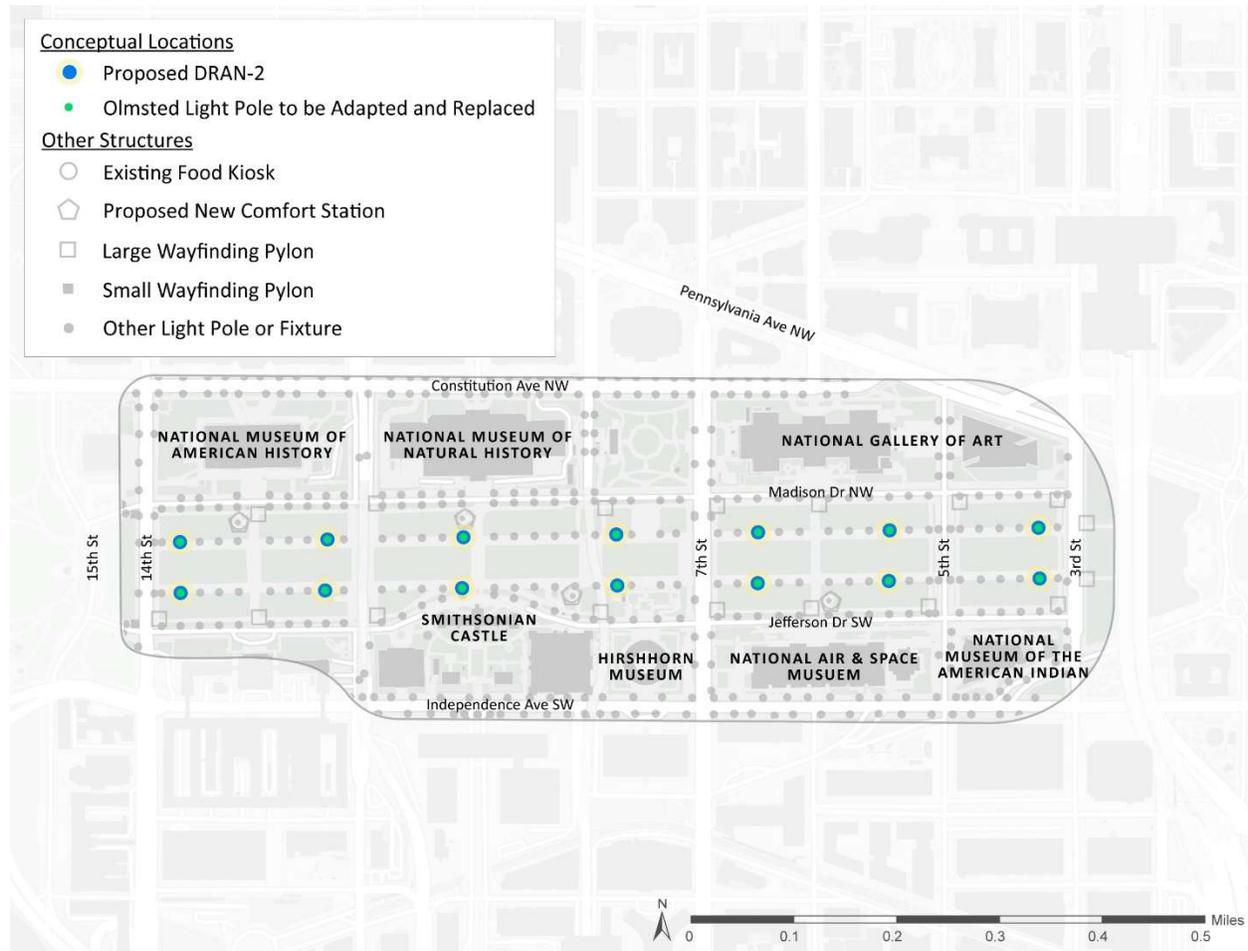


### 6.1.2 DRAN-2 Topology

A DRAN-2 design for this area would consist of a total of 14 sites spread evenly along the two lines of Olmsted lights. Each antenna pole would have an adjacent medium-sized equipment enclosure that could be concealed in a bench or large trash and recycling receptable.

A conceptual map of the locations and a scale elevation of ground-level infrastructure for a DRAN-2 deployment is shown in Figure 28.

**Figure 28: DRAN-2 Deployment for National Mall East**

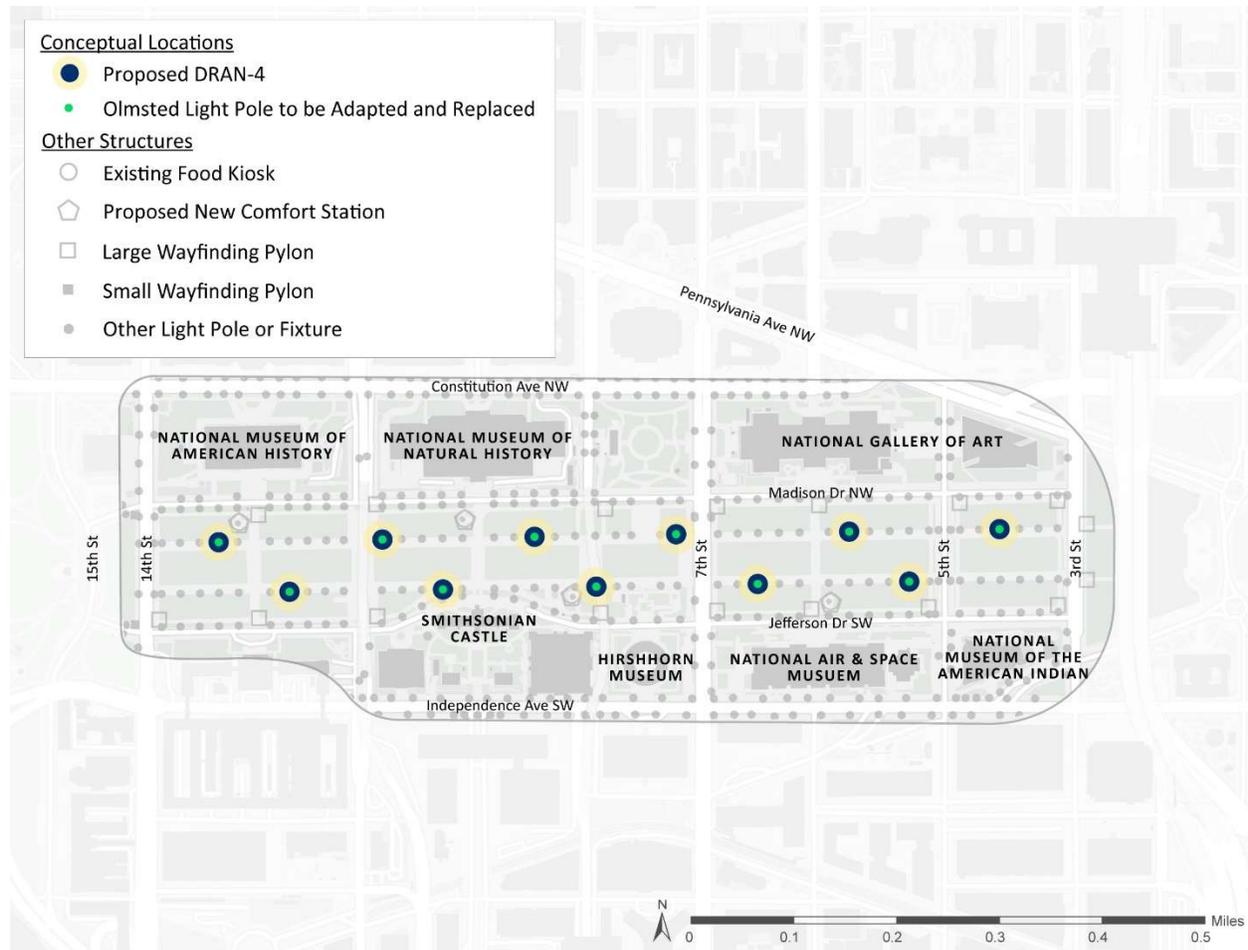


### 6.1.3 DRAN-4 Topology

A DRAN-4 design for this area would consist of a total of eleven sites split between the two lines of Olmsted lights. Each antenna pole would have a large adjacent equipment enclosure, which could not easily be concealed. This Topology would provide sufficient capacity to the area although it may suffer from macro site interference between antenna sites.

A conceptual map of the locations and a scale elevation of ground-level infrastructure for a DRAN-4 deployment is shown in Figure 29.

**Figure 29: DRAN-4 Deployment in National Mall East**

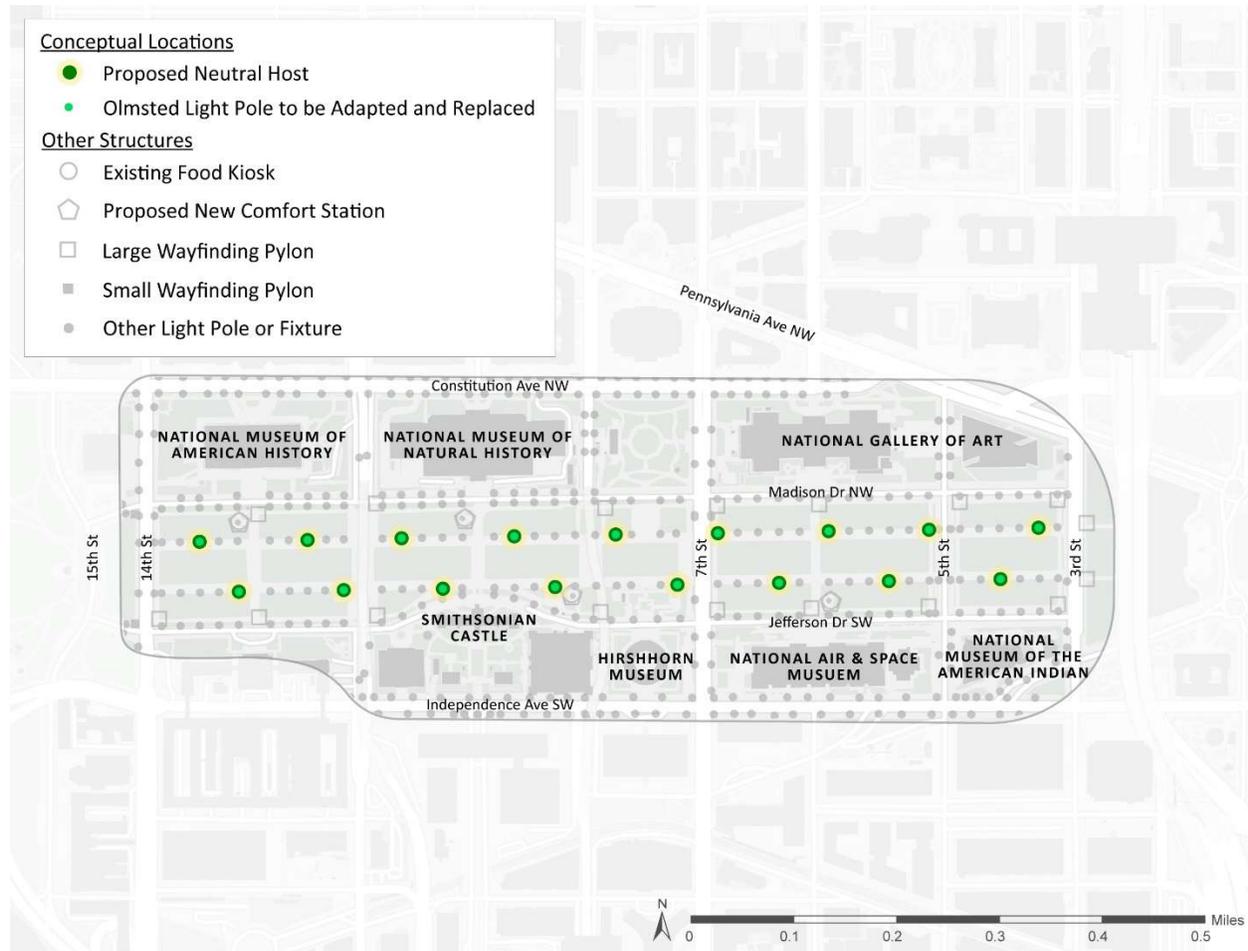


### 6.1.4 Neutral Host Topology

A Neutral Host design for this area would consist of a total of 17 sites split between the two lines of Olmsted lights. Each antenna pole would have a small adjacent equipment enclosure that could be concealed in a bench or trash receptacle.

A conceptual map of the locations and a scale elevation of ground-level infrastructure for a Neutral Host deployment is shown in Figure 30.

**Figure 30: Neutral Host Deployment in National Mall East**



### 6.1.5 National Mall East Sub-Area Preferred and Alternative Concepts

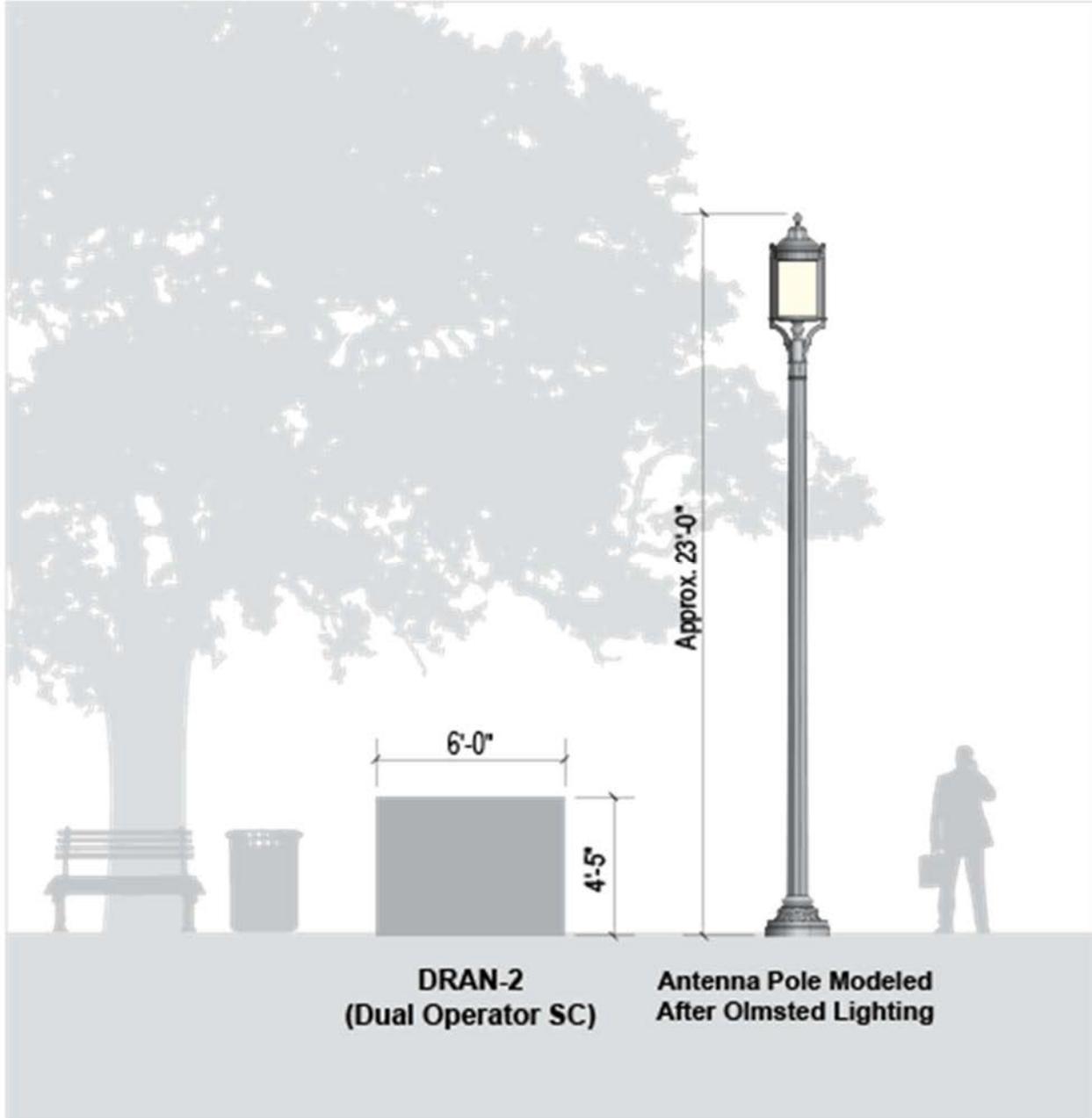
As mentioned in the opening of this section, the open nature of the National Mall and frequent crowds requires both a high-performance network and a solution that can be readily concealed and integrated into the sensitive cultural landscape, including the primary view reciprocal view between the Lincoln Memorial, Washington Monument, and the U.S. Capitol. For these reasons, the preferred topology for this area is DRAN-2, while the alternative topology is SASC. See Table 13 for a summary.

**Table 13: Summary of Criteria by Topology – National Mall East**

Criteria	SASC	DRAN-2	DRAN-4	Neutral Host	Preferred: DRAN-2
Minimize impact on cultural resources	Olmsted lights would be similar in appearance; smallest cabinet size	Olmsted lights would be similar in appearance; medium cabinet size	Olmsted lights would be similar in appearance; largest cabinet size	Olmsted lights would be similar in appearance; smallest cabinet size	Olmsted lights would be similar in appearance; medium cabinet size
Use non-contributing resources, if possible	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired
Minimize maintenance	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types
Limit number of sites	28	14	11	17	14

**Preferred Concept:** The DRAN-2 Topology is an ideal combination of capacity and manageable enclosure size. The 14-site count can be integrated within the existing series of light poles, while the enclosures can be creatively concealed adjacent to the poles (Figure 31).

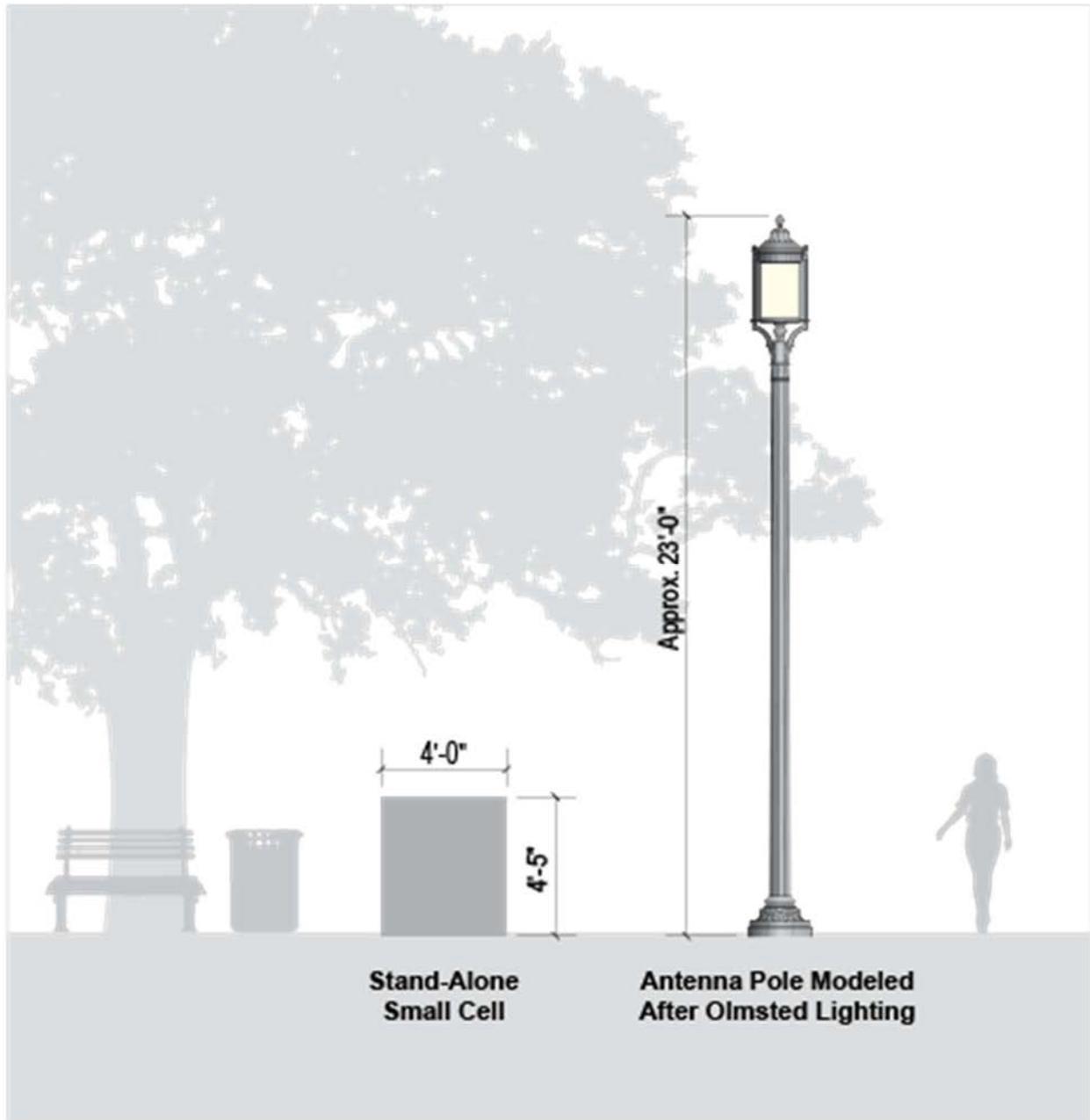
**Figure 31: Preferred Concept for National Mall East - Elevation Diagram of Olmstead Lighting with Network Infrastructure and DRAN-2 Equipment Housing**



*Note: Diagram is for illustrative purposes only*

**Alternative Concept:** The SASC solution requires double the antenna poles, presenting a greater challenge to integrate poles within the existing line of infrastructure. The smaller enclosures offset this concern when compared to the DRAN-2 solution (Figure 32).

**Figure 32: Alternative Concept for National Mall East – Elevation Diagram of Olmsted Lighting with Network Infrastructure and SASC Equipment Housing**



*Note: Diagram is for illustrative purposes only*

**Unfavorable Concepts:** The DRAN-4 is unfavorable due to the extreme enclosure sizes presenting an immense concealment challenge. The Neutral Host, conversely, has limited capacity per site and therefore requires more infrastructure than other topologies.

## 6.2 Washington Monument Grounds and President's Park South

The Washington Monument Grounds and President's Park South sub-area is mostly an open pedestrian area with some intersecting traffic thoroughfares, most notably Constitution Avenue which separates the Monument Grounds from President's Park South. This area frequently attracts heavy crowds, particularly on the Monument Grounds, and will require a high-capacity sites to minimize the site count in that area. The preferred conceptual design will primarily draw from small cell topologies to the south while allowing for more flexibility in and near President's Park South.

This sub-area has a limited set of existing features on the Washington Monument Grounds, including the stanchions. President's Park South features are limited to Washington Globe light fixtures. Targeting the use of the few existing infrastructure features would be important, such as the antenna poles integrated into the stanchions of the Washington Monument and integrated into Washington Globe lights at the President's Park South. Equipment enclosures would be immediately adjacent to the antenna poles and will have more flexibility near the stanchions and require concealment at President's Park South.

It should be noted that each MNO is investigating placing a high-capacity rooftop macro site at the NMAAHC, which would have a tremendous impact on this area. Depending on what is deployed, a site at that location could meet the full capacity requirements of President's Park South and northern Washington Monument Grounds, leaving only the need for antenna sites to the south (collocated on the lighting stanchions south of the Washington Monument). Due to the uncertainty of this deployment, this study assumes this macro change will not occur. However, if the macro site is deployed, the minimum build-out requirement would only be two (2) DRAN-4 sites, one at each of the southern Washington Monument stanchions. While the maps identify Washington Globe lights to be adapted or replaced in President's Park South, these could also be potential locations of standalone poles.

The Washington Monument Grounds and President's Park South sub-area includes multiple views, including reciprocal views to the Lincoln Memorial, White House, Thomas Jefferson Memorial, and the U.S. Capitol, as well as views of the Washington Monument.

### 6.2.1 SASC Topology

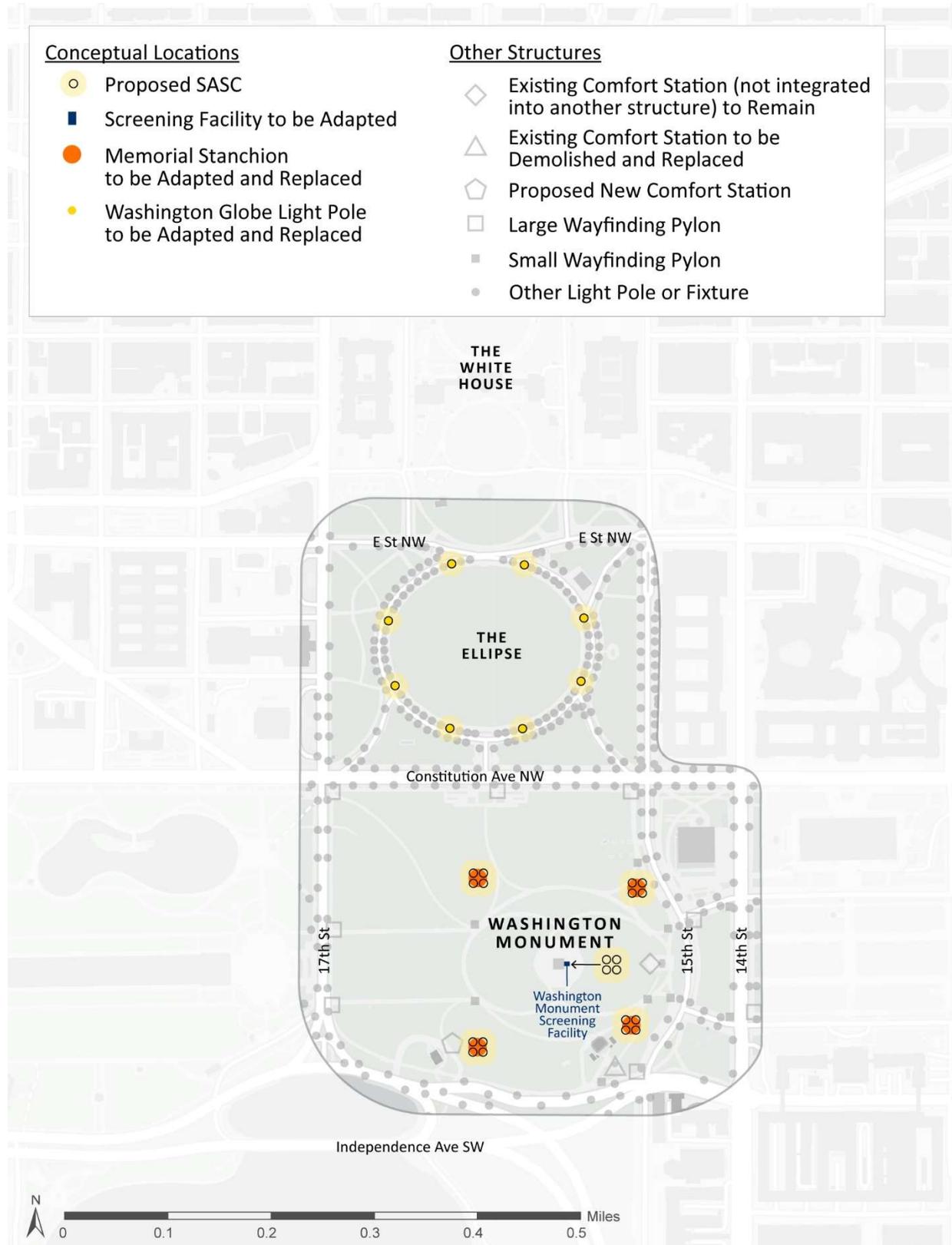
A SASC design for this area would consist of a total of 28 sites, or seven (7) sites per MNO. One (1) site for each MNO would be collocated on each of the four stanchions (total of 16 sites) and at the screening facility (total of 4 sites), while the remaining two (2) sites per MNO would be sited at President's Park South.

On the stanchions, the sites would be collocated on redesigned stanchions and would utilize shared enclosures. At the screening facility, a stovepipe shroud on the roof would house the antenna (similar to that shown in Figure 21, page A-39) and the equipment would be in a concealed enclosure integrated into the southern wall of the building.

At President's Park South, the antenna poles for the sites would mimic the Washington Globe light poles, possibly using slightly larger luminaires to house the small cell antennas, would be positioned symmetrically on an East-West axis, and would be either added between or be installed as a replacement for the existing Washington Globe light poles that ring President's Park South. We also anticipate the site locations to be in the ring of lights to provide optimal capacity to the area and minimize coverage issues posed by the trees just outside the Ellipse. Each antenna pole would have a small adjacent equipment enclosure that could be disguised (e.g., as a bench or trash receptacle).

A conceptual map of the locations for a SASC deployment is shown in Figure 33.

**Figure 33: SASC deployment in Washington Monument Grounds and President’s Park South**



## 6.2.2 DRAN-2 Topology

A conceptual DRAN-2 design for this area would consist of a total of 14 sites, or seven (7) sites each supporting two (2) MNOs. Two (2) sites would be collocated on each of the four stanchions and at the screening facility (total of 10 sites), while the remaining four (4) sites would be sited at President's Park South.

On the stanchions, the sites would be collocated on redesigned stanchions and would utilize shared enclosures. At the screening facility, a stovepipe shroud on the roof would house the antenna (similar to that shown in Figure 21, page A-39) and the equipment would be in a concealed enclosure integrated into the southern wall of the building.

At President's Park South, the antenna poles for the sites, just as explained in detail in Section 6.2.1, would mimic the Washington Globe light poles and would be added in place of or between the existing Washington Globe light poles that ring President's Park South. Each antenna pole would have a medium-sized adjacent equipment enclosure as that could be disguised (e.g., as a bench or trash receptacle).

A conceptual map of the locations for a DRAN-2 deployment is shown in Figure 34.

**Figure 34: DRAN-2 Deployment in Washington Monument Grounds and President's Park South**



### 6.2.3 DRAN-4 Topology

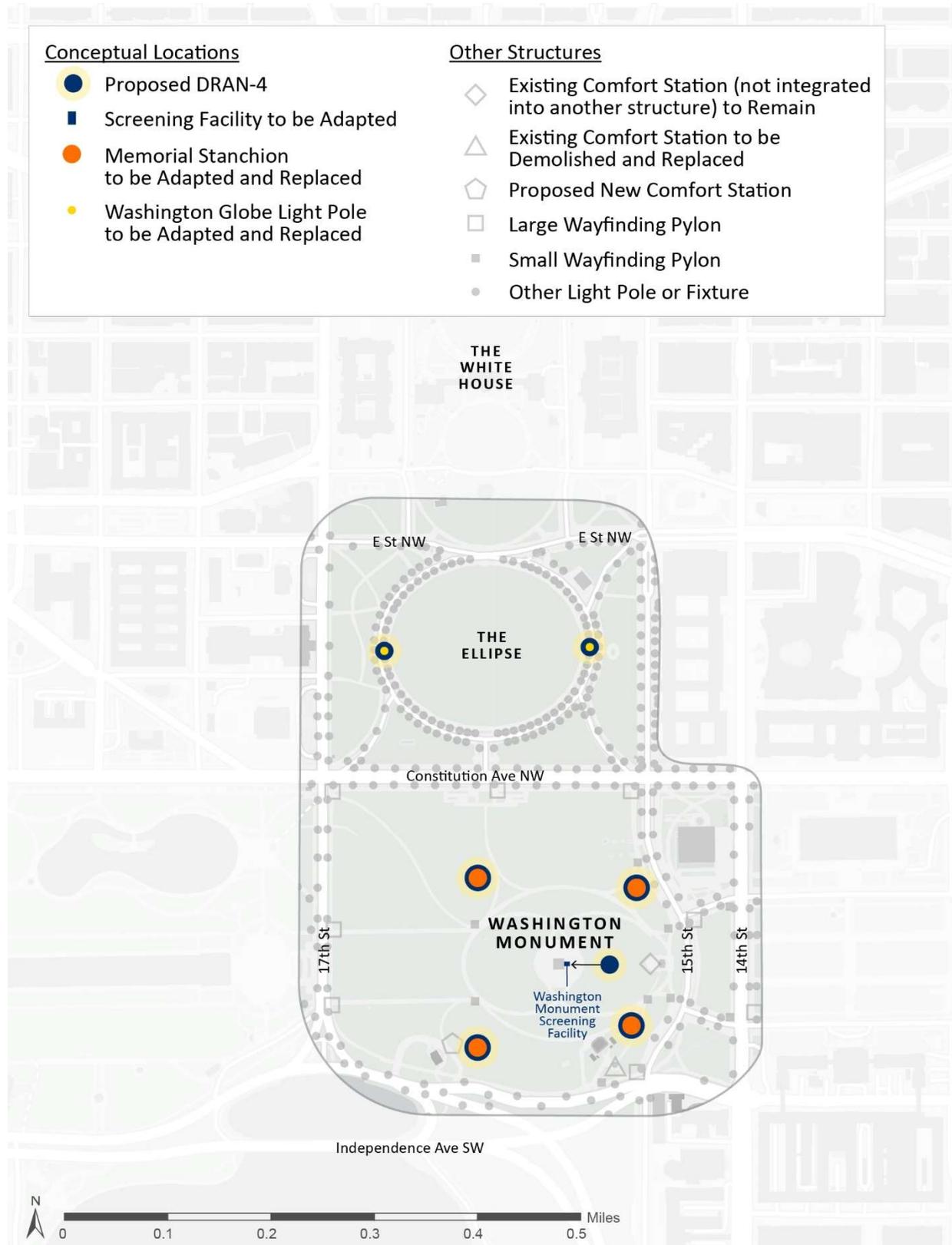
A DRAN-4 design for this area would consist of a total of seven (7) sites, each supporting all four MNOs. One site would be collocated on each of the four stanchions and at the screening facility (total of 5 sites), while the remaining two sites would be sited at the Ellipse.

On the stanchions, the sites would be located on redesigned stanchions and would utilize shared enclosures. At the screening facility, a stovepipe shroud on the roof would house the antenna (similar to that shown in Figure 21, page A-39) and the equipment would be in a concealed enclosure integrated into the southern wall of the building.

At President's Park South, the antenna poles for the sites, just as explained in detail in Section 6.2.1, would mimic the Washington Globe light poles and would be added in place of or between the existing Washington Globe light poles that ring President's Park South. Each antenna pole would have a medium-sized adjacent equipment enclosure that could be disguised (e.g., as a bench or trash receptacle).

A conceptual map of the locations for a DRAN-4 deployment is shown in Figure 35.

**Figure 35: DRAN-4 Deployment in Washington Monument Grounds and President's Park South**



## 6.2.4 Neutral Host Topology

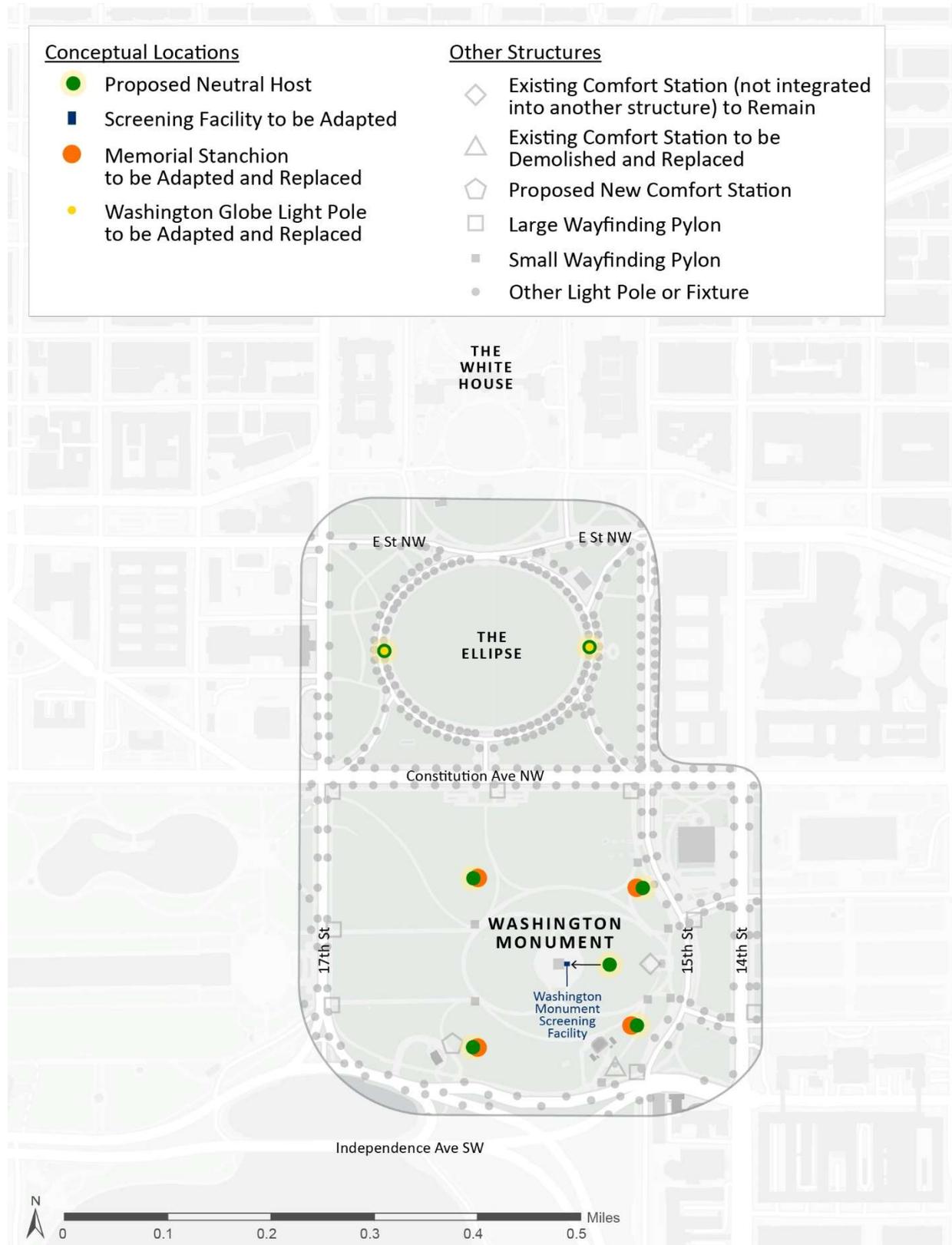
A Neutral Host design for this area would consist of a total of seven (7) sites, each supporting all four MNOs. One site would be collocated on each of the four stanchions and at the screening facility (total of 5 sites), and the remaining two sites would be sited at President's Park South.

On the stanchions, the sites would be located on redesigned stanchions and would utilize shared enclosures. At the screening facility, a stovepipe shroud (smaller than the DRAN-4 shroud) on the roof would house the antenna and the equipment would be in a concealed enclosure integrated into the southern wall of the building .

At President's Park South, the antenna poles for the sites, just as explained in detail in Section 6.2.1, would mimic the Washington Globe light poles and would be added in place of or between the existing Washington Globe light poles that ring President's Park South. Each antenna pole would have a medium-sized adjacent equipment enclosure as that could be disguised (e.g., as a bench or trash receptacle).

A conceptual map of the locations for a Neutral Host deployment is shown in Figure 36.

**Figure 36: Neutral Host Deployment in Washington Monument Grounds and President’s Park South**



### 6.2.5 Washington Monument Grounds and President’s Park South Sub-Area Preferred and Alternative Concepts

The limited features in this area require careful design selections to ensure compatibility with the cultural landscape. The stanchions should be maximized, and the remaining areas for deployment carefully selected. For these reasons, the selected Topologies for this area are hybrid designs utilizing DRAN-4 along with Neutral Host (preferred) or DRAN-2 (alternate). See Table 14 for a summary.

**Table 14: Summary of Criteria by Topology – Washington Monument Grounds and President’s Park South**

Criteria	SASC	DRAN-2	DRAN-4	Neutral Host	Preferred: Hybrid (Neutral Host and DRAN-4)
Minimize impact on cultural resources	Replaces most Washington Globes, including those within the 150-foot view corridor between the White House and Jefferson Memorial; stanchions in view corridor would be minimally altered	Replaces medium number of Washington Globes in President’s Park South, including those within the 150-foot view corridor between the White House and Jefferson Memorial; stanchions in view corridor would be minimally altered	Replaces fewest Washington Globes in President’s Park South that are not on axis with primary view corridor; includes larger cabinet; stanchions in view corridor would be minimally altered	Replaces fewest Washington Globes in President’s Park South that are not on axis with primary view corridor and smaller cabinet; stanchions in view corridor would be minimally altered	Replaces fewest Washington Globes in President’s Park South that are not on axis with primary view corridor smaller cabinet; stanchions in view corridor would be minimally altered
Use non-contributing resources, if possible	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions
Minimize maintenance	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types
Limit number of sites	28	14	7	7	7

**Preferred Concept:** A hybrid concept with the DRAN-4 concept on the stanchions and Neutral Host concept on the screening facility and at President’s Park South is an ideal combination. The seven-site count (four DRAN-4, one Neutral Host at the screening facility, and two Neutral Host at President’s Park South) could be integrated within the existing features, while enclosures could be creatively concealed adjacent to the poles in the most conspicuous areas.

A conceptual map of the locations and illustrative elevation for this hybrid deployment is shown in Figure 37 and Figure 38.

**Figure 37: Preferred Concept for Washington Monument Grounds and President’s Park South**



**Figure 38: Preferred Concept for Washington Monument Grounds and President's Park South – Elevation Diagram of Washington Globe Lighting with Neutral Host Equipment Housing**



*Note: Diagram is for illustrative purposes only*

**Alternative Concept:** A similar hybrid concept with the DRAN-4 concept on the stanchions and screening facility and DRAN-2 concept on President's Park South would also be an effective combination. The nine-site count (five DRAN-4, four DRAN-2 at President's Park South) could be integrated within existing features, while enclosures could be creatively concealed adjacent to the poles in the most conspicuous areas.

A conceptual map of the locations and an illustrative elevation for this hybrid deployment is shown in Figure 39 and Figure 40.

**Figure 39: Alternative Concept for Washington Monument Grounds and President’s Park South**



**Figure 40: Alternative Concept for Washington Monument Grounds and President's Park South –Elevation Diagram of Washington Globe Lighting with DRAN-2 Equipment Housing**



*Note: Diagram is for illustrative purposes only*

**Unfavorable Concepts:** For the stanchions, both the SASC and DRAN-2 concepts would be impractical due to the need for collocated antennas on each stanchion. The DRAN-4 offers a more integrated deployment with only a slight cost of coverage. The Neutral Host solution on the stanchions would have the advantage of a smaller (and easier to integrate) antenna but would lose approximately 40% of the capacity of a small cell Topology.

For the screening center, compatibility with the cultural landscape is paramount. The multiple required antennas for SASC and DRAN-2 make them poor choices.

Finally, at President's Park South, the DRAN-4 concept results in large equipment enclosures that would be exceedingly difficult to effectively blend into the landscape. Each of the other concepts could work on President's Park South due to small enclosures and the anticipation that the added poles would be compatible with the landscape.

### 6.3 West Potomac Park – Lincoln Memorial

The West Potomac Park – Lincoln Memorial is a lightly wooded pedestrian area with numerous visitor attractions, including the Lincoln, Korean War Veterans, Vietnam Veterans, World War II, and 56 Signers of the Declaration of Independence Memorials. While many areas experience dense crowds and therefore require a high-capacity network, other areas are limited by coverage and can utilize lower capacity sites to meet both coverage and capacity targets. The number of trees in this area also make the design challenging as this vegetation limits signal propagation.

Currently, the analysis (confirmed by MNO qualitative feedback) suggests this sub-area is the area most lacking in capacity and coverage within the Project Area (refer to Table 6). The lack of nearby infrastructure to house traditional macro sites, coupled with the area's dense vegetation, makes it a challenging area for network planning.

New sites here should utilize diverse existing features to effectively conceal the poles and equipment while protecting the viewshed. The two primary (eastern) lighting stanchions for the Lincoln Memorial are key features that would need to be utilized. Overall, the use, features, and viewshed diversity of this area requires flexibility in planning; therefore, a hybrid concept is likely to be deployed. While the maps identify Washington Globe or Twin Twenty lights to be adapted or replaced, these could also be potential locations of standalone poles.

Within West Potomac Park - Lincoln Memorial Area are multiple contributing views. These include the primary reciprocal views between the Lincoln Memorial, Washington Monument, and the U.S. Capitol; and views related to the Lincoln Memorial and Constitution Gardens list in Table 2.

#### 6.3.1 SASC Topology

A theoretical SASC design for this area would consist of a total of 40 sites, or ten (10) sites per MNO. Sites (one per MNO) would be located as follows:

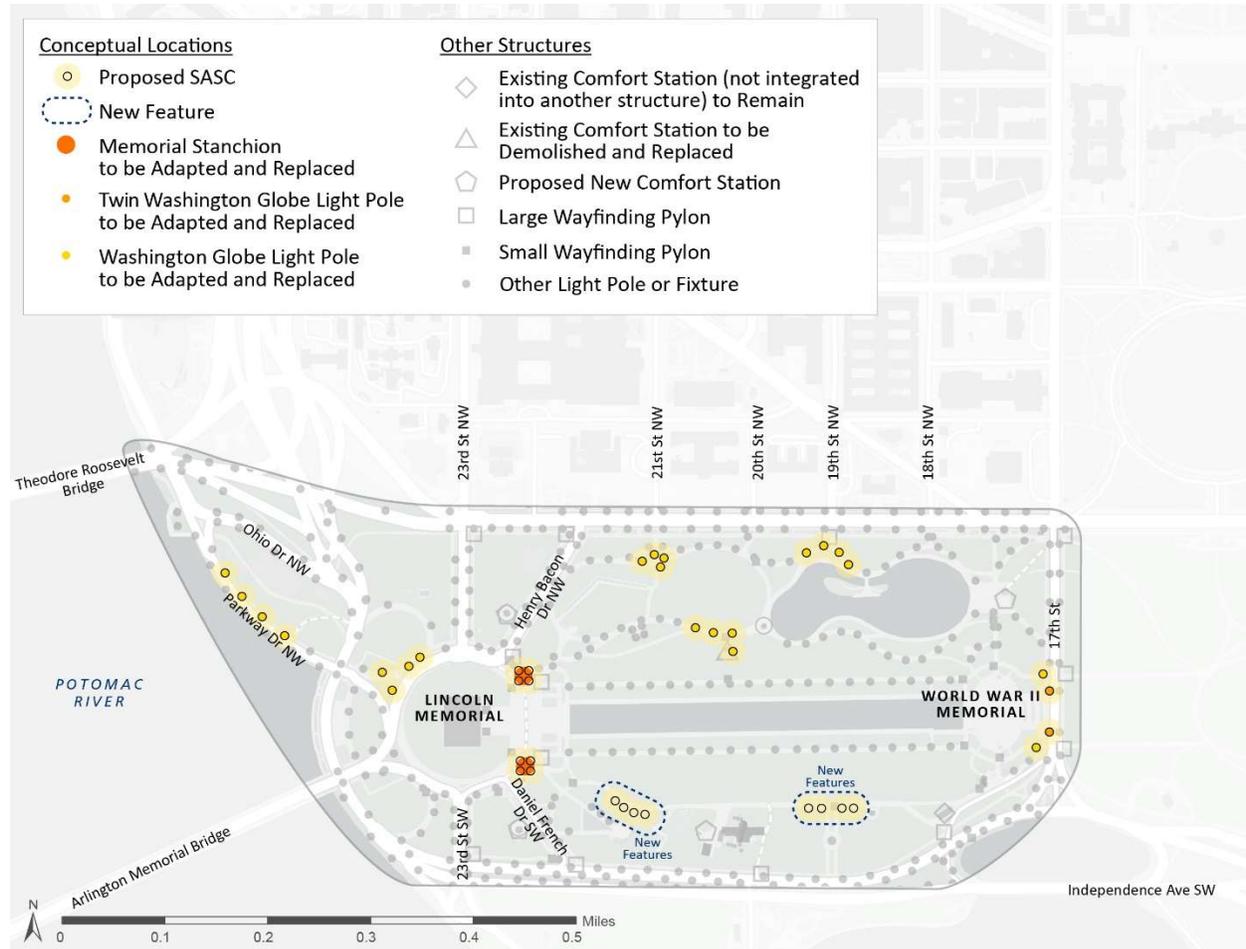
- Collocated on each of the two stanchions (total of eight sites)
- Two locations west of the Lincoln Memorial (total of eight sites)
- Three locations north of the Reflecting Pool (total of 12 sites)
- Two locations south of the Reflecting Pool (total of eight sites)
- One location east of the Reflecting Pool (total of four sites)

On the stanchions, the sites would be collocated on redesigned stanchions and, because the equipment is collocated, would utilize shared enclosures.

At all other locations, the antenna poles for the sites could be added between the existing light poles, replace existing light poles, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have a small adjacent equipment enclosure that could be disguised as a bench or trash receptacle.

A conceptual map of the locations for a SASC deployment is shown in Figure 41.

**Figure 41: SASC Deployment in West Potomac Park – Lincoln Memorial**



### 6.3.2 DRAN-2 Topology

A theoretical DRAN-2 design for this area would consist of a total of 20 sites, or ten (10) sites per MNO. Sites (two at each location, each supporting two MNOs) would be located as follows:

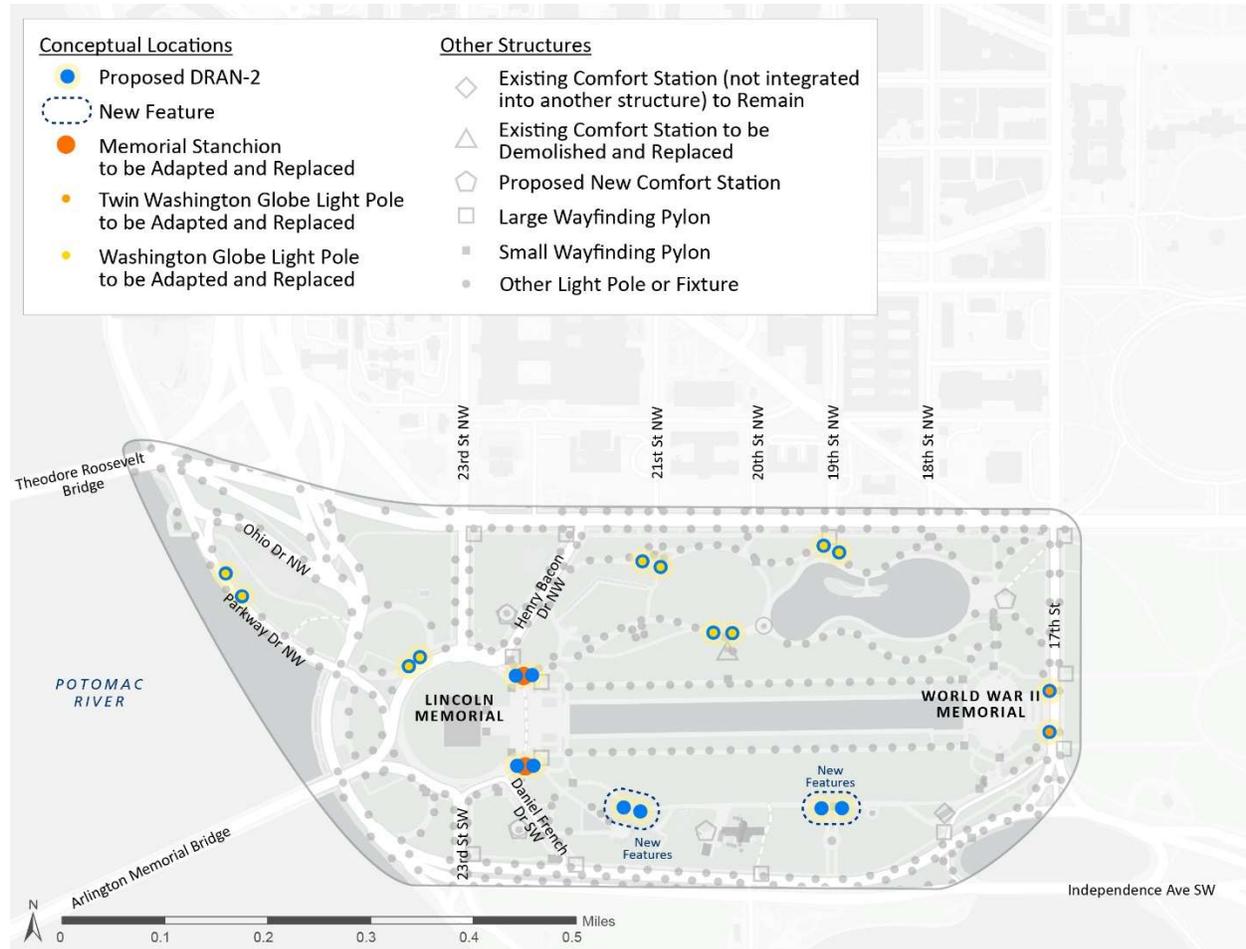
- Collocated on each of the two stanchions (total of four sites)
- Two locations west of the Lincoln Memorial (total of four sites)
- Three locations north of the Reflecting Pool (total of six sites)
- Two locations south of the Reflecting Pool (total of four sites)
- One location east of the Reflecting Pool (total of two sites)

On the stanchions, the sites would be collocated on redesigned stanchions and, because the equipment is collocated, would utilize shared enclosures.

At all other locations, the antenna poles for the sites could be added between the existing light poles, replace existing light poles, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have an adjacent medium-sized equipment enclosure that could be disguised as a large bench or trash receptacle.

A conceptual map of the locations for a DRAN-2 deployment is shown in Figure 42.

**Figure 42: DRAN-2 Deployment in West Potomac Park – Lincoln Memorial**



### 6.3.3 DRAN-4 Topology

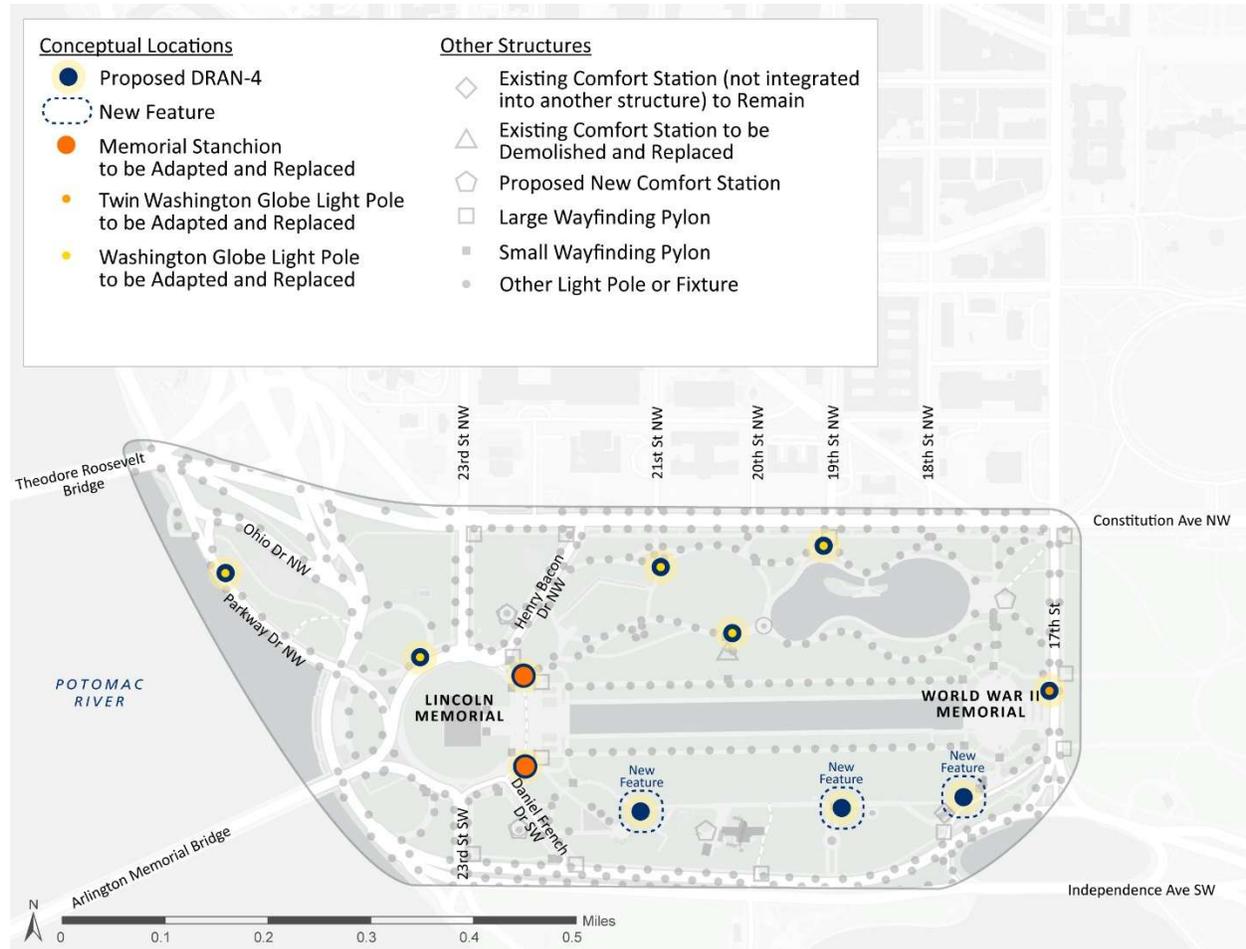
A DRAN-4 design for this area would consist of a total of 11 sites, each supporting all four MNOs. Sites would be located as follows:

- Collocated on each of the two stanchions (total of two sites)
- Two locations west of the Lincoln Memorial (total of two sites)
- Three locations north of the Reflecting Pool (total of three sites)
- Three locations south of the Reflecting Pool (total of three sites)
- One location east of the Reflecting Pool (total of one site)

On the stanchions, the sites would be integrated into redesigned stanchions and utilize the DRAN-4 enclosures. At other locations, the antenna poles for the sites could be added between the existing light poles, replace existing light poles, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have an adjacent large-sized equipment enclosure that would be difficult to disguise.

A conceptual map of the locations for a DRAN-4 deployment is shown in Figure 43.

**Figure 43: DRAN-4 Deployment in West Potomac Park – Lincoln Memorial**



### 6.3.4 Neutral Host Topology

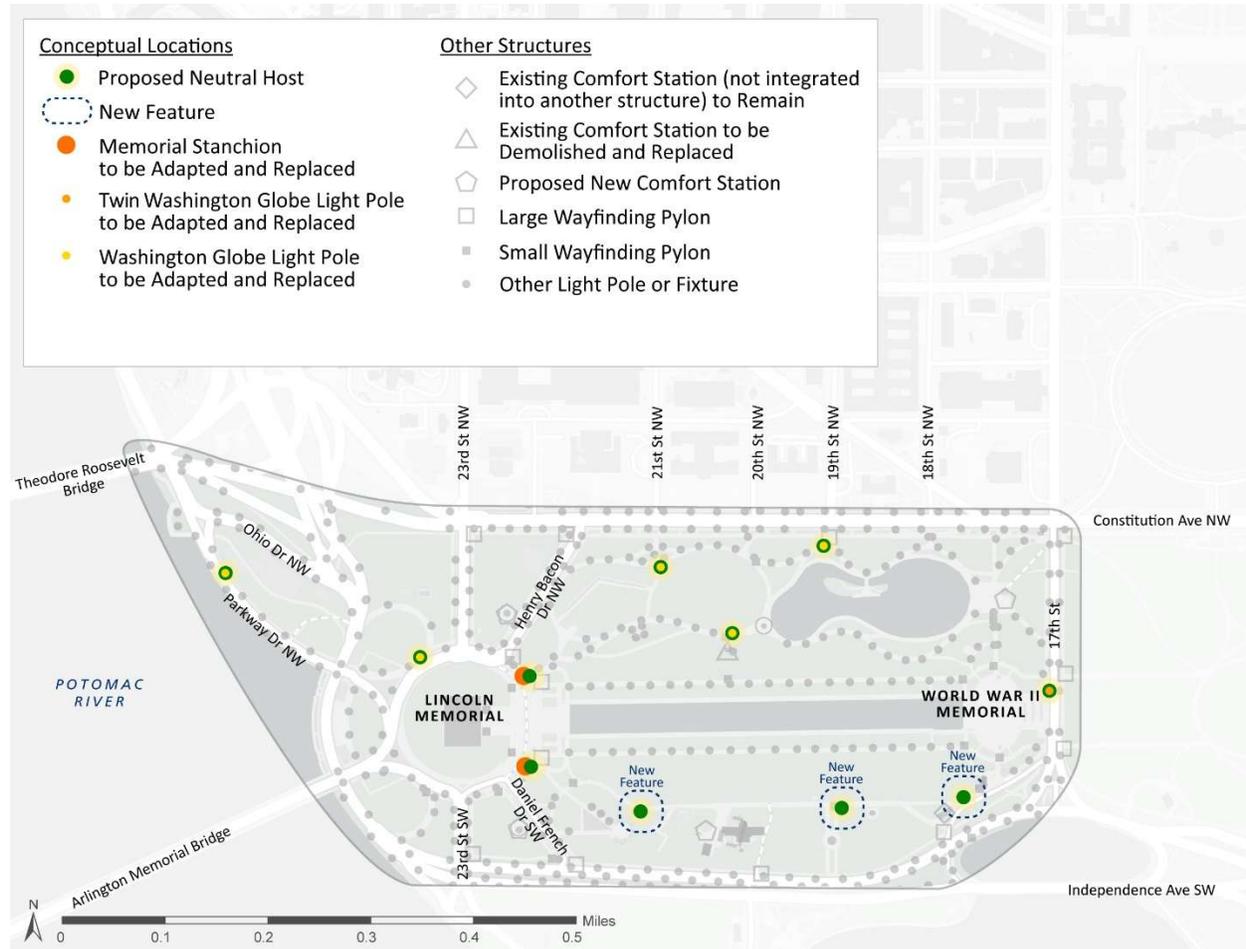
A Neutral Host design for this area would consist of a total of 11 sites, each supporting all four MNOs. Sites would be located as follows:

- Collocated on each of the two stanchions (total of two sites)
- Two locations west of the Lincoln Memorial (total of two sites)
- Three locations north of the Reflecting Pool (total of three sites)
- Three locations south of the Reflecting Pool (total of three sites)
- One location east of the Reflecting Pool (total of one site)

On the stanchions, the sites would be integrated into redesigned stanchions and utilize the Neutral Host enclosures. At other locations, the antenna poles for the sites could be added between the existing light poles, replace existing light poles, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have an adjacent medium-sized equipment enclosure that could be disguised as a large bench or trash receptacle.

A conceptual map of the locations for a Neutral Host deployment is shown in Figure 44.

**Figure 44: Neutral Host Deployment in West Potomac Park – Lincoln Memorial**



### 6.3.5 West Potomac Park – Lincoln Memorial Area Sub-Area Preferred and Alternative Concepts

The nature of this area requires a mixed design selection to best fit the network concept into the cultural landscape. The stanchions at the Lincoln Memorial should be maximized and the remaining sites should be carefully selected. As a result, the preferred topology for this area is a hybrid design utilizing DRAN-4, and potentially Neutral Host or DRAN-2. See Table 15 for a summary.

**Table 15: Summary of Criteria by Topology – West Potomac Park – Lincoln Memorial**

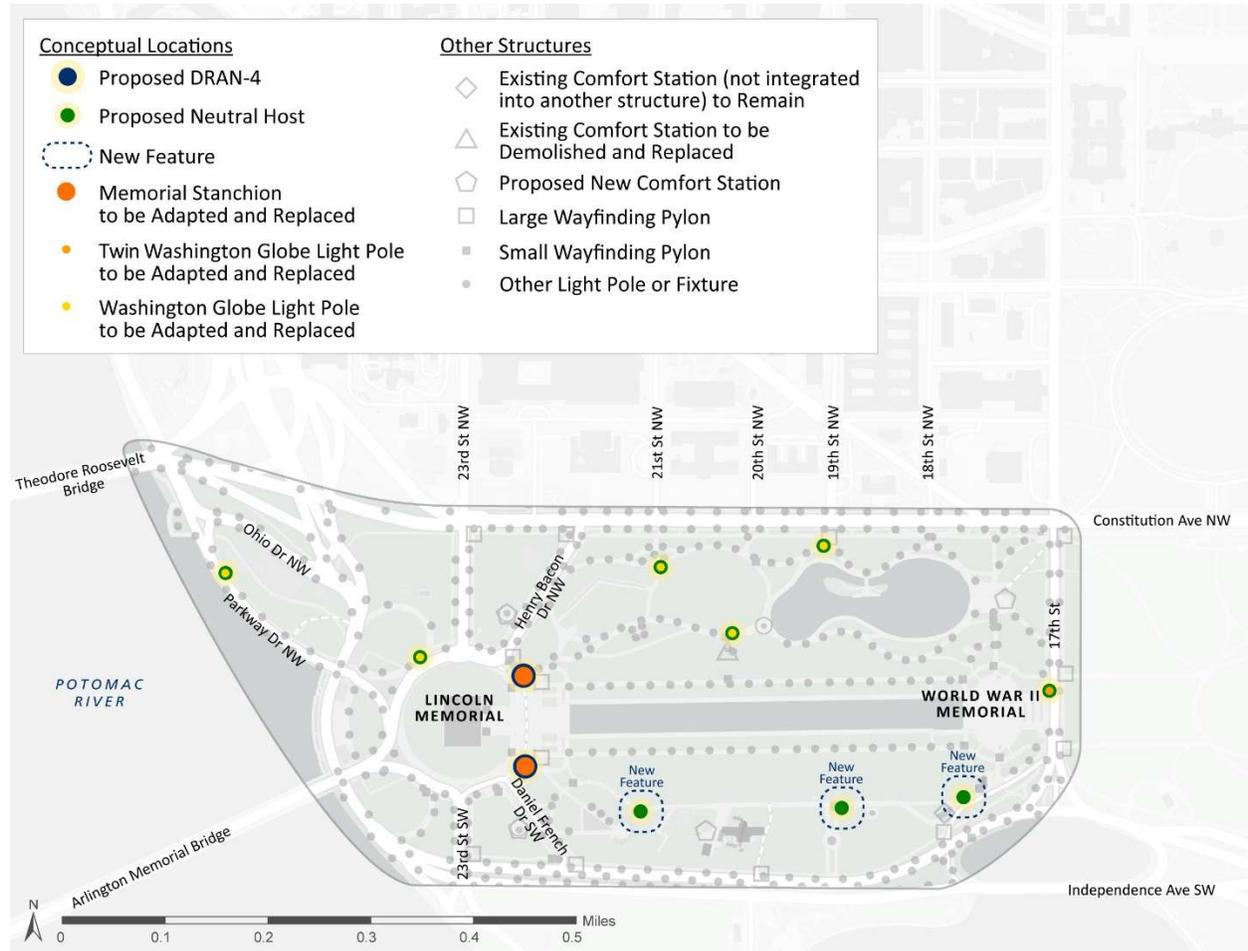
Criteria	SASC	DRAN-2	DRAN-4	Neutral Host	Preferred: Hybrid (Neutral Host and DRAN-4)
Minimize impact on cultural resources	Replaces most Washington Globes and 2 Twin Twenties, including in reciprocal views; stanchions would be minimally altered; new features along Ash Woods Drive would avoid contributing views	Replaces medium number of Washington Globes and 2 Twin Twenties, including in reciprocal views; stanchions would be minimally altered; new features along Ash Woods Drive would avoid contributing views	Replaces fewest Washington Globes and 1 Twin Twenty, including one in including in reciprocal views; stanchions would be minimally altered; new features along Ash Woods Drive would avoid contributing views	Replaces fewest Washington Globes and 1 Twin Twenty, including one in including in reciprocal views; stanchions would be minimally altered; new features along Ash Woods Drive would avoid contributing views	Replaces fewest Washington Globes and 1 Twin Twenty, including one in including in reciprocal views; stanchions would be minimally altered; new features along Ash Woods Drive would avoid contributing views
Use non-contributing resources, if possible	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions
Minimize maintenance	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types
Limit number of sites	40	20	11	11	11

**Preferred Concept:** A hybrid concept with the DRAN-4 topology on the memorial stanchions and the Neutral Host topology elsewhere would be an ideal combination. The eleven-site count (two DRAN-4, nine Neutral Host) could be integrated within the existing features and the enclosures could be creatively concealed adjacent to the poles in the most conspicuous areas.

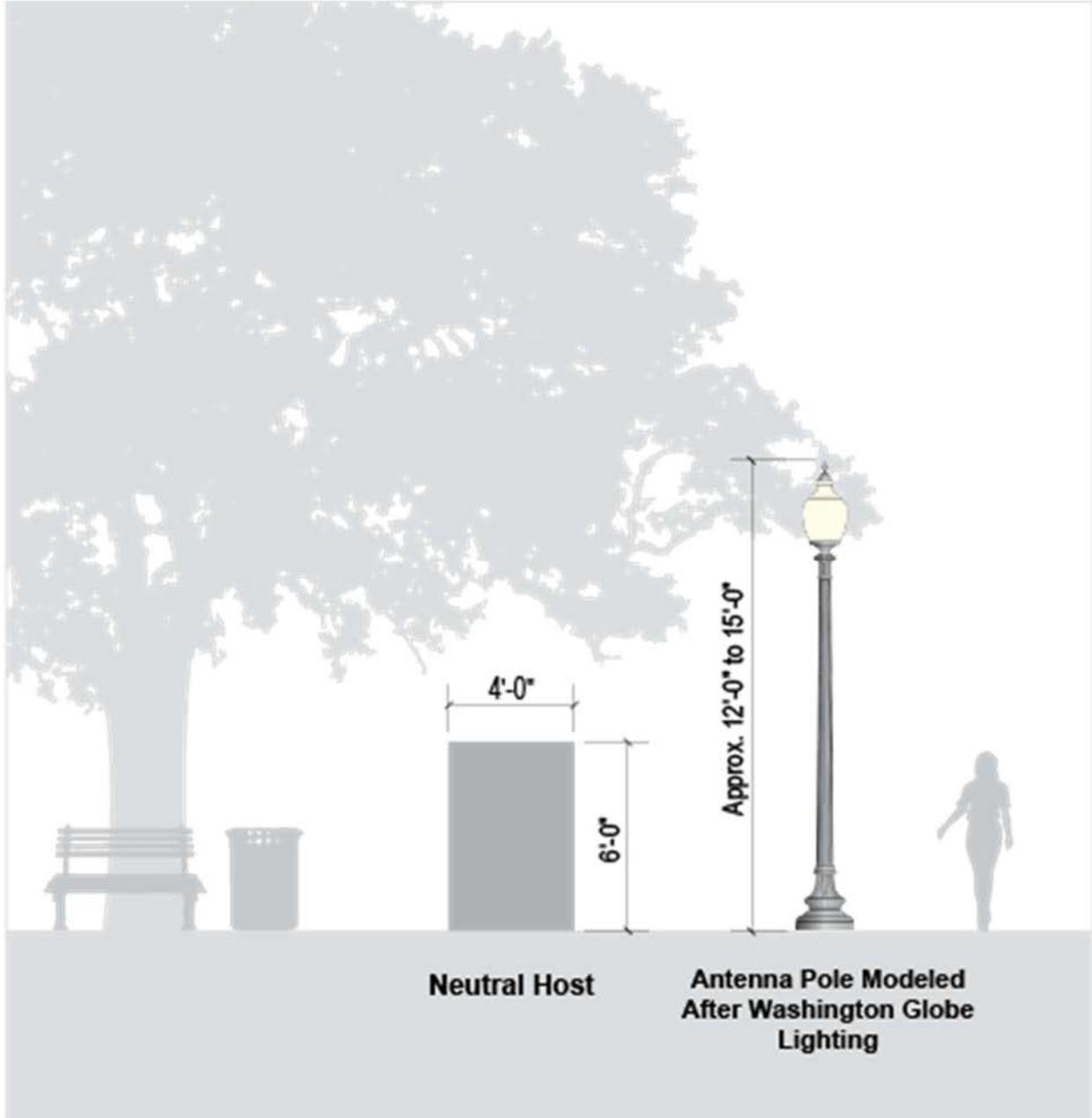
The primary advantage of this concept is the ability to target the highest capacity sites near the more densely crowded spaces just east of the Lincoln Memorial and utilize Neutral Host sites for more coverage limited areas.

A conceptual map of the locations and an illustrative elevation for this hybrid deployment is shown in Figure 45, Figure 46, and Figure 47.

**Figure 45: Preferred Concept for West Potomac Park – Lincoln Memorial**

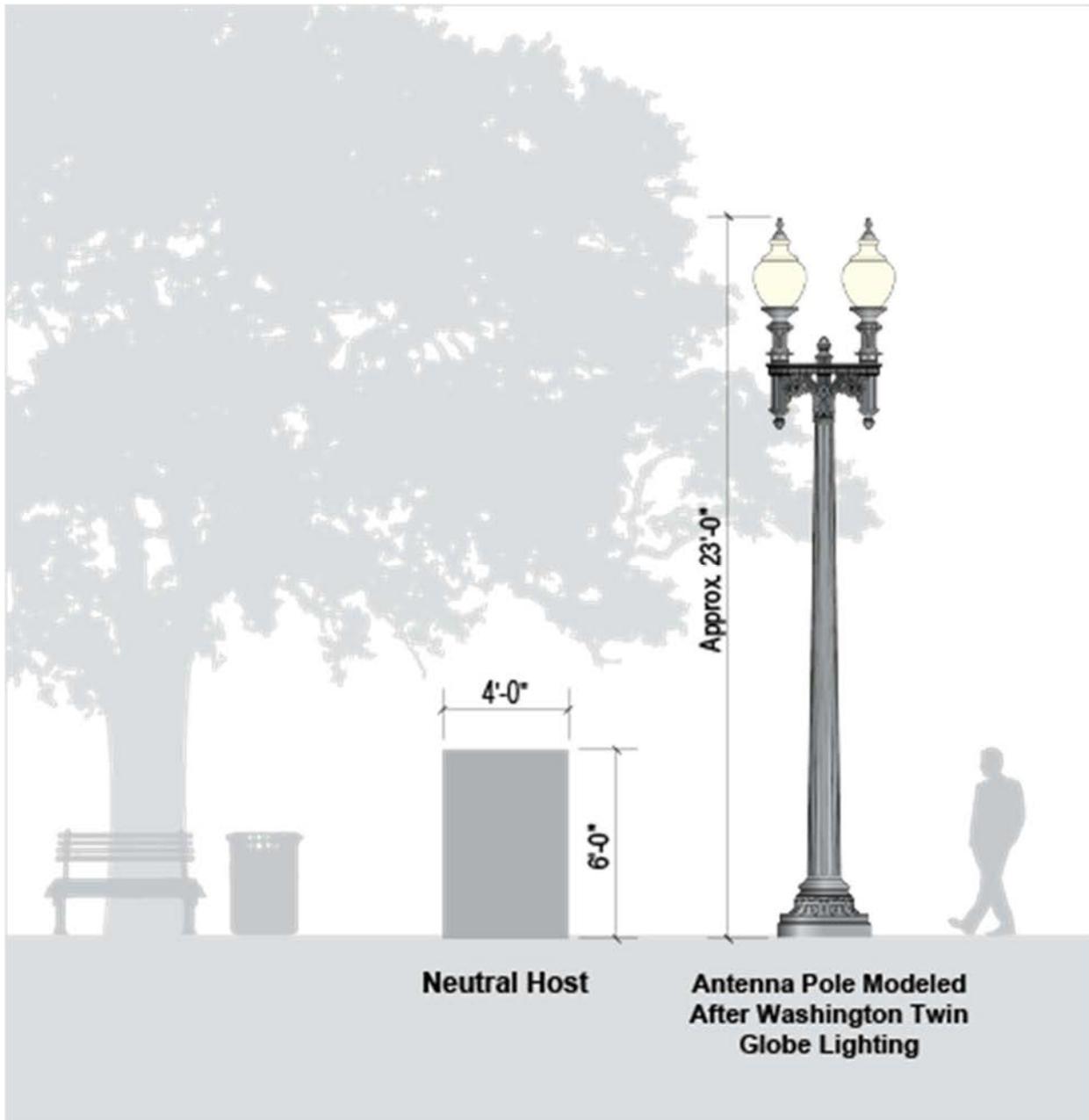


**Figure 46: Preferred Concept for West Potomac Park – Lincoln Memorial –Elevation Diagram of Washington Globe Lighting with Neutral Host Equipment Housing**



*Note: Diagram is for illustrative purposes only*

**Figure 47: Preferred Concept for West Potomac Park – Lincoln Memorial – Elevation Diagram of Washington Twin Globe Lighting with Neutral Host Equipment Housing**



*Note: Diagram is for illustrative purposes only*

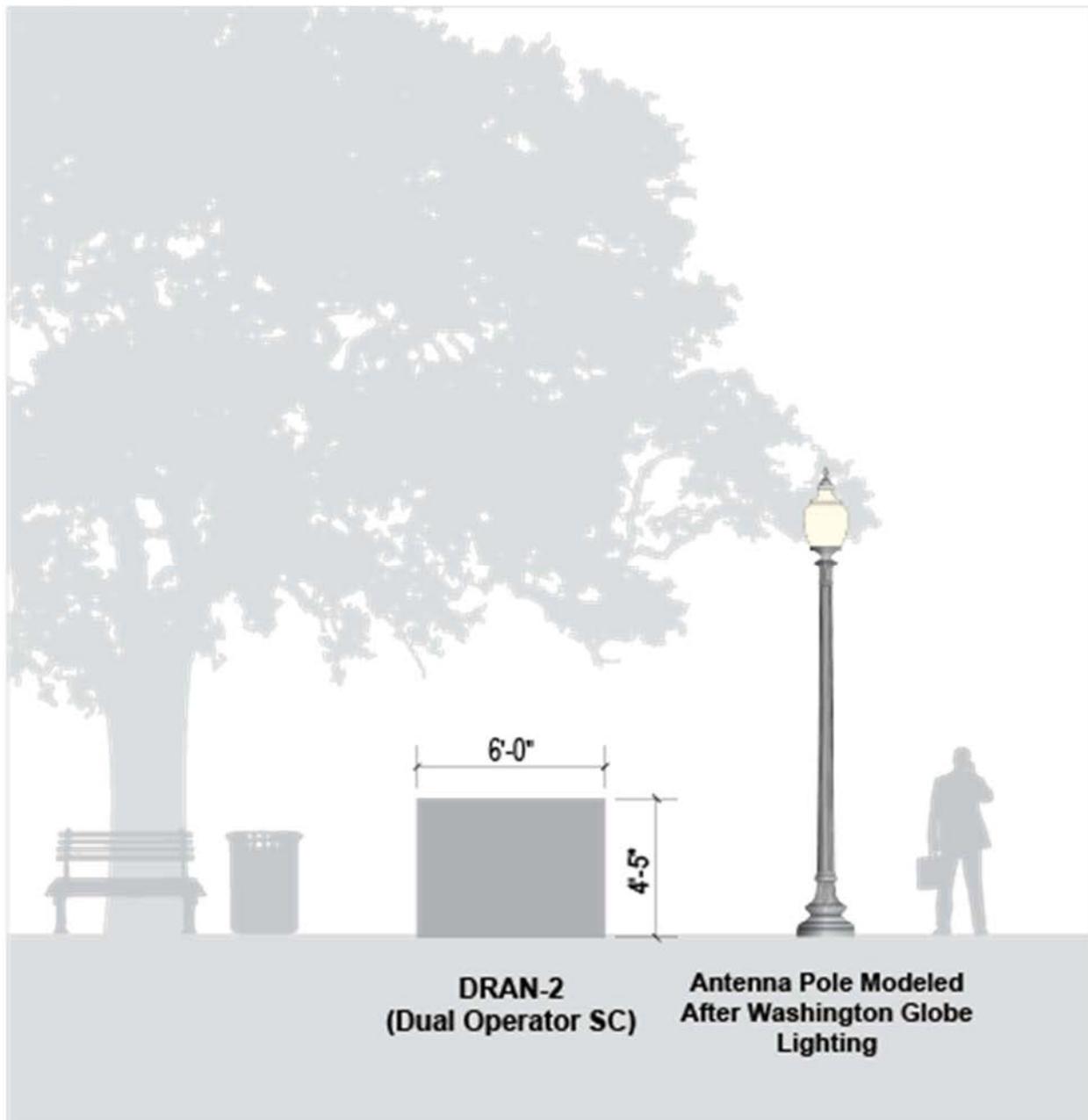
**Alternative Concept:** An alternative hybrid concept pairs the DRAN-4 and the DRAN-2 concepts. The fifteen-site count (seven DRAN-4, eight DRAN-2) could be integrated within the existing features, while the enclosures could be creatively concealed adjacent to the poles. DRAN-4 sites would be placed on the stanchions and at the sites to the west of the Lincoln Memorial and south of the Reflecting Pool. The remaining sites – one pair east of the Reflecting Pool and three pairs north of the Reflecting Pool – would be DRAN-2.

This concept enhances capacity within the area versus the preferred concept, but with some additional impact to the viewshed. A conceptual map of the locations and an illustrative elevation for this hybrid deployment is shown in Figure 48 and Figure 49.

**Figure 48: Alternative Concept for West Potomac Park – Lincoln Memorial**



**Figure 49: Alternative Concept for West Potomac Park – Lincoln Memorial – Elevation Diagram of Washington Globe Lighting with DRAN-2 Equipment Housing**



*Note: Diagram is for illustrative purposes only*

**Unfavorable Concepts:** For the stanchions, both the SASC and DRAN-2 concepts would be impractical due to the need for collocated antennas on each stanchion. The DRAN-4 offers a more integrated deployment with only a slight cost of coverage. The Neutral Host solution on the stanchions would have the advantage of a smaller (and easier to integrate) antenna but would lose approximately 40% of the capacity of a small cell Topology and would therefore be a poor selection.

For more frequently traveled and open areas, the DRAN-4 concept results in large equipment enclosures which will be exceedingly difficult to effectively blend into the landscape. Each of the other concepts could work in these types of areas due to small enclosures and the anticipation that the added features will integrate well into the viewshed.

## 6.4 West Potomac Park – Tidal Basin

The West Potomac Park – Tidal Basin sub-area is comprised of southern West Potomac Park, including the Tidal Basin, the Thomas Jefferson Memorial, and various athletic fields. It also includes other prominent memorials including those honoring Franklin Delano Roosevelt, George Mason, and Martin Luther King, Jr.

Like the area surrounding the Lincoln Memorial and Reflecting Pool, this area has sections that draw dense crowds and other sections where crowds are more transitory. Due to these crowd types a hybrid solution is favored, combining (1) high-capacity sites for the crowded areas surrounding the Lincoln Memorial and (2) more coverage-oriented sites for the rest of the sub-area. The considerable number of trees in this sub-area also makes the design challenging. While the maps identify Washington Globe lights to be adapted or replaced, these could also be potential locations for standalone poles.

The West Potomac Park – Tidal Basin Area contains multiple vistas, including the reciprocal views to the Lincoln Memorial, White House, and Thomas Jefferson Memorial, reciprocal views between memorials around the Tidal Basin, and seasonal views from locations along the Tidal Basin path.

### 6.4.1 SASC Topology

A theoretical SASC design for this area would consist of a total of 40 sites, with each MNO supported at a total of 10 sites each. Sites would be located as follows:

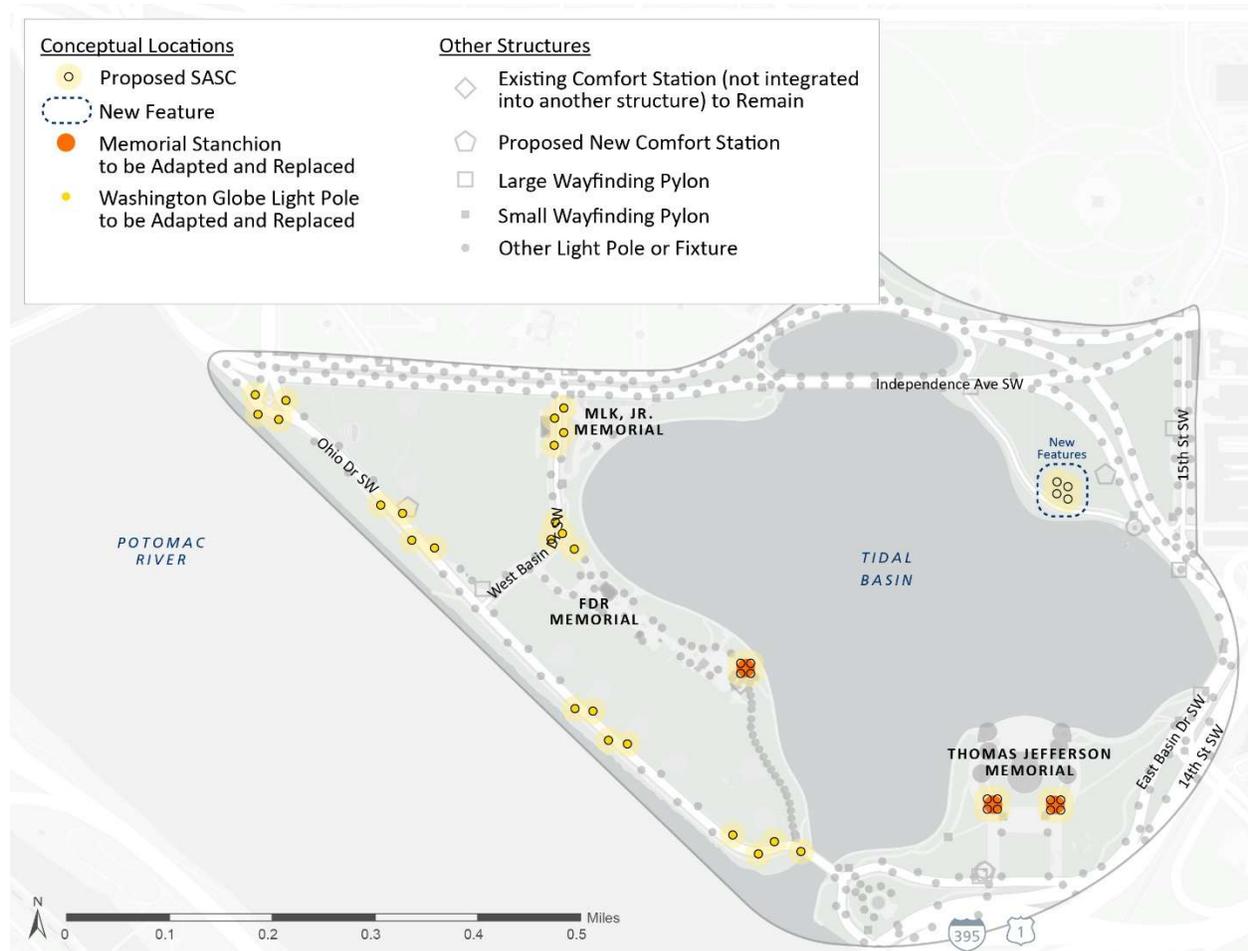
- All MNOs collocated on each of three stanchions (two at the Jefferson Memorial, one at the FDR Memorial; total of 12 sites)
- Six sites west of the Tidal Basin (total of 24 sites)
- One site east of the Tidal Basin (total of 4 sites)

On the stanchions, the sites would be collocated on redesigned stanchions and, because the equipment is collocated, would utilize shared enclosures.

At all other locations, the antenna poles for the sites could be added between the existing light poles, replace existing light poles, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have a small adjacent equipment enclosure that could be disguised as a bench or trash receptacle.

A conceptual map of the locations for a SASC deployment is shown in Figure 50.

**Figure 50: SASC Deployment in West Potomac Park – Tidal Basin**



### 6.4.2 DRAN-2 Topology

A theoretical DRAN-2 design for this area would consist of a total of 22 sites, or eleven (11) sites per MNO. Sites (two at each location, each supporting two MNOs) would be located as follows:

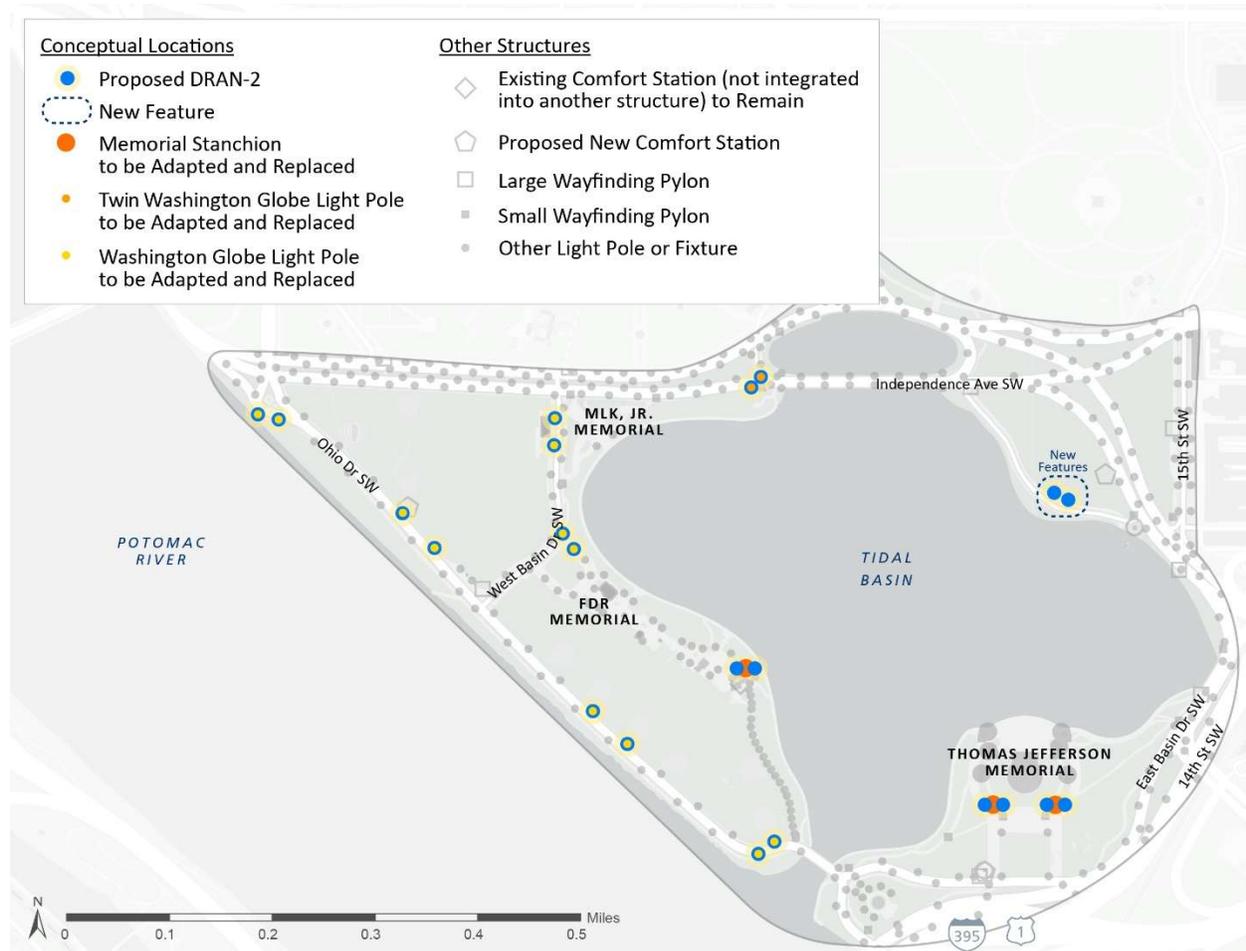
- Collocated on each of the three stanchions (two at the Jefferson and one at the FDR Memorials; total of six sites)
- Seven locations west of the Tidal Basin (total of 14 sites)
- One location east of the Tidal Basin (total of two sites)

On the stanchions, the sites would be collocated on redesigned stanchions and, because the equipment is collocated, would utilize shared enclosures.

At all other locations, the antenna poles for the sites could be added between the existing light poles, replace existing light poles, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have an adjacent medium-sized equipment enclosure that could be disguised as a large bench or trash receptacle.

A conceptual map of the locations for a DRAN-2 deployment is shown in Figure 51.

**Figure 51: DRAN-2 Deployment in West Potomac Park – Tidal Basin**



### 6.4.3 DRAN-4 Topology

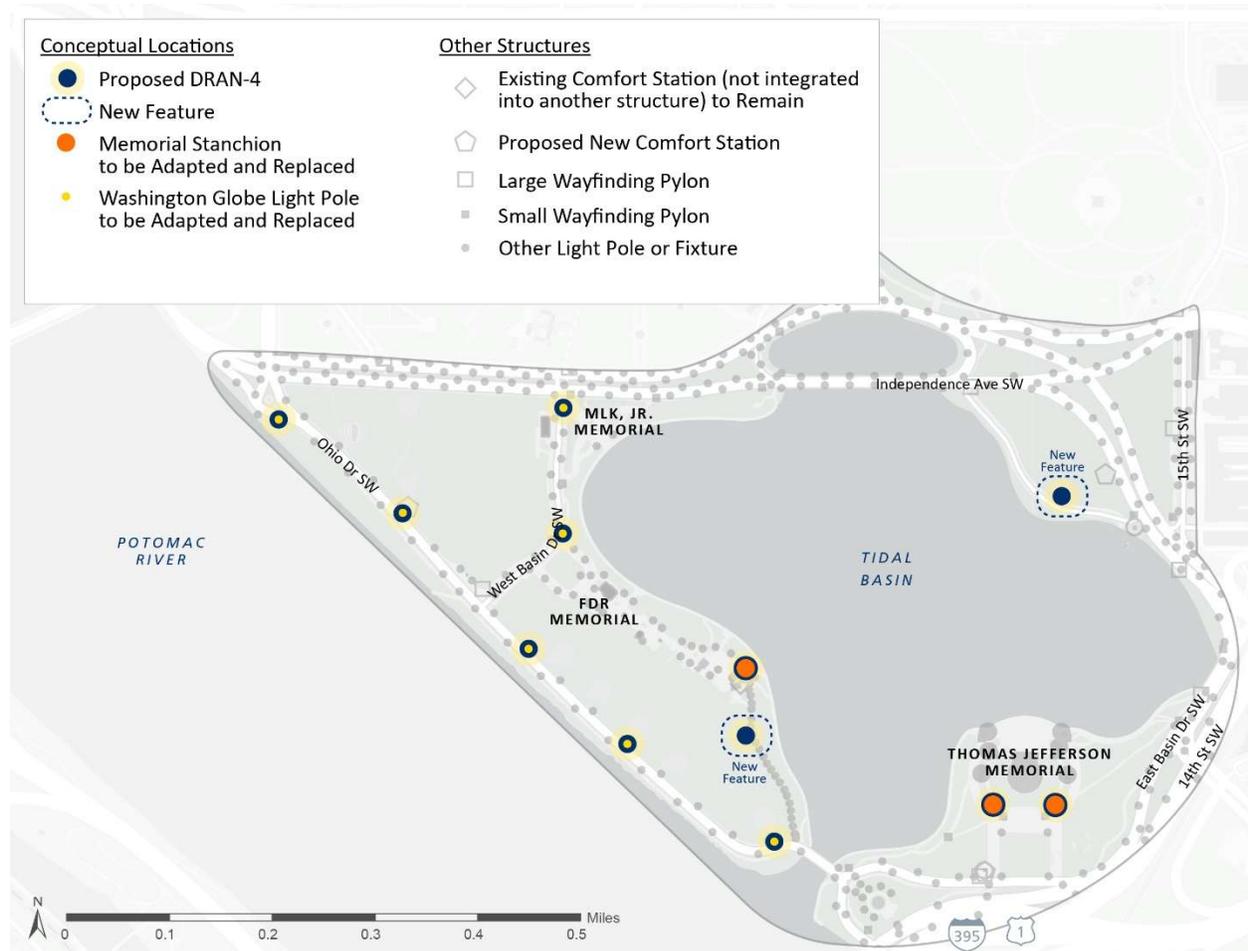
A DRAN-4 design for this area would consist of a total of 12 sites, each supporting all four MNOs. Sites would be located as follows:

- Collocated on each of the three stanchions (two at the Jefferson and one at the FDR Memorials; total of 3 sites)
- Eight locations west of the Tidal Basin (total of eight sites)
- One location east of the Tidal Basin (total of one site)

On the stanchions, the sites would be integrated into redesigned stanchions and utilize the DRAN-4 enclosures. At all other locations, the antenna poles for the sites could be added between the existing light poles, replace existing light poles, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have an adjacent large-sized equipment enclosure that would be difficult to disguise.

A conceptual map of the locations for a DRAN-4 deployment is shown in Figure 52.

**Figure 52: DRAN-4 Deployment in West Potomac Park – Tidal Basin**



### 6.4.4 Neutral Host Topology

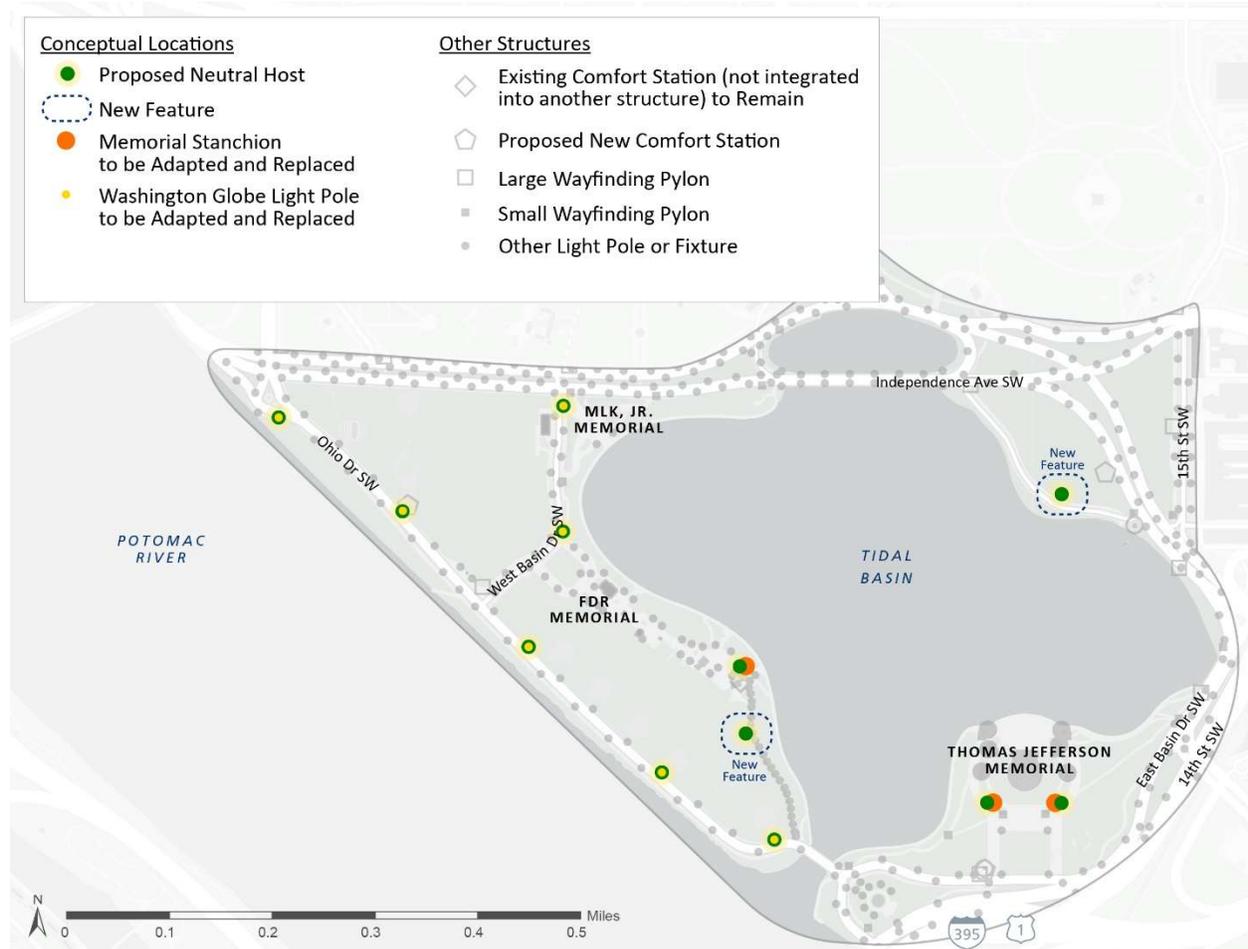
A Neutral Host design for this area would consist of a total of 12 sites, each supporting all four MNOs. Sites would be located as follows:

- Collocated on each of the three stanchions (two at the Jefferson and one at the FDR Memorials; total of 3 sites)
- Eight locations west of the Tidal Basin (total of eight sites)
- One location east of the Tidal Basin (total of one site)

On the stanchions, the sites would be integrated into redesigned stanchions and utilize the Neutral Host enclosures. At all other locations, the antenna poles for the sites could be added between the existing light poles, replace or enhance wayfinding pylons, or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have an adjacent medium-sized equipment enclosure that could be disguised as a large bench or trash receptacle.

A conceptual map of the locations for a Neutral Host deployment is shown in Figure 53.

**Figure 53: Neutral Host Deployment in West Potomac Park – Tidal Basin**



### 6.4.5 West Potomac Park Sub-Area Preferred and Alternative Concepts

A mixed design would best fit the network concept to complement the cultural landscape. The stanchions at the Jefferson Memorial and FDR Memorial should be maximized and the remaining sites should be carefully selected. For these reasons, the preferred topology for this area is a hybrid design utilizing DRAN-4, and potentially Neutral Host or DRAN-2. See summary in Table 16.

**Table 16: Summary of Criteria by Topology – West Potomac Park – Tidal Basin**

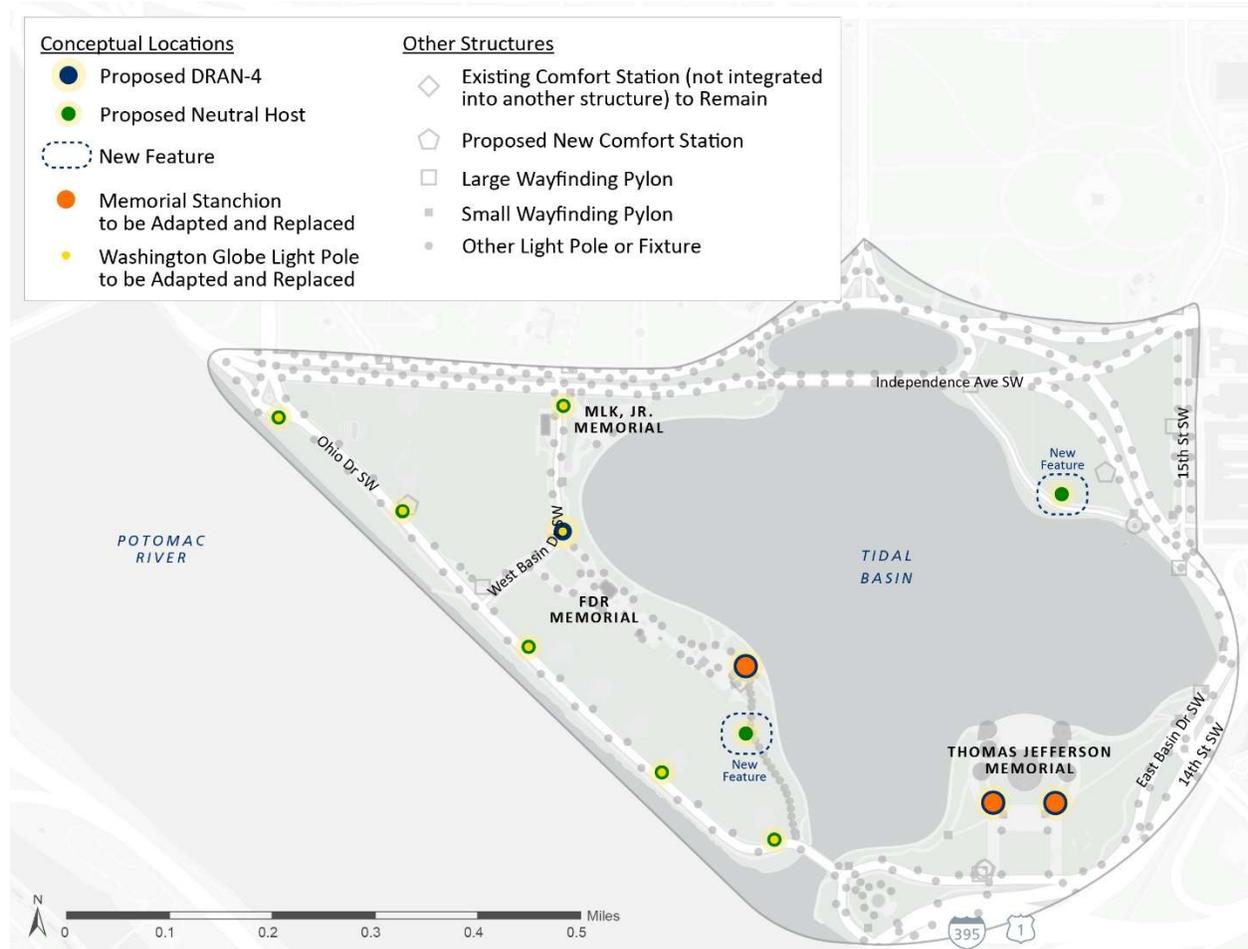
Criteria	SASC	DRAN-2	DRAN-4	Neutral Host	Preferred: Hybrid of Neutral Host and DRAN-4
Minimize impact on cultural resources	Inserts most new, taller Washington Globes; stanchions would be minimally altered; new features would be placed near Tidal Basin path	Inserts middle number of new, taller Washington Globes; stanchions would be minimally altered; new features would be placed near Tidal Basin path	Inserts fewest taller Washington Globes; stanchions would be minimally altered; new features would be placed near Tidal Basin path	Inserts fewest taller Washington Globes; stanchions would be minimally altered; new features would be placed near Tidal Basin path	Inserts fewest taller Washington Globes; stanchions would be minimally altered; new features would be placed near Tidal Basin path
Use non-contributing resources, if possible	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions	Could use stand-alone poles, if desired; uses light stanchions
Minimize maintenance	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types
Limit number of sites	40	22	12	12	12

**Preferred Concept:** A hybrid concept is an ideal combination and would have four DRAN-4 sites – two on the Jefferson Memorial stanchions, one on the south end stanchion of the FDR Memorial, and one just north of the FDR Memorial – plus eight Neutral Host sites. The twelve-site count design can be integrated within the existing features, while the enclosures can be creatively concealed adjacent to the poles in the most conspicuous areas.

The primary advantage of this concept is focusing on the highest capacity sites near the more densely crowded spaces near the Jefferson and FDR Memorials and utilizing Neutral Host sites for more coverage limited areas.

A conceptual map of the locations and an illustrative elevation for this hybrid deployment is shown in Figure 54 and Figure 55.

**Figure 54: Preferred Concept for West Potomac Park – Tidal Basin**



**Figure 55: Preferred Concept for West Potomac Park – Tidal Basin –Elevation Diagram of Washington Globe Lighting with Neutral Host Equipment Housing**

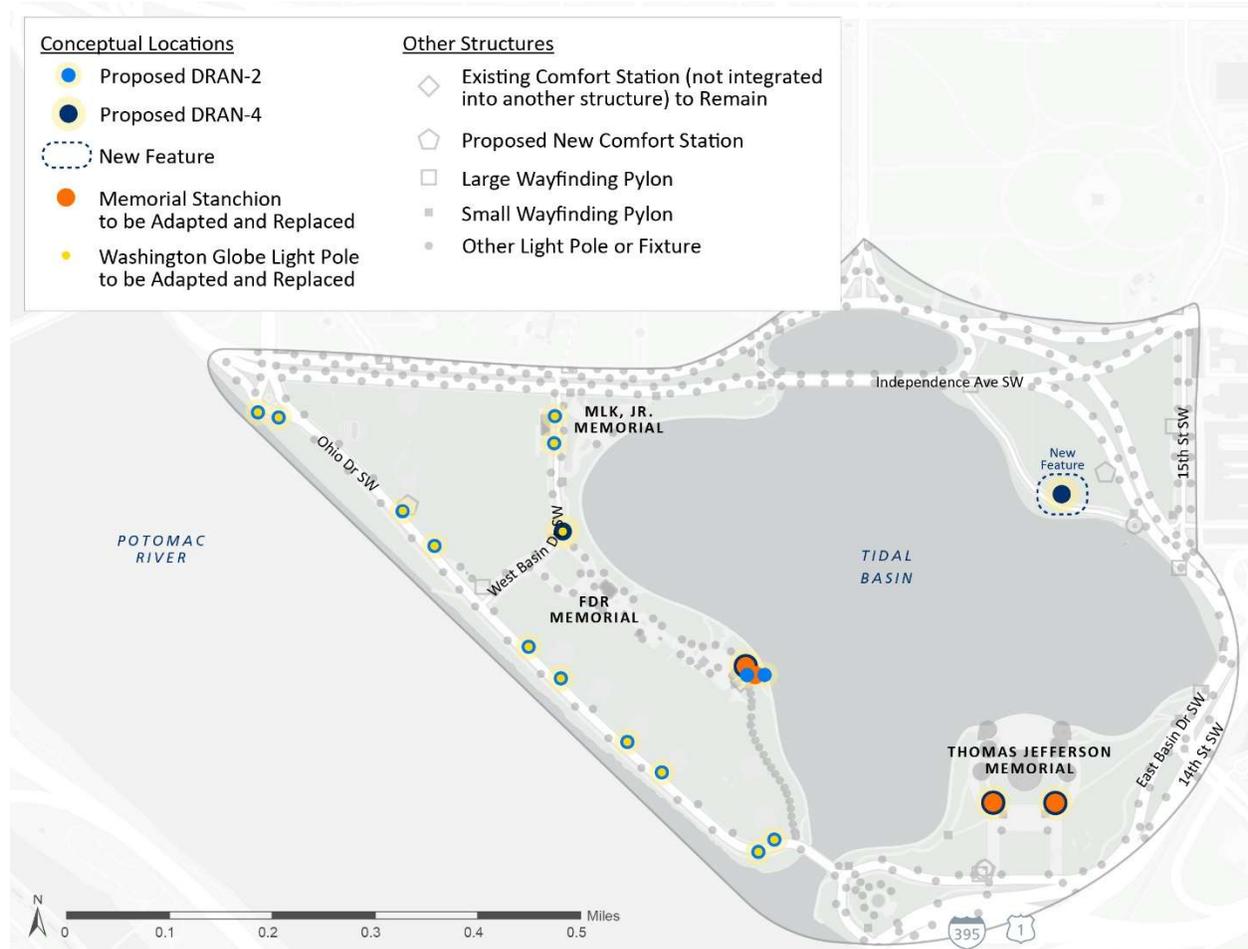


*Note: Diagram is for illustrative purposes only*

**Alternative Concept:** An alternative hybrid concept pairs the DRAN-4 and the DRAN-2 concepts. The 18-site count (four DRAN-4, 14 DRAN-2) can be integrated within the existing features, while the enclosures can be creatively concealed adjacent to the poles in the most conspicuous areas. DRAN-4 sites would be placed on the three stanchions – two on the Jefferson Memorial stanchions, one on the south end stanchion of the FDR memorial – and one just north of the FDR Memorial. The remaining sites – all in West Potomac Park – would be DRAN-2.

This concept enhances capacity within the area versus the preferred concept, but with some additional impact to the viewshed. A conceptual map of the locations and an illustrative elevation for this hybrid deployment is shown in Figure 56 and Figure 63.

**Figure 56: Alternative Concept for West Potomac Park – Tidal Basin**



**Figure 57: Alternative Concept for West Potomac Park – Tidal Basin – Elevation Diagram of Washington Globe Lighting with DRAN-2 Equipment Housing**



**Unfavorable Concepts:** For the stanchions, both the SASC and DRAN-2 concepts would be impractical due to the need for collocated antennas on each stanchion. The DRAN-4 offers a more integrated deployment with only a slight cost of coverage. The Neutral Host solution on the stanchions would have the advantage of a smaller (and easier to integrate) antenna but would lose approximately 40% of the capacity of a small cell Topology and would therefore be a poor selection.

For the more crowded and visually open areas, the DRAN-4 concept includes large equipment enclosures which will be exceedingly difficult to effectively blend into the landscape. Each of the other concepts could work in these types of areas due to small enclosures and the anticipation that the added features will integrate well into the viewshed.

## 6.5 East Potomac Park

The East Potomac Park area houses the NPS and U.S. Park Police offices, the tennis center, and the East Potomac Golf Links among other things. This area is heterogenous and could be served in several ways, though the trees in this area make designs more challenging.

Currently, the MNOs serve this area with traditional macro sites in adjacent areas leading to spotty coverage and poor capacity. The focus in this area is to create a dominant signal across the sub-area to maintain a strong, reliable, high-capacity mobile phone service. Each of the topologies can meet this requirement, therefore the ultimate choice in concept focuses on integrating the concept into the historical landscape of the sub-area.

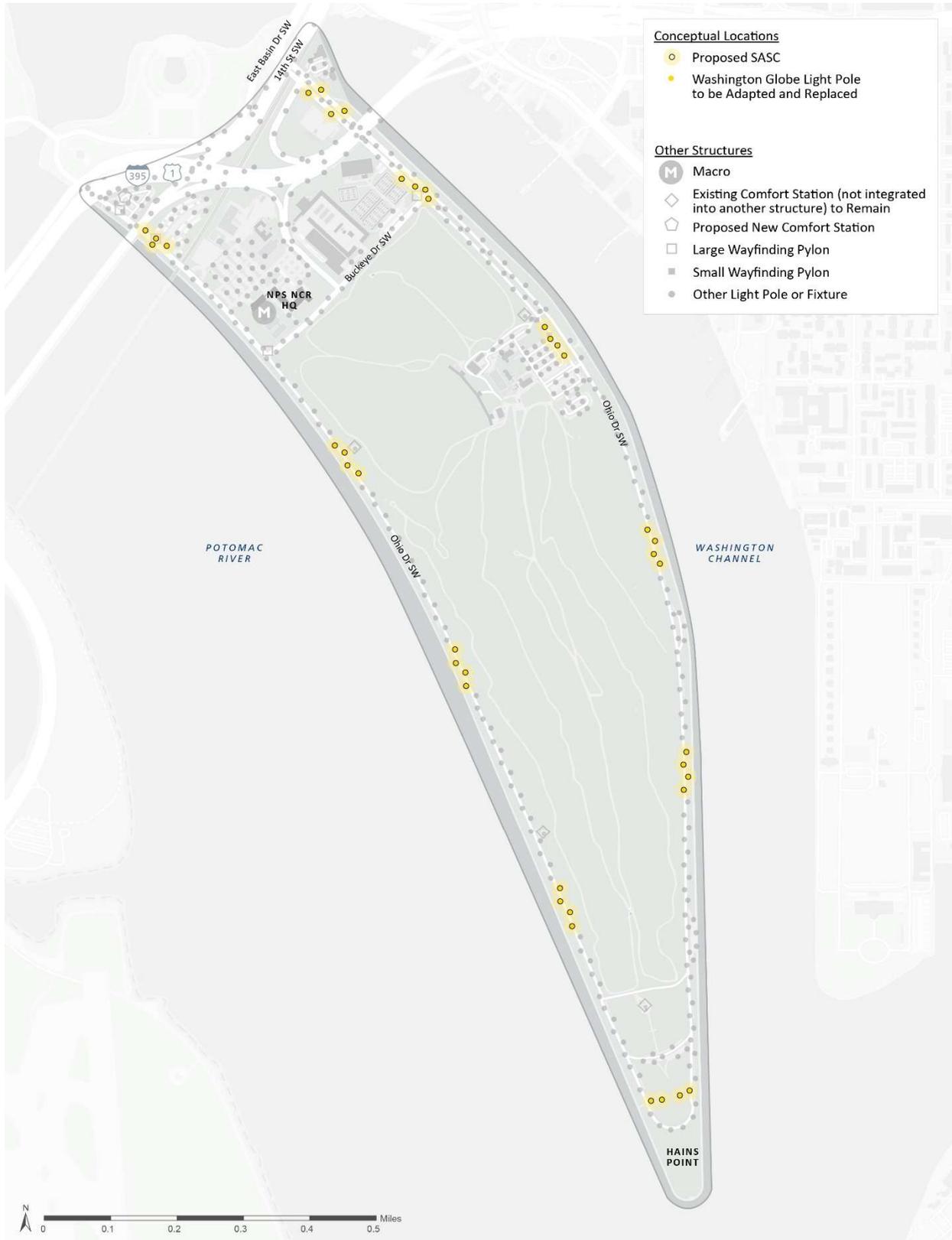
### 6.5.1 SASC Topology

A SASC design for this area would consist of a total of 40 sites, or ten sites per MNO. The sites (each housing one MNO) would be located around the perimeter of the sub-area.

The antenna poles for the sites could be added between, or in place of, the existing light poles or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have a small adjacent equipment enclosure that could be disguised as a bench or trash receptacle.

A conceptual map of the locations for a SASC deployment is shown in Figure 58.

Figure 58: SASC Deployment in East Potomac Park



## 6.5.2 DRAN-2 Topology

A DRAN-2 design for this area would consist of a total of 20 sites, or ten sites per MNO. Sites (two MNOs per site) would be located around the perimeter of the sub-area.

The antenna poles for the sites could be added between, or in place of, the existing light poles or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have a medium-sized adjacent equipment enclosure that could be disguised as a large bench or trash receptacle.

A conceptual map of the locations for a DRAN-2 deployment is shown in Figure 59.

Figure 59: DRAN-2 Deployment in East Potomac Park



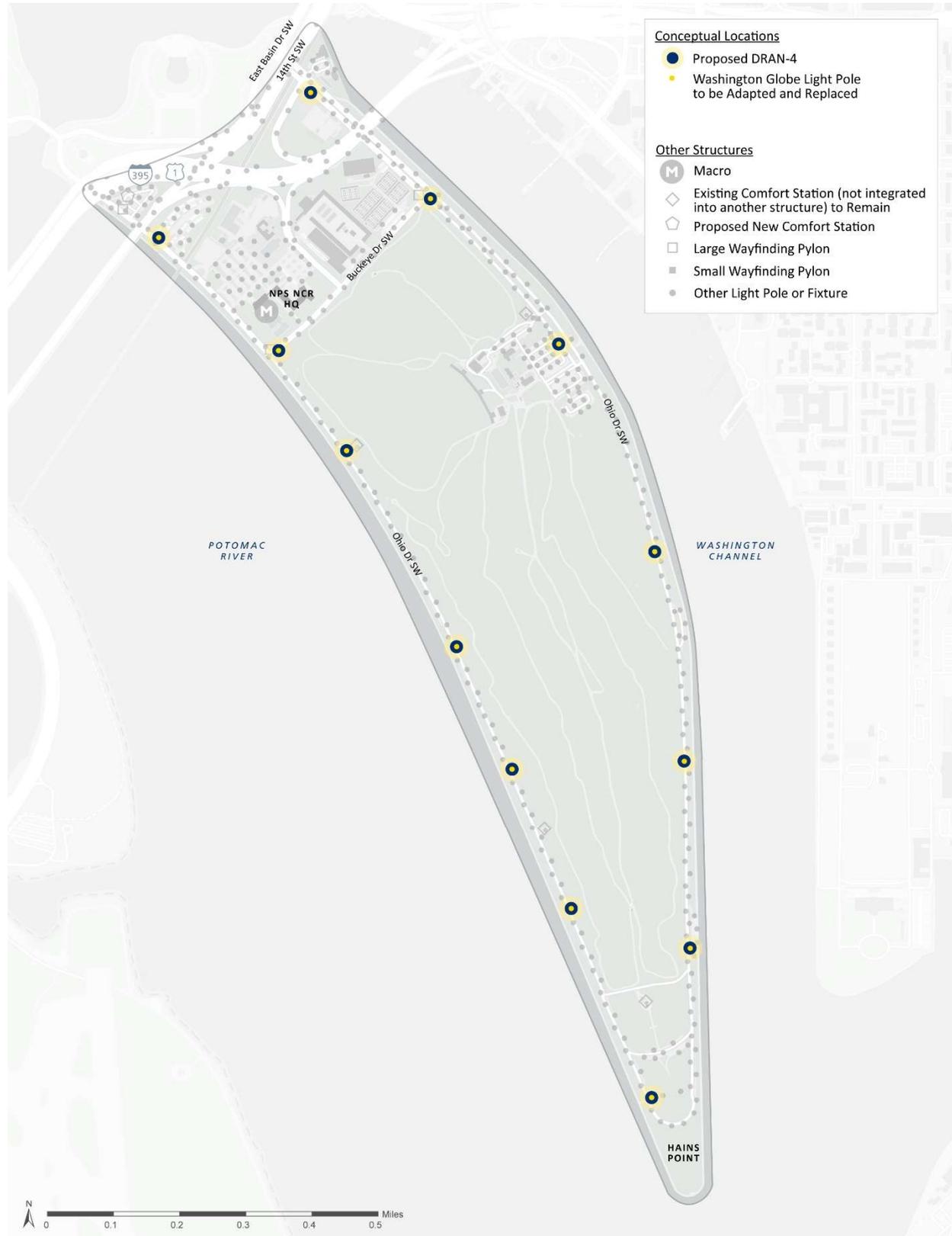
### **6.5.3 DRAN-4 Topology**

A DRAN-4 design for this area would consist of a total of 13 sites, each supporting all MNOs. Sites would be located around the perimeter of the sub-area.

The antenna poles for the sites could be added between, or in place of, the existing light poles or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have a large adjacent equipment enclosure as shown that would be difficult to disguise.

A conceptual map of the locations for a DRAN-4 deployment is shown in Figure 60.

Figure 60: DRAN-4 Deployment in East Potomac Park



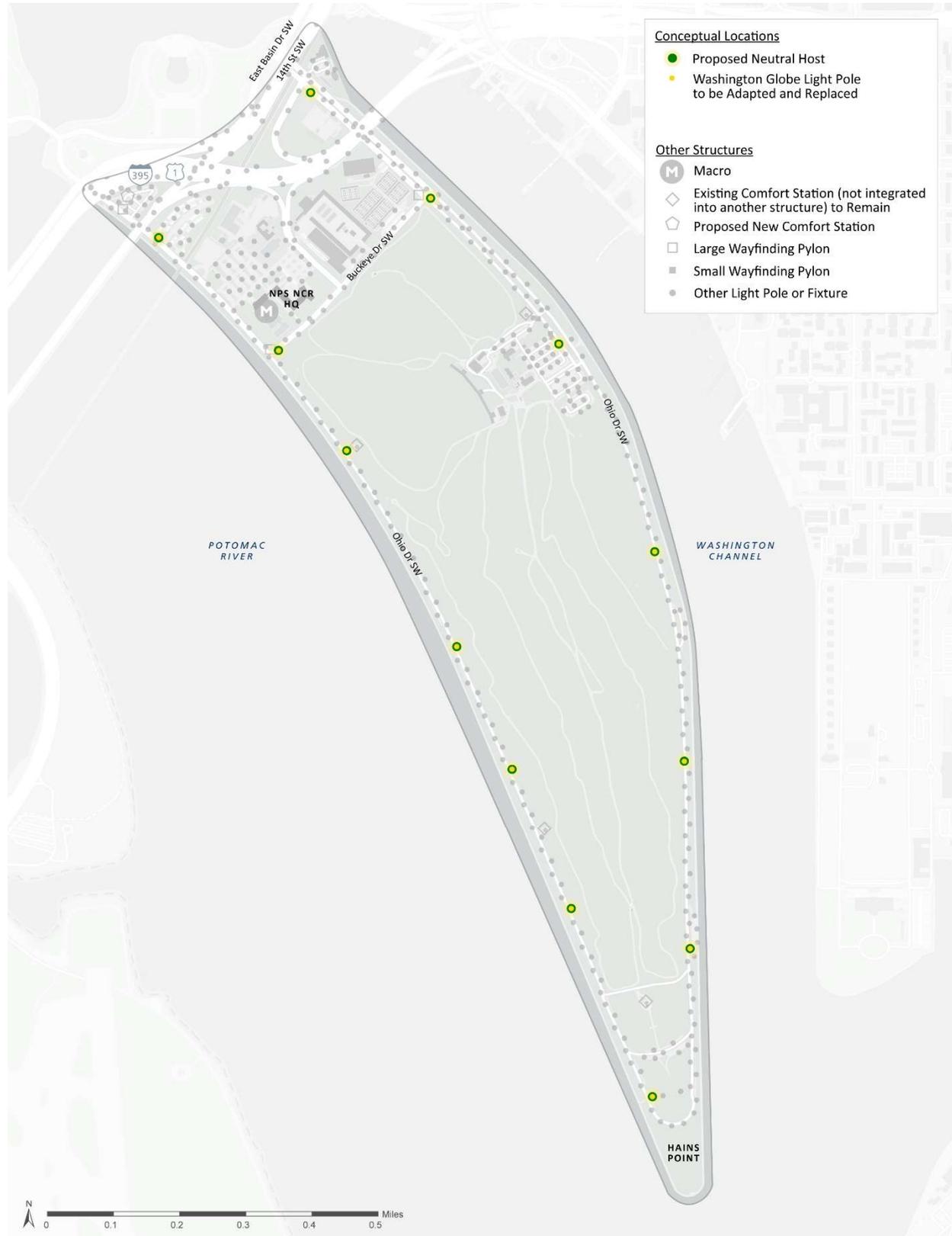
#### **6.5.4 Neutral Host Topology**

A Neutral Host design for this area would consist of a total of 13 sites, each supporting all MNOs. Sites would be located around the perimeter of the sub-area, with additional sites required due to the more limited coverage of a Neutral Host site.

The antenna poles for the sites could be added between, or in place of, the existing light poles or capitalize on other existing features to minimize viewshed impact. Each antenna pole would have a medium-sized adjacent equipment enclosure that could be disguised as a large bench or trash receptacle.

A conceptual map of the locations for a Neutral Host deployment is shown in Figure 61.

Figure 61: Neutral Host Deployment in East Potomac Park



### 6.5.5 East Potomac Park Area Preferred and Alternative Concepts

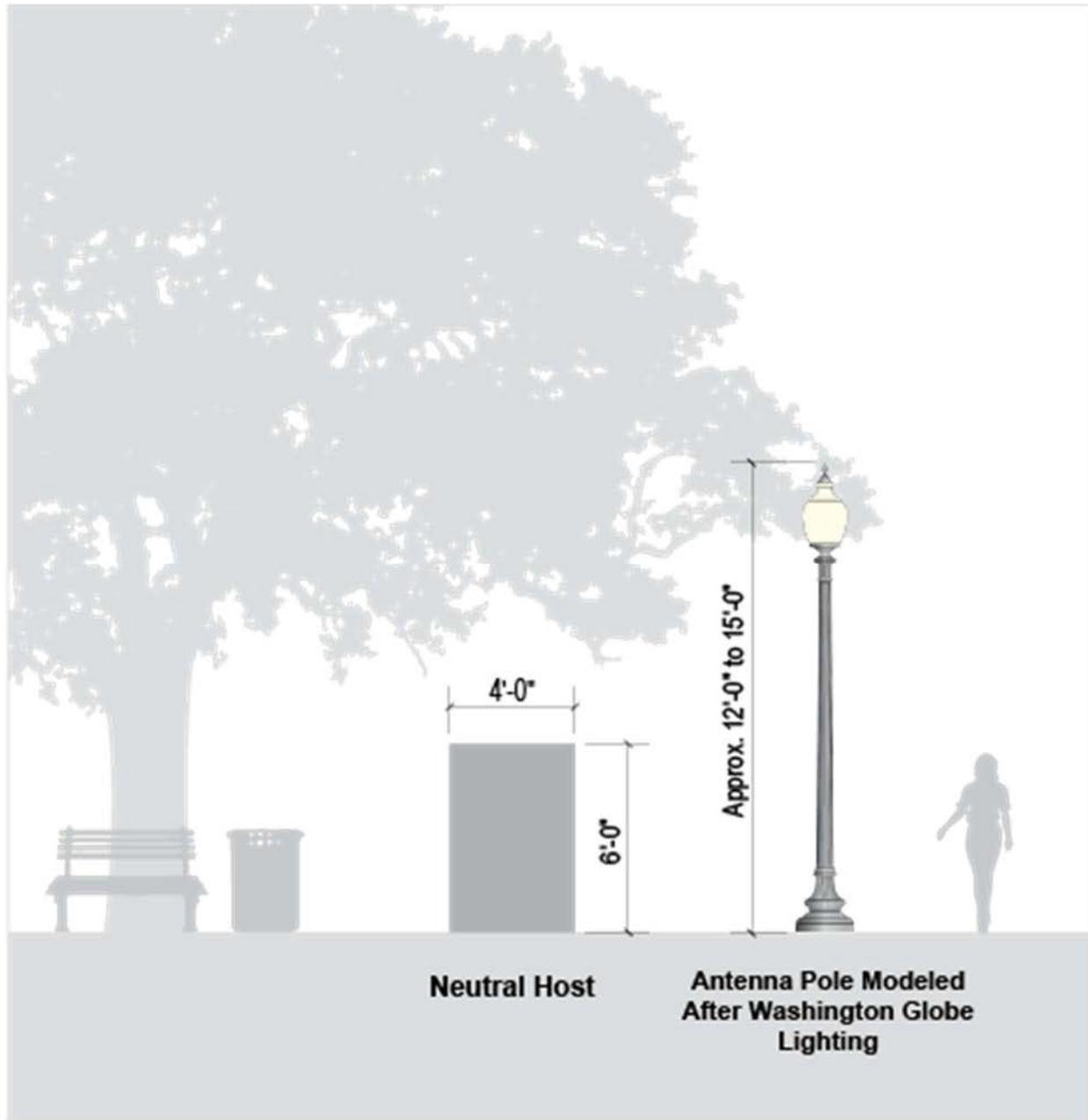
A more uniform design selection is preferred in this area. The sites in the area would need to be integrated into the line of Washington Globe lights on the perimeter of the sub-area, which are notably smaller than some light poles in the Project Area. See summary in Table 17.

**Table 17: Summary of Criteria by Topology – East Potomac Park**

Criteria	SASC	DRAN-2	DRAN-4	Neutral Host	Preferred: Neutral Host
Minimize impact on cultural resources	Washington Globe lights would be similar in appearance; smallest cabinet size	Washington Globe lights would be similar in appearance; medium cabinet size	Washington Globe lights would be similar in appearance; largest cabinet size	Washington Globe lights would be similar in appearance; smallest cabinet size	Washington Globe lights would be similar in appearance; smallest cabinet size
Use non-contributing resources, if possible	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired	Could use stand-alone poles, if desired
Minimize maintenance	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types	Uses existing pole types
Limit number of sites	40	20	13	13	13

**Preferred Concept:** A Neutral Host concept is an ideal solution for this area. Although the nature of the Neutral Host sites requires a few more site locations versus other topologies, the smaller antenna requirements would allow the site pole to better fit into the landscape of the area at each site and when considering the entire concept in the area. The small equipment enclosure is also an asset as it would be easy to conceal at each site. A conceptual map of the locations for this concept is shown previously in Figure 61 and an illustrative elevation in Figure 62.

**Figure 62: Preferred Concept for East Potomac Park – Elevation Diagram of Washington Globe Lighting with Neutral Host Equipment Housing**



*Note: Diagram is for illustrative purposes only*

**Alternative Concept:** The alternative is the DRAN-4 concept. The ten-site count can be integrated within the existing light pole lines, while the large enclosures we believe can be suitably presented in the context of the landscape. A conceptual map of the locations for this concept is previously shown in Figure 60.

**Unfavorable Concepts:** Both the SASC and DRAN-2 concepts would be the most impractical due to the need for significantly more sites in the area. The larger antennas required for the small cell sites (versus the Neutral Host) combined with the significant site counts leads to a more impactful deployment if these topologies were to be used.

## 7. Conclusion

To best meet the requirements of the project, the following infrastructure solutions are recommended for each of the five sub-areas.

**National Mall East Sub-Area.** The DRAN-2 Topology would provide an ideal combination of capacity and manageable antenna enclosure size. This solution requires 14 sites which can be integrated within the existing line of light poles along the turf panels, while the equipment enclosures can be creatively concealed adjacent to the poles. (See Section 6.1 for more information.)

**Washington Monument Grounds and President's Park South Sub-Area.** The preferred solution would utilize the DRAN-4 Topology at the existing Washington Monument stanchions and the Neutral Host Topology at the Washington Monument screening facility and President's Park South. A total of seven sites would be needed (four DRAN-4 sites on the stanchions, one Neutral Host site at the screening facility, and two Neutral Host sites at President's Park South). The Neutral Host sites could be integrated at the screening facility and with the existing light poles at President's Park South, and the equipment enclosures could be creatively concealed at the sites. (See Section 6.2 for more information.)

**West Potomac Park - Lincoln Memorial Sub-Area.** An ideal combination would be to apply the DRAN-4 solution on the existing Memorial stanchions and the Neutral Host solution on light poles elsewhere. A total of eleven sites would be needed (two DRAN-4 and nine Neutral Host). The Neutral Host sites could be integrated within existing light poles and the equipment enclosures would be concealed adjacent to the poles. (See Section 6.3 for more information.)

**West Potomac Park – Tidal Basin Sub-Area.** A solution with the DRAN-4 Topology on the Jefferson stanchions, one FDR Memorial stanchion, and one light pole, and Neutral Host Topology elsewhere is the preferred solution. The twelve sites (four DRAN-4, eight Neutral Host) can be integrated within existing features, while the enclosures would need to be creatively concealed adjacent to the poles. (See Section 6.4 for more information.)

**East Potomac Park Sub-Area.** A 13-site Neutral Host Topology would best serve this sub-area. Although this Topology requires a few more sites relative to the other solutions, the smaller antenna requirements would allow for a new, taller pole to better fit into the visual landscape. The small enclosure is also an asset as it would be more easily concealed at each site. (See Section 6.5 for more information.)

**Table 18: Summary of Preferred Solutions**

Sub-Area	Recommended Topology	Details
<b>National Mall East</b>	DRAN-2	<ul style="list-style-type: none"> <li>➤ 14 sites</li> <li>➤ Sites integrated with existing light poles along turf panels, with equipment enclosures concealed adjacent to poles</li> <li>➤ Ideal combination of capacity and size</li> </ul>
<b>Washington Monument Grounds and President's Park South</b>	Hybrid (DRAN4 and Neutral Host)	<ul style="list-style-type: none"> <li>➤ 7 sites (4x DRAN-4, 3x Neutral Host)</li> <li>➤ Four DRAN-4 sites on existing Washington Monument stanchions</li> <li>➤ One Neutral Host site on the screening facility and 2 sites on poles at President's Park South</li> <li>➤ Best combination of capacity, coverage, and concealment</li> </ul>
<b>West Potomac Park – Lincoln Memorial</b>	Hybrid (DRAN-4 and Neutral Host)	<ul style="list-style-type: none"> <li>➤ 11 sites (2x DRAN-4, 9x Neutral Host)</li> <li>➤ Two DRAN-4 on existing Memorial stanchions</li> <li>➤ Nine Neutral Host sites on light poles</li> <li>➤ Best combination of capacity, coverage, and concealment</li> </ul>
<b>West Potomac Park – Tidal Basin</b>	Hybrid (DRAN4 and Neutral Host)	<ul style="list-style-type: none"> <li>➤ 12 sites (4x DRAN-4, 8x Neutral Host)</li> <li>➤ Three DRAN-4 on lighting stanchions</li> <li>➤ One DRAN-4 on existing pole</li> <li>➤ Eight Neutral Host on poles spread throughout sub-area</li> <li>➤ Best combination of capacity, coverage, and concealment</li> </ul>
<b>East Potomac Park</b>	Neutral Host	<ul style="list-style-type: none"> <li>➤ 13 sites</li> <li>➤ Sites integrated in new, taller light poles with identical luminaires and easy-to-conceal equipment enclosures</li> <li>➤ Small site footprint with sufficient coverage and capacity</li> </ul>

## **Appendix A: [Drive Test Paper]**

[Attached]

## **Appendix B: [Capacity White Paper]**

[Attached]

End of document.

**National Mall**  
**Washington, District of Columbia**  
**RF Survey Report**

**September 2023**

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# 1 Purpose

## 1.1 Introduction

The National Mall Cellular Coverage Report provides an overview of the service and signal quality for major wireless carrier, i.e., Verizon, AT&T and T-Mobile, at the historic National Mall and surrounding parks. Based on the data from the report we will determine the best available solution(s) required to provide sufficient coverage and capacity on the National Mall, using the findings in support of the National Park Service Telecommunications Infrastructure Plan.

## 1.2 Project Overview

The National Park Service (NPS) is proposing to develop a Telecommunications Infrastructure Plan (“Plan”) that would provide a framework and guidance for the future construction and operation of communications infrastructure utilizing NPS assets, specifically: roof top antennas, temporary antenna locations, small-cell sites, and fiber optic communications cable (fiber) and power infrastructure. The Plan will encompass the areas shown in Figure 1 including the National Mall and Memorial Parks, as well as the Presidents’ Park (including the Washington Monument grounds, Lincoln Memorial and Reflecting Pool, Constitution Gardens, Jefferson Memorial, East Potomac Park, West Potomac Park, Tidal Basin area, and the Ellipse). The Plan intends to provide a proactive approach for determining potentially acceptable telecommunications infrastructure within the park that are consistent with the cultural landscape, NPS mission, enabling legislation, existing park management documents, and future planning considerations.

## 1.3 Capacity Requirement

In January 2022, the National Security Council’s (NSC) National Capital Region (NCR) Security Interagency Policy Committee (IPC) identified that the current wireless infrastructure around the National Mall is insufficient for large emergencies and short-notice events, thereby posing risks to emergency managers, first responders, and civilians. To address the issue, the NSC designated the Cybersecurity and Infrastructure Security Agency (CISA) and the General Services Administration (GSA) to lead a Working Group (WG) comprised of departments and agencies, as well as partners from local government and industry organizations, to examine existing wireless infrastructure challenges and bureaucratic obstacles to wireless infrastructure expansion in Washington, D.C. The group was directed to determine potential solutions to these challenges.

The WG engaged with the wireless infrastructure project approval entities — including the National Capital Planning Commission, Commission of Fine Arts, Advisory Council on Historic Preservation, National Park Service, and Architect of the Capitol — and with the three major wireless carriers in the NCR. From these engagements and further assessment of the current wireless infrastructure, the WG determined that action must be taken to improve the wireless infrastructure around the National Mall, and nearby locations, and has drafted a Corrective Action Plan (CAP). The CAP recommends that the wireless infrastructure capacity must be increased to, at least, five times the current daily busy hour capacity<sup>1</sup> to ensure the safety and security of the area’s residents, workers, and visitors. To do this most effectively, the WG recommended the installation of a heterogenous design of macro and small cell systems, combined with use of low-, mid-, and high-frequency bands. In addition, since the capacity threshold increase will not account for large mass gatherings, the WG recommended that mobile antenna locations need to be designated, with permanent power and fiber hookups, to

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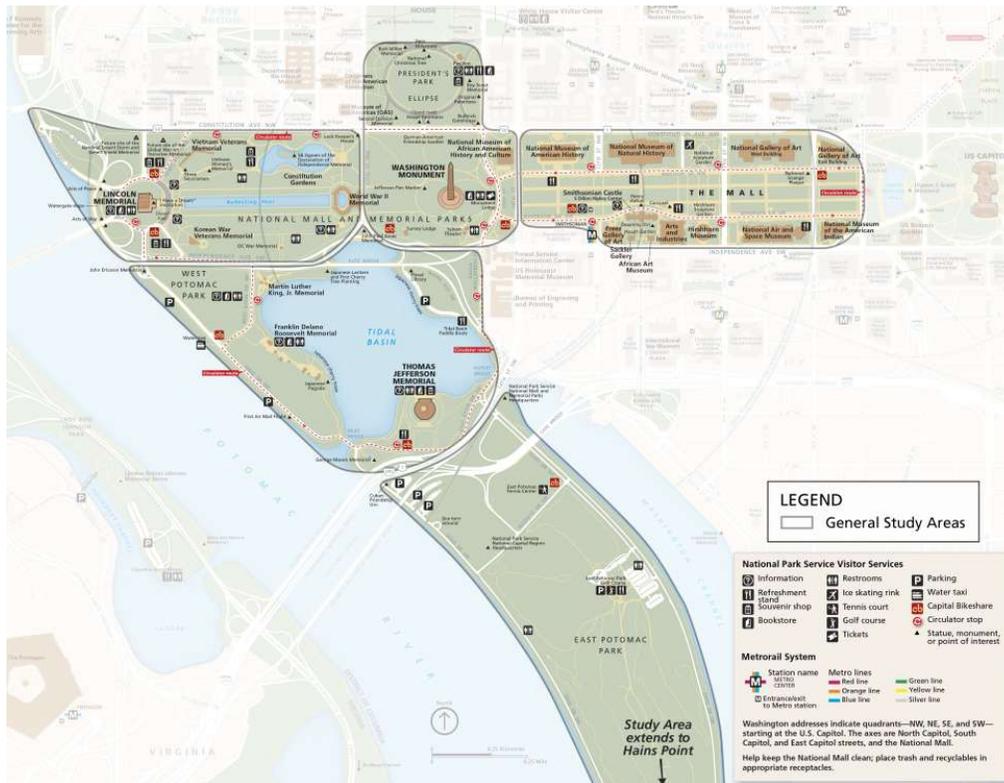
<sup>1</sup> The quantified capacity definition has not yet been determined by the WG but is expected in Q4 of 2023.

enable the service providers to more effectively and more safely support high peak demands during special events.

### 1.4 RF Survey Overview

AECOM performed cellular signal survey for the purpose of collecting data for the three major carriers covering National Mall and Memorials Parks and President’s Park to include the Washington Monument Grounds, Lincoln Memorial and Reflecting Pool, Constitution Gardens, the Jefferson Memorial, East Potomac Park, West Potomac Park and Tidal Basin areas as well as the Ellipse.

The RF signal survey data was collected<sup>2</sup> for the three major carriers using the digital scanner that captured data from the 600 MHz band through the C-Band. The data collected is for all known bands/channels for each of the carriers which helps determine the capacity that a carrier can provide to its users in a giving area. The data also identifies which site the signal is coming from which helps with identifying the coverage from each site and some insight to current capacity. The survey data helps identify the quality of signal which in turn provides an insight to the coverage and capacity each band can provide to the users.



**General Survey Area – Verify and Update**

<sup>2</sup> The data was collected using a PCTEL scanner connected to antennas. A GPS unit attached to the scanner provided the exact location of each data point collected. A computer is connected to the scanner logged the data and allowed for data verification during collection.

<sup>3</sup> The data was collected using a PCTEL scanner connected to antennas. A GPS unit attached to the scanner provided the exact location of each data point collected. A computer is connected to the scanner logged the data and allowed for data verification during collection.

## 2 Definitions

### 2.1 Reference Signal Received Power (RSRP)

Reference Signal Received Power is a measure of the power level of a received signal in an LTE cell network. RSRP is the average power of the received pilot signals or the level of the received signal from the base station. RSRP is measured in decibels milliwatts (dBm). Values closer to zero indicate stronger signals. For example, an RSRP of -95 dBm would be a strong signal, while -115 dBm would be very weak.

### 2.2 Reference Signal Received Quality (RSRQ)

Reference Signal Received Quality is a measure of the signal quality of a cellular connection. RSRQ is calculated using the values of RSSI and RSRP. It's a ratio of the carrier power to the interference power. The closer to zero the RSRQ is, the higher the power of the signal.

RSRQ is typically displayed in a range from 0 dB (highest quality) to -20 dB (lowest quality). Better signal quality results in a more reliable connection.

### 2.3 Received Signal Strength Indication (RSSI)

Received Signal Strength is a measurement of how well a device can hear a signal. RSSI is a value for determining a good wireless connection.

RSSI is indicated by a negative dBm value. The higher the number, the better the signal. For example, an RSSI of -40 or better is considered good or excellent. An RSSI of -60 or worse is considered poor.

RSSI ranges from -100 to 0. The closer to 0, the better signal strength.

### 2.4 Carrier to Interference plus Noise Ratio (CINR)

Carrier to Interference plus Noise Ratio is the ratio of the signal level to the noise level, also known as Signal to Interference plus Noise Ratio (SINR). CINR is measured in decibels (dB). A positive CINR value means that the signal is more effective than the noise. A higher CINR value means that the signal strength is stronger in relation to the noise levels. This allows for higher data rates and fewer retransmissions, which offers better throughput.

### 2.5 Primary Synchronization Signal Received Power (PSS\_RP)

Primary Synchronization Signal reference signal received power is defined as the linear average over the power contributions (in Watt) of the resource elements that carry SS. The SS-RSRP value is used for cell selection, cell reselection, power control, mobility procedures, and beam management procedures. The SS-RSRP value is generated and reported at both Layer 1 (Phy) and Layer 3 (RRC). The reporting range of SS-RSRP for L3 is defined from -156 dBm to -31 dBm. The typical range of RSRP is around -44 dBm (good) to -140 dBm (bad).

### 2.6 Primary Synchronization Signal Received Quality (PSS\_RQ)

Primary Synchronization Signal Reference Signal Received Quality is a measurement of the quality of the synchronization signal received by a device. SS-RSRQ is used in 5G NR networks to determine the quality of the radio channel. It can be used for cell selection, reselection, and mobility (handover) procedures. The 5G RSRQ range is defined as -43 dB to 20 dB.

## 2.7 Primary Synchronization Carrier to Interference plus Noise Ratio (PSS\_CINR)

Primary Synchronization Carrier to Interference-plus-Noise Ratio is the ratio of the signal level to the sum of interference from competing signals and background noise. CINR is measured in decibels (dB). A positive CINR value means that the signal is more effective than the noise. A higher CINR value means that the signal strength is stronger in relation to the noise levels. This allows for higher data rates and fewer retransmissions, which offers better throughput.

## 2.8 Low, Mid and High Band

The definition for these has changed over time, but of the purpose of this documentation these definitions will be used:

- Low-band spectrum is any spectrum lower than 2.3 GHz on the spectrum chart.
- Mid-band spectrum (2.3 GHz - 6 GHz) is considered perfect for 5G because it can carry plenty of data while traveling significant distances. The GSMA describes spectrum in the 3.3 GHz to 3.8 GHz range as ideal because many countries worldwide have already designated it for 5G.
- High-band is in the millimeter wave spectrum – 24 GHz band and higher on the spectrum chart. The GSMA recommends that CSPs support millimeter wave spectrum in the 26 GHz, 40 GHz, 50 GHz, and 66 GHz bands for mobile services. Millimeter wave (high-band) spectrum is limited because signals cannot travel as far as mid and low-band signals. Sometimes, the signal will travel less than a mile and is more susceptible to interference from things such as trees, buildings, and even glass. But the benefit of millimeter wave spectrum is that if the signal is unencumbered, users can get connection speeds between 1 Gbps to 3 Gbps or even higher.

### 3 RF Survey

#### 3.1 Test Setup

The survey test setup consists of the following:

- PCTEL Scanner - HBflex device release 3.8.3.0 ESN 051907021
- GPS L1/GLONASS L1 Active Magnetic Mount Antenna
- (2) OP691 Indoor Antenna, 600 MHz - 6 GHz
- (2) OP313 - Kit, Omni Antenna for mmWave (4.5-40 GHz)
- OP417- HBflex Battery Pack
- Samsung Galaxy TAB S6 10.5" - Black with Stylus



▲ HBflex™ Scanning Receiver with I-CBL-ANT-HBP Kit

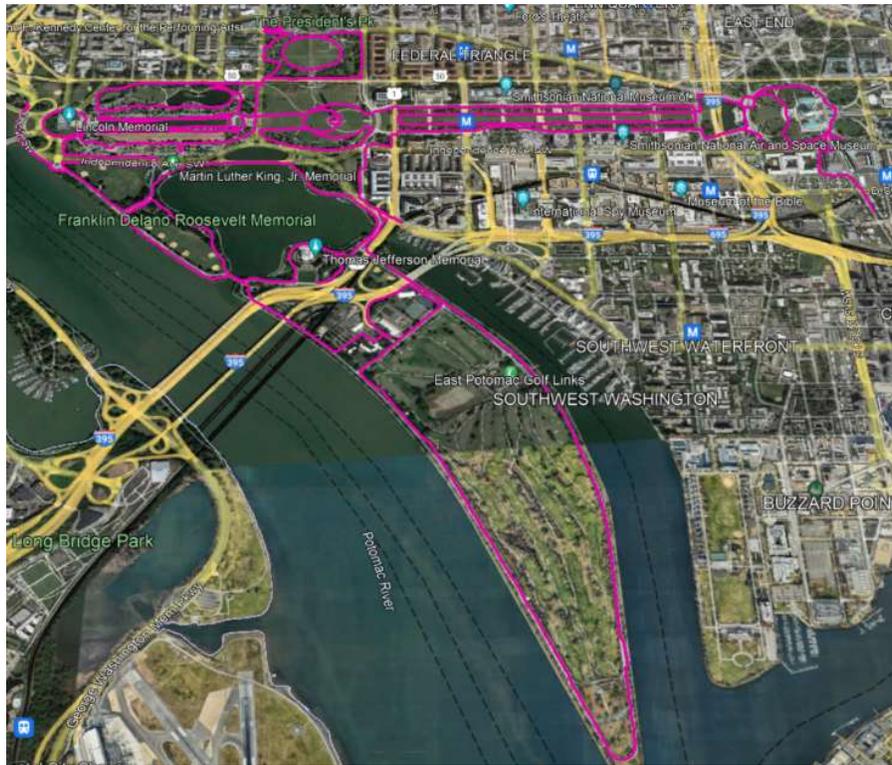


PCTEL Scanner



### 3.2 RF Survey Route

The PCTEL test gear for performing survey/data collection was placed in a bag pack that was easy to carry by the Survey Engineer while riding on an electric scooter to be able to efficiently access the busy areas of the mall. The Survey Engineer was able to gather data for the mall, providing a better picture of the overall coverage in and around the study area. The map below shows the route that was used by the survey team to gather data along the highlighted path.



**Survey Route**

Due to the quantity of the data being collected the survey had to be performed twice to capture information for all three carriers. The survey was performed to capture low bands for one walk and capture high bands for the second walk.

To evaluate the RF signal quality, we have divided the entire study area into six smaller portions. This will also give us the opportunity to have a closer look at each of the smaller areas and come up with solutions that might be different depending on the area or a mix per each smaller study area.

Below is the representation of each of the areas.



**Supplemental Area: The Capitol**



**Study Area 2: The Washington Monument / Ellipse**



**Study Area 1: The National Mall**



**Study Area 3: Lincoln Memorial / Constitution Garden**



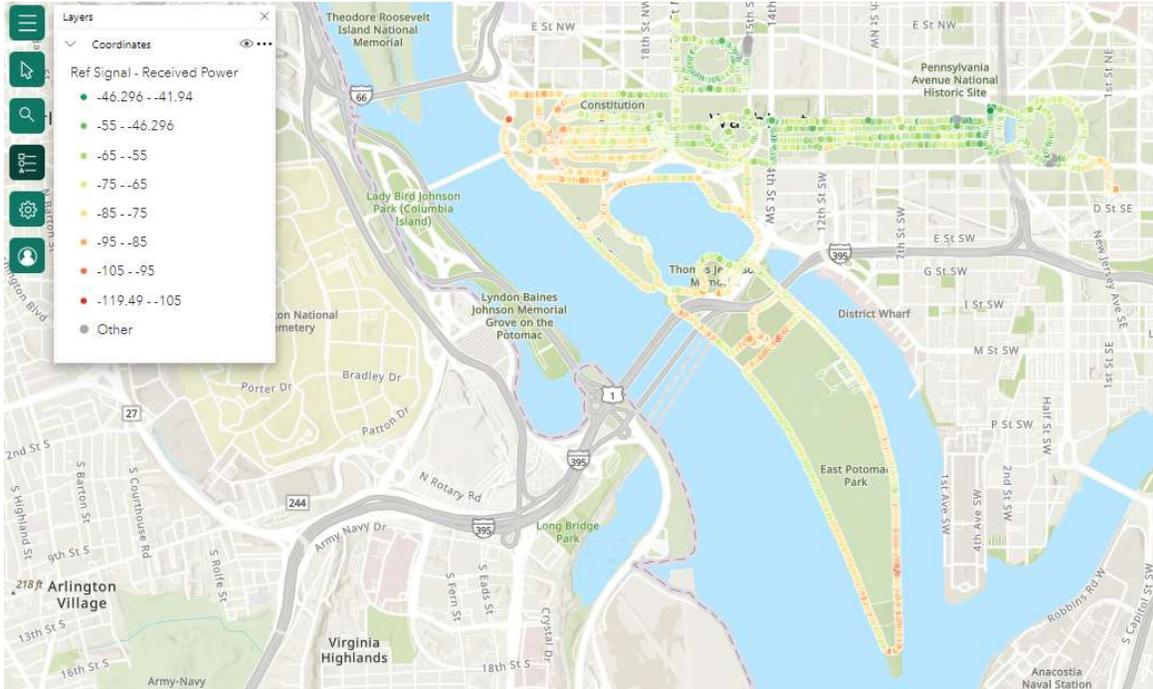
**Study Area 4: Tidal Basin / West Potomac Park**



**Study Area 5: East Potomac Park**

### 3.3 Data Processing

The data was processed using SeeHawk Collect software and further moved into the GIS database. Below is a sample of the survey data showing the Verizon 700 RSRP in GIS.



**Sample Survey - Reference Signal Received Power**

## 4 Survey Data Evaluation

### 4.1 Data Collected

The survey was performed to capture data for Verizon, AT&T and T-Mobile bands that are serving the Washington, DC market. This included the frequency range from 600 MHz to 6 GHz. Although the survey was performed to capture all the bands owned by the three carriers, there was no active signal for C-band or mmWave for any of the carriers. The table below shows all the bands on which the PCTEL scanner gathered data.

	Band										
	600	700	800	1900	2100	1900 Ext	2100 Ext	AWS-3	WCS	2.5	C-Band
<b>Verizon</b>		✓	✓	✓	✓	✓	✓	✓			
<b>AT&amp;T</b>		✓	✓	✓	✓	✓	✓	✓	✓		
<b>T-Mobile</b>	✓	✓		✓	✓	✓	✓	✓		✓	

**Table 1 – Bands Per Carrier**

There are different channels that belong to each of the carrier in the bands specified above. The setup for the scanner was to capture both 4G LTE channels and 5G NR channels, most of the active channels surveyed being 4G LTE. The 5G NR channels that were available included AT&T 850 MHz and a portion of 2100 MHz; T-Mobile 600 MHz, 2100 MHz and 2500 MHz.

Below is a comprehensive list of all the channels that were captured during the survey.

<b>Technology</b>	<b>Band</b>	<b>Channel/ Frequency</b>	<b>Network</b>
LTE	01 2100 (IMT-2000)	550 / 2165.00	ATT
LTE	01 2100 (IMT-2000)	175 / 21275 MHz	Verizon
LTE	02 1900 PCS	675 / 1937.5	T-Mobile
LTE	02 1900 PCS	1125 / 1982.5	Verizon
LTE	02 1900 PCS	850 / 1955.00	ATT
LTE	04 2100 AWS	2000 / 2115.0	ATT
LTE	04 2100 AWS	2125 / 2127.5	Verizon
LTE	04 2100 AWS	2300 / 2145.00	T-Mobile
LTE	05 850 AWS	2560 / 885.00	Verizon
LTE	10 Ext 2100 AWS	4200 / 2115.00	ATT
LTE	11 Ext 2100 AWS	4500 / 2145.00	Verizon
LTE	12 US Lower 700 ABC	5035 / 731.5	T-Mobile
LTE	12 US Lower 700 ABC	5110 / 739.00	ATT
LTE	13 US Upper 700 C	5230 / 751.00	Verizon
LTE	14 US Upper 700 D	5330 / 763.00	FirstNet
LTE	17 US Upper 700 B C	5780 / 739.00	ATT
LTE	25 1900 Ext PCS	8115 / 1937.5	T-Mobile
LTE	25 1900 Ext PCS	8565 / 1982.5	Verizon
LTE	26 1900 Ext PCS	8290 / 1955.00	ATT
LTE	29 US 700	9685 / 719.5	ATT
LTE	66 AWS-3	66486 / 2115	ATT
LTE	66 AWS-3	67086 / 2175.00	Verizon
LTE	66 AWS-3	66786 / 2145.00	T-Mobile
LTE	71 600	68661 / 624.5	T-Mobile
LTE	EB 30: 2.3 GHz (WCS A/B) DL	9820	ATT
TD-LTE	EB 41: TDD 2.5 GHz	39750	T-Mobile
TD-LTE	EB 41: TDD 2.5 GHz	39948	T-Mobile
TD-LTE	EB 41: TDD 2.5 GHz Lower	39750	T-Mobile
TD-LTE	EB 41: TDD 2.5 GHz Lower	39948	T-Mobile

**Table 2 – 4G LTE Channels Captured During Survey**

Technology	Band	Channel / Frequency	Network
NR	FR1 FDD n5 DL	174770	ATT
NR	FR1 TDD n41 / n90	510270 / 2551.350000 MHz	TM
NR	FR1 TDD n41 / n90	520110 / 2600.550000 MHz	TM
NR	FR1 FDD n65 DL	423150 / 2115.750000 MHz	ATT
NR	FR1 FDD n65 DL	2190.150000 MHz	Dish
NR	FR1 FDD n66 DL	2115.750000 MHz	ATT
NR	FR1 FDD n70 DL	2005.250000 MHz	Dish
NR	FR1 FDD n71 DL	632.550000 MHz	TM

**Table 3 – 5G NR Channels Captured During Survey**

## 4.2 Data Evaluation

The Key Performance Indicators (KPI) used to evaluate the availability and quality of the signal for each band are:

- 4G LTE: Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Carrier to Interference plus Noise Ratio (CINR)
- 5G NR: Primary Synchronization Signal Received Power (PSS\_RP), Primary Synchronization Signal Received Quality (PSS\_RQ), and Primary Synchronization Carrier to Interference plus Noise Ratio (PSS\_CINR)

Signal quality KPIs are measured by user equipment (UE) equipment at any given point and time. The network can automatically “throttle” speeds to users depending on the signal quality they report back by assigning less “resources” (i.e., bandwidth). Devices reporting low signal quality conditions will experience lower speeds, which typically is caused by low signal strength, high noise, or signal pollution.

While signal quality usually has a direct correlation to signal strength, areas of high signal strength do not always experience high signal quality; too much noise from too many signals in an area will reduce the signal to noise ratio which in turn reduces the quality of the signal. “Pilot Pollution” is a term commonly used when many competing signals result in a lower quality signal.

Where signal quality is poor, the network will reduce modulation rates for a UE to ensure reliability. This not only reduces the throughput for the UE, but also diminishes the spectral efficiency of the network and therefore reduces overall network capacity.

Based on these KPIs for each of the bands we have evaluated the signal quality for each of the carriers and its performance.

### 4.3 Verizon Coverage and Capacity Overview

The RF survey collected key information for the active Verizon carriers in the subject area. AECOM found active service in the low bands (700, 850, 1900, and 2100 MHz) but were unable to identify any usable carriers in the C-Band or mm-Wave bands.

#### 4.3.1 Existing Verizon Coverage

Although there is largely adequate coverage from the Verizon low bands, there are other factors that affect quality of service and thus reduce the capacity and throughput for the end user. We have investigated three of the most important KPIs to evaluate the quality of services (QOS) provided by each of the carriers. These KPIs are the Received Power (RSRP), Received Quality (RSRQ), and Carrier Interference to Noise Ratio (CINR). For the purposes of this analysis, we have set the following thresholds for acceptability:

- RSRP: greater than -90 dBm
- RSRQ: greater than -15 dB (LTE) or greater than -20 dB (NR)
- CINR: greater than 0 dB

While our survey data found that the subject area is covered for basic communication, the general level of signal strength and signal quality is insufficient for typical demand in many areas. 700 MHz 4G LTE service covers the subject area with adequate signal strength at more than 90% and with adequate signal quality at more than 50%. For the subject area, most of the remaining lower band frequencies provide adequate signal strength and quality at more than 50% (with most exceptions falling in the East Potomac Park area).

For a better understanding of the available signal and its quality we created a table to represent the percentage of adequate service for each of the three KPIs. These are separated into the six areas of our study to get a closer look at the service for each band and how it is propagating throughout the study area. The tables on the following page show the percentage of each of the KPI per area, per each band.

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	100%	100%	100%	98%	97%	90%
<b>RSRQ &gt; -15</b>	93%	94%	92%	50%	65%	66%
<b>CINR &gt; 0</b>	70%	60%	60%	55%	70%	45%

**Verizon 700 Channel 5230 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	90%	63%	57%	60%	65%	65%
<b>RSRQ &gt; -15</b>	90%	50%	43%	60%	60%	45%
<b>CINR &gt; 0</b>	70%	40%	55%	45%	50%	55%

**Verizon 850 Channel 2560 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	97%	100%	99%	70%	75%	55%
<b>RSRQ &gt; -15</b>	95%	97%	80%	65%	70%	55%
<b>CINR &gt; 0</b>	83%	90%	60%	55%	55%	35%

**Verizon 1900 Channel 1125 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	80%	96%	95%	65%	70%	50%
<b>RSRQ &gt; -15</b>	80%	91%	70%	70%	55%	45%
<b>CINR &gt; 0</b>	80%	94%	65%	50%	55%	50%

**Verizon 2100 Channel 2125 -LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	95%	35%	75%	73%	70%	35%
<b>RSRQ &gt; -15</b>	97%	80%	80%	70%	73%	30%
<b>CINR &gt; 0</b>	88%	40%	60%	65%	67%	30%

**Verizon AWS-3 Channel 67086 - LTE**

## **4.4 AT&T Coverage and Capacity Overview**

The RF survey collected key information for the active AT&T carriers in the subject area. AECOM found active service in the low bands (700, 850, 1900, and 2100 MHz) but were unable to identify any usable carriers in the C-Band or mm-Wave bands.

### **4.4.1 Existing AT&T Coverage**

While AT&T has some level of coverage throughout the study area from most of the low bands (700, 800, 1900, and 2100 MHz) and the mid band (2.3 GHz), but the signal strength and signal quality are not great throughout the study area. AT&T 700 LTE signal covers more than 90% of the entire project area at good signal strength and signal quality. The rest of the lower band and midband provides adequate quality signal for over 50% of the study area.

Like Verizon, while there is largely adequate coverage from the AT&T low bands and mid band that does not provide the complete picture. We further evaluated the RSRP, RSRQ, and CINR to get a better understanding of the overall quality of service. The tables on the next page show the percentage of each of the KPI per area, per each band.

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	100%	100%	100%	96%	98%	99%
<b>RSRQ &gt; -15</b>	75%	63%	60%	61%	71%	57%
<b>CINR &gt; 0</b>	50%	35%	37%	65%	50%	33%

**ATT 700 Channel 5780 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	100%	100%	100%	70%	87%	65%
<b>RSRQ &gt; -15</b>	87%	84%	85%	60%	75%	55%
<b>CINR &gt; 0</b>	70%	68%	62%	64%	70%	45%

**ATT 1900 Channel 850 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	80%	95%	85%	50%	30%	40%
<b>RSRQ &gt; -15</b>	70%	85%	55%	70%	30%	45%
<b>CINR &gt; 0</b>	70%	67%	50%	67%	35%	30%

**ATT 2100 Channel 2000 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	98%	95%	96%	77%	75%	90%
<b>RSRQ &gt; -15</b>	80%	83%	58%	42%	53%	40%
<b>CINR &gt; 0</b>	62%	52%	41%	37%	55%	35%

**ATT WCS Channel 9820 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	100%	100%	100%	99%	98%	98%
<b>RSRQ &gt; -20</b>	92%	88%	95%	92%	95%	96%
<b>CINR &gt; 0</b>	55%	67%	63%	45%	65%	60%

**ATT 850 Channel 174770 - 5G NR**

## **4.5 T-Mobile**

The RF survey collected key information for the active T-Mobile carriers in the subject area. AECOM found active service in the low bands (600, 700, 1900 and 2100 MHz) and mid band (2.5 GHz or BRS) but were unable to identify any usable carriers in the C-Band or mm-Wave bands.

### **4.4.1 Existing T-Mobile Coverage**

From the survey data, we found that T-Mobile largely has sufficient signal coverage throughout the study area for basic communications however, the signal strength and signal quality are not adequate for our objectives. While T-Mobile 700 LTE has adequate signal over more than 90% of the entire project area, the remaining lower band and midband only provide adequate quality signal over 50% of the study area. The 600 5G NR also covers more than 90% of the study area with good signal quality, but it does not have sufficient capacity for heavy traffic areas.

The tables on the next page show the percentage of each of the KPI per area, per each band.

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	100%	99%	100%	97%	96%	98%
<b>RSRQ &gt; -20</b>	65%	55%	30%	42%	40%	35%
<b>CINR &gt; 0</b>	60%	30%	33%	38%	33%	34%

**T-Mobile 600 Channel 68661 – NR**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	100%	100%	100%	99%	99%	91%
<b>RSRQ &gt; -15</b>	92%	93%	95%	41%	65%	55%
<b>CINR &gt; 0</b>	91%	89%	73%	35%	40%	41%

**T-Mobile 700 Channel 5230 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	95%	89%	96%	87%	88%	96%
<b>RSRQ &gt; -15</b>	80%	50%	70%	60%	50%	52%
<b>CINR &gt; 0</b>	55%	27%	55%	60%	42%	35%

**T-Mobile 1900 Channel 675 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	95%	93%	97%	75%	70%	94%
<b>RSRQ &gt; -15</b>	80%	50%	43%	42%	43%	50%
<b>CINR &gt; 0</b>	60%	37%	42%	46%	40%	52%

**T-Mobile 2100 Channel 2300 -LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	50%	40%	65%	35%	58%	39%
<b>RSRQ &gt; -15</b>	95%	87%	91%	80%	85%	80%
<b>CINR &gt; 0</b>	90%	82%	83%	72%	75%	45%

**T-Mobile BRS Channel 39750 – LTE**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	100%	100%	100%	100%	100%	100%
<b>RSRQ &gt; -20</b>	94%	97%	99%	97%	97%	98%
<b>CINR &gt; 0</b>	67%	70%	75%	63%	60%	37%

**T-Mobile 600 Channel 135700 - 5G NR**

	Capitol Area	National Mall	Washington Monument / Ellipse	Lincoln Memorial	Tidal Basin / West Potomac Park	East Potomac Park
<b>RSRP &gt; -90</b>	50%	63%	65%	40%	65%	63%
<b>RSRQ &gt; -20</b>	94%	96%	99%	96%	97%	95%
<b>CINR &gt; 0</b>	63%	66%	70%	47%	57%	53%

**T-Mobile BRS Channel 510270 - 5G NR**

## 5 Conclusion

Although there are not many coverage gaps for most of the study area, the quality of the signal is not adequate for much of the study area. The percentage of adequate CINR is even lower than RSRQ over the study area and, when you combine those factors, the end user devices are going to have a difficult time communicating especially during periods of heavy foot traffic. During periods of low foot traffic, the carriers appear to have sufficient quality of service such that the end user may have a fair experience in a majority of the study area.

The other major factor for low QoS is the signal pollution in the study area. Considering that most of the signal in the study area is coming from sites that are well away from the mall, the carriers have many sites contributing to coverage in the area. However, due to the signal coming from many different locations, the noise levels in the area increases which causes the end user device to work harder to communicate.

Based on our study, we recommend increasing the coverage for high-capacity bands with signal sources close to the end user devices. This will create a “dominate” server (a significantly stronger serving site than the other non-serving sites) thus increasing the RSRQ and CINR and creating a high quality of service for the subscribers.

## Appendix A

### A.1 Coverage Maps

We have compiled all the survey data into a GIS database for easier understanding of the important KPIs throughout the study area. These can be accessed at the link below.

<https://app.powerbi.com/groups/me/reports/9013350e-7fae-4e96-954f-f4caba3dd7ce/ReportSectionf69171c629583d014cee?ctid=16ed5ab4-2b59-4e40-806d-8a30bdc9cf26&experience=power-bi&clientSideAuth=0>



# National Mall, Washington DC

## White Paper: Calculation of Capacity Density

National Park Service

Project number: 60709901  
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FINAL DRAFT

**Prepared for:**

National Park Service

**Prepared by:**

Michael T. Cassell  
Global Wireless Co-leader  
M: 410 446 8888  
E: michael.cassell@aecom.com

AECOM  
4 North Park Drive  
Hunt Valley, MD 21030  
aecom.com

**Acronyms and Abbreviations**

4G-LTE	Fourth Generation – Long-Term Evolution
5G-NR	Fifth Generation – New Radio
BW	Bandwidth
Bps	Bits per second
CINR	Carrier to Interference and Noise Ratio
CISA	Cybersecurity and Infrastructure Security Agency
dB	Decibel
E.G.	Exempli Gratia (for Example)
Mbps	Megabits per Second
MIMO	Multiple Input Multiple Output
MHz	Megahertz
MNO	Mobile Network Operator
NAMA	National Mall and Memorial Parks
NCR	National Capital Region
NPS	National Park Service
RAN	Radio Access Network
RF	radio frequency
RP	Received Power
RQ	Received Quality
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SINR	Signal to Interference and Noise
SISO	Single input Single Output

## 1. Introduction

As part of the minimum build out study for the National Park Service(NPS) of the National Mall and Memorial Parks, AECOM was tasked with modeling the network capacity of the Mobile Network Operators' (MNO) systems using publicly available information. At the direction of the Cybersecurity and Infrastructure Security Agency (CISA), AECOM worked to develop this methodology using data collected using standard drive testing methods. This document provides an outline of the ultimate path chosen and the sensitivity to the parameters included to the assumptions used. This paper ultimately is provided as an explanation of the underlying methodology to provide the interested parties a better understanding of the analysis supporting the minimum build-out study.

## 2. Data Collection and Analysis

AECOM's Engineers utilized PCTel Seahawk test equipment deployed in a backpack configuration while traveling on an electric scooter on the pathways of the study area and adjacent Capitol grounds. This data included testing of all commercially active bands for each of the four MNOs (AT&T, Verizon Wireless, T-Mobile, and Dish) while logging standard applicable 4G or 5G datasets including RSRP, RSRQ, CINR, RSSI and other standard parameter for physical and logical channels. The data was qualitatively compared with the CISA's and MNO's own test data to verify its validity.

The data was analyzed for each MNO on a carrier<sup>1</sup>-by-carrier basis. The modeling of capacity density was achieved using the algorithm below.

### 2.1 Development of the Algorithm

The CISA team set the goal for the study to increase the downlink capacity on the NAMA properties to five times the current capacity. During the process, we have defined "1x" as the current capacity as of the time of testing and "5x" as the capacity goal.

### 2.2 Original Algorithm

"1x" capacity (measured in Mbps) for a specific carrier was initially determined to be:

$$\text{Capacity} = \text{Occupied BW} \times \text{"Up to" Spectral Efficiency} \times \text{Overhead Factor}$$

Where:

- "Occupied BW" is defined as the carrier bandwidth in MHz. This is a carrier-specific characteristic reported within the test data.
- "Up to Spectral Efficiency" is defined as the "up to" limit based on the 3GPP curve. This was set at 4.5 bps/Hz.
- "Overhead Factor" for 1x is not only accounting for overhead but also for non-NAMA traffic levels. This factor is defined as the percentage of carrier capacity available for traffic geographically located on NAMA and is set at 55%, consistent with the recommendation by CISA and validated by each MNO in review calls. For 5x, this factor is increased to 80% as we assume 20% of the capacity is used for overhead and no traffic from outside of NAMA is carried by the system nodes.
- "Capacity" is the estimated available capacity in Mbps for a specified carrier of at a specific frequency, bandwidth, and technology.

After analysis of the results, it was determined that using an "up to" spectral efficiency would inadvertently overestimate the relative capacity of 1x due to the inherent increase in CINR (and thereby spectral efficiency) expected with a NAMA-based deployment.

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<sup>1</sup> "Carrier" is the physical channel utilized by the MNO. E.g., Verizon utilizes a 15 MHz 4G-LTE carrier in Band 2 (PCS).

## 2.3 Revised Algorithm

In response, the 1x calculation was modified to utilize the CINR average calculated from the results applied to the 3GPP curve<sup>2</sup> to calculate a theoretical spectral efficiency. Related to this, it was also determined that the spectral efficiency of 4G-LTE and 5G-NR would be considered equal (excluding MIMO-related factors). This resulted in a slight change to the formula:

$$\text{Capacity} = \text{Occupied BW} \times \text{Estimated Spectral Efficiency} \times \text{Overhead Factor}$$

It was also determined that the capacity calculation did not consider the additional capacity provided by multiple sectors serving the area. To address this, a threshold was created defining a serving sector as a carrier that is the best server for a given band for at least 5% of the measurement points in a zone. This further modified the formula:

$$\text{Capacity} = \text{Occupied BW} \times \text{Estimated Spectral Efficiency} \times \text{Overhead Factor} \times \text{Sector Count}$$

Finally, to normalize the results across the zones, the results were converted to “capacity density” (in bps/m<sup>2</sup>) by dividing the capacity by the area of the zone in square meters. A final 1x formula is therefore:

$$\text{Capacity Density} = \frac{\text{Occupied BW} \times \text{Estimated Spectral Efficiency} \times \text{Overhead Factor} \times \text{Sector Count}}{\text{Zone Area}}$$

This equation does not require modification for the 5x calculation, although the “Overhead Factor” value used is increased to 80% due to the dedicated nature of the nodes deployed.

## 3. Monte Carlo (Sensitivity) Analysis

To see the sensitivity of the results of the 1x and 5x calculations to the variables included in the formula, we can inspect the ranges of the variables and the magnitude of the variables. For each:

**Occupied Bandwidth:** a linear factor, this is fixed based on the deployed carriers deployed or to-be-deployed by each MNO.

**Spectral Efficiency:** this is the most non-linear term and is calculated, based on a best fit to the curve, from the equation:

$$\text{Spectral Efficiency} = \left( \log_2 \frac{\text{CINR}}{10} + 1 \right) \times \text{Shannon's Constant} \times \text{Shannon Ratio}$$

where:

- CINR is the CINR of the Reference Signal (RS-CINR)<sup>3</sup> for each carrier
  - For 1x calculations, this is calculated as the average CINR across the measurements
  - For 5x calculations, we have assumed a CINR of 6.0 dB for both 4G-LTE and 5G-NR
- Shannon’s Constant is 0.75 for both 4G and for 5G

<sup>2</sup> It should be noted that while the use of the generic 3GPP spectral efficiency curve is not strictly accurate due to the variances in spectral efficiency curves for specific manufacturers and other factors not considered here, it is appropriate to be used as a relative comparison of before and after spectral efficiency of the 1x and 5x modeling.

<sup>3</sup> This could have also been defined as the Synchronization Channel CINR (SC-CINR) but we have simply selected the Reference Signal. Any variance between the average of the RS-CINR and SC-CINR are very small, typically <0.5 dB, and therefore have minimal impact on the capacity calculation result.

- Shannon Ratio is the MIMO-induced spectral efficiency increase and is defined as
  - 1.0 for SISO
  - 1.5 for 2x2 MIMO
  - 1.8 for 4x4 MIMO

The variability and sensitivity of each of these components are as follows:

- CINR (1x): overall, any variability in this number is muted by it being a logarithmic function
  - CINR ranges across the testing are quite large (from < -10 dB to > 40 dB) so localized throughput may be significantly different than the normalized value (i.e., -90% to +900% at -10 dB and 40 dB respectively)
  - The CINR average across all zones is approximately 2 dB
- CINR (5x): assumptions in the analysis place this value at 6 dB
  - In comparison to the 2 dB CINR reference for 1x, the 5x 6 dB CINR results in about a 100% capacity increase over 1x
- Shannon's Constant: Arguably, that it should be increased to approximately 1.0 for 5G-NR. The overall effect of a change for 5G to 1.0 would result in a 33% increase in the capacity calculations for the dedicated system (or an increase to about 6.5x). Based on MNO feedback and real-world results, however, we have decided to hold this at 0.75 for both 4G-LTE and 5G-NR to best reflect anticipated results.
- Shannon Ratio: as with Shannon's Constant, this arguably could be increased. However, again based on MNO feedback of field results, we have determined that 1.5 for 2x2 MIMO (50% increase over SISO) and 1.8 for 4x4 MIMO (20% increase over 2x2 MIMO) are the best values to use. Any (small) variances in this variable would have a linear effect on the capacity results.

**Overhead Factor:** also linear, this variable would vary by sector but is applied as an average here. Based on sector best server areas and the known surrounding traffic patterns, this may be slightly exaggerated. Most importantly though, the value used for this factor varies between the 1x and 5x calculations and therefore creates a special sensitivity in the relative capacity increase. Specifically, if the actual percentage of NAMA-based traffic is lower than 55% a linear decrease in the 1x calculation would occur (e.g., 27.5% would cut the 1x value in half). Because the 5x Overhead Factor is independent of the 1x factor, if we are overestimating this for 1x our relative increase for the 5x calculations would in fact be higher than five times.

**Sector Count:** also linear, this variable is based on the threshold mentioned above applied to the test results. The current 5% of bins threshold is already near the lower end of what would seem reasonable and increasing it to 20% (probably the upper limit) would decrease the sector count (and therefore capacity) approximately by a factor of two. As with the Overhead Factor, if we are overestimating the Sector Count the 5x increase will be more than five-fold.

## 4. Conclusion

The final algorithm allows an accurate estimation of relative capacity increase between the existing ("1x") and the potential system build-out ("5x"). The algorithm used to calculate the system capacity for each MNO is, by necessity, a rough estimation. Based on publicly available information, the capacity density algorithm has evolved with a focus on better estimating the relative capacity increase (i.e., 1x vs. 5x) associated with a potential National Mall and Memorial Parks system build-out. The Overhead Factor and Sector Count factors stand out as the most influential in the calculation of relative capacity. For 1x, each factor is based on an estimated value while for 5x they are more specifically defined, meaning any overestimation of the factors could lead to an underestimation of the 5x increase. The other factors in the algorithm are more stable between the 1x and 5x calculations; the Spectral Density, while logarithmic, is believed to be a very well quantified relative value between the 1x and 5x calculations, and the remaining factors are all linear in nature with minimal ultimate impact on the relative capacity calculations.