Hyperlocal Ambient Air Pollution Mapping: Washington, DC 2024 Survey

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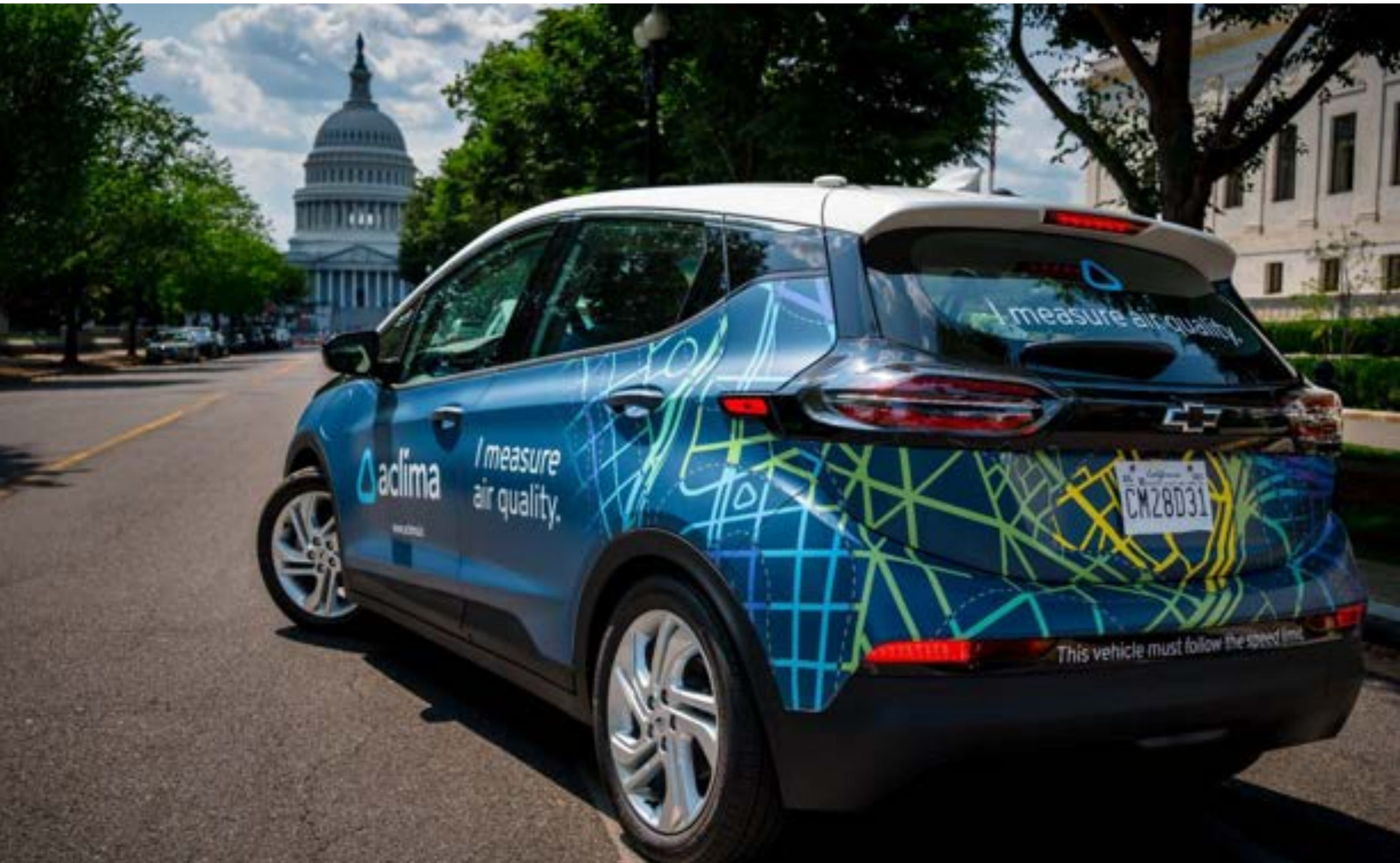


1 Introduction

Aclima is a mission-driven Public Benefit Corporation that deploys active moving fleets of vehicles instrumented with Aclima's proprietary vehicle-mounted mobile sensors and leading-edge sensing technologies, to measure and analyze concentrations of air pollutants and greenhouse gases over broad geographic areas and with hyperlocal, block-by-block resolution.

From August 8 through September 30, 2024, Aclima conducted six weeks of hyperlocal mobile air quality measurement in part or all of 7 wards, including 11 neighborhoods as specified by Washington, DC's Department of Energy and Environment (DOEE):

- Columbia Heights/Park View
- Howard/LeDroit Park
- Eckington/Edgewood/Bloomingdale
- Ivy City/Brentwood
- Trinidad/Carver
- South Capitol Hill/Barney Circle
- Buzzard Point
- River Terrace
- Greater Anacostia/Naylor Gardens/Good Hope
- Bellevue/Congress Heights
- Georgetown/Palisades

The monitoring areas were selected by DOEE, and the majority of the neighborhoods included in the monitoring project were chosen due to their history of disproportionate exposure to environmental hazards. Georgetown was chosen to provide comparison data to areas of the city that have been historically disadvantaged. DOEE held listening sessions in preparation for data collection and included community input in the final selection of the monitoring areas.

Three of the neighborhoods in the 2024 measurement campaign were previously monitored by Aclima in a 2-week pilot study in 2023 (Ivy City/Brentwood, Buzzard Point, and River Terrace). Results from the pilot study are documented in a report available via the DOEE website.

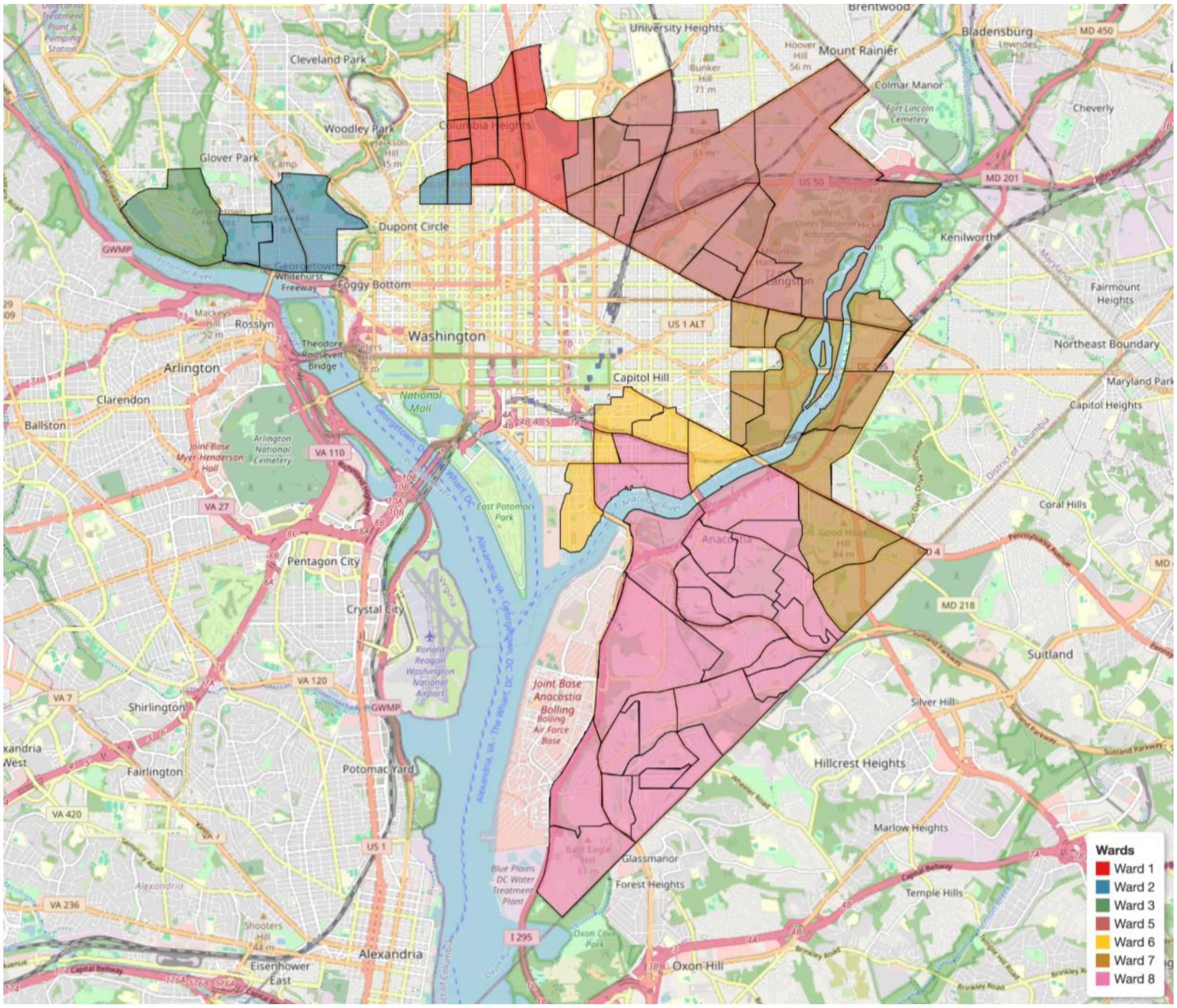


Figure 1. Locations of the wards where Aclima conducted hyperlocal monitoring. Boundaries inside the wards are census tract boundaries.

Measurements included CO_2, $PM_{2.5}$, NO_2, CO, O_3, black carbon, methane, and TVOCs.

The goal of this three-month study was to provide DOEE and community members with actionable analysis about local air pollution, and to support regulators in their mission to understand emissions hotspots of air pollution, target interventions, engage communities, benchmark progress, and optimize investments in local interventions for maximum impact.

Aclima uses its specialized mobile mapping and analysis to generate maps that show typical pollution concentrations with high spatial resolution ("Hyperlocal Maps") across a specific region, city, or community. These maps highlight typical concentrations over a defined measurement period, in this case a six-month period, illustrating areas of high and low pollution concentrations at the street level. The maps are only one of many data analyses that can be generated from mobile mapping, but represent a foundational result that fills a critical gap in understanding the spatial distribution of air pollution. Aclima uses measurements collected at a 1-second frequency to produce concentration estimates aggregated across ~100 m-diameter hexagons, allowing persistent pollution to be observed block-by-block in the monitored neighborhoods.

This report includes the following:

- Pollution maps, including median concentrations for $PM_{2.5}$, O_3, NO_2, CO, CO_2, and black carbon, aggregated to ~100 m-diameter hexagons, and plotted with colors representing median concentrations on the map. These visualizations will allow users to identify areas with the highest air pollution and detect spatial patterns among the different pollutants.
- Air Toxics maps, which highlight locations where repeated local enhancements of total volatile organic compounds (TVOCs) were observed. These maps can help in the identification of local TVOC hotspots.
- Potential air pollution areas of concern.

Aclima's analysis includes hourly time resolution for each of the monitored neighborhoods to provide insight into diurnal patterns of different air pollutants, helping to identify sources that might be active at specific times of day (e.g., traffic during rush hour). Because the duration of this monitoring was 6 weeks, longer-term analyses such as seasonality, day-of-week, and annual averages on a hyperlocal spatial scale are not possible.

The high spatial resolution of Aclima's resulting data products supports the identification of emissions sources as well as information on neighborhood-level variability in air pollution concentrations to support disparity analysis.

2 Methodology

Aclima's mobile air pollution monitoring fleets provide a flexible method to measure concentrations of a broad range of air pollutants and greenhouse gases over large, user-defined geographic areas and at higher spatial resolution than traditional monitoring techniques can provide. Aclima's fleet deploys on all public and accessible roadways within a user-defined area. The hyperlocal measurements produced by mobile monitoring can identify localized pollution sources as well as spatial gradients of pollutants across and between neighborhoods. Aclima's sensing system measures ambient air pollution and greenhouse gases at 1-second time resolution. Our mapping methodology is designed to drive each road multiple times, balancing sampling across different days of the week and times of day.

The mobile mapping method is not a reference method designed to support the National Ambient Air Quality Standards (NAAQS), which leverage a network of stationary regulatory monitors. Thus, data products from the mobile method do not support the assessment of compliance with NAAQS. We assess the single-pass mean segment data for conditions that, due to their sampling conditions or timing, are likely to result in biased estimates for typical ambient concentrations. The mobile mapping method is designed to complement NAAQS stationary networks by providing unique hyperlocal data.

2.1 One-second concentration measurements, geolocation, and aggregation into road segments

As Aclima's cars drive along publicly accessible roads, sensors within the Aclima Mobile Node (AMN) sample at a 1-second frequency. These measurements are associated in the Aclima database with a specific 1-s Global Positioning System (GPS) time and location. The raw GPS position information can at times be some meters from the road the car was driving due to the fundamental uncertainty in the GPS measurement as well as external factors, such as tall buildings, interfering with the ability of the GPS system to achieve a solid location fix. The position of the raw GPS data is corrected to align with the route driven by the car, often termed snapping to the road, reducing location uncertainty.

All 1-second measurements (Figure 2) are assigned to a standard-size hex bin (Figure 3) based on the location (latitude and longitude) of the data point. Within each hex bin, each unique hour is defined as a pass. Aclima calculates a mean (average) for all 1-second measurements taken for each pass of a specific hex bin to represent the concentrations of the roadways within that hex bin. The number of 1-second measurements for each hex bin varies based on the drive route, the speed limit of the street, and traffic conditions during the drive pass. Using hex bins for data aggregation allows multiple data points to be included in the calculation of the single-pass mean, improving the estimate of the mean pollution level at that location. The use of the single mean for a hex bin gives equal weight to all hex bins along a drive, regardless of how many 1-second data points were collected in each segment. The result is time-resolved data at the hex bin level rather than the 1-second level. A common way to visualize this data is to assign an individual road segment the same mean value as the hex bin containing that segment (Figure 4). In this way, all road segments falling within a given hex bin receive the same mean value.

The mean of the 1-second data points will be influenced by outliers, resulting in a collection of single-pass means that accommodate a greater degree of variability due to sampling than a collection of medians. Therefore, the resultant uncertainty estimates will be more conservative than if a single median had been selected.

Figure 2. Illustration of 1-second data points as red dots aligned to the route of the car.

Figure 3. 1-second data points are assigned to standard size hex bins.

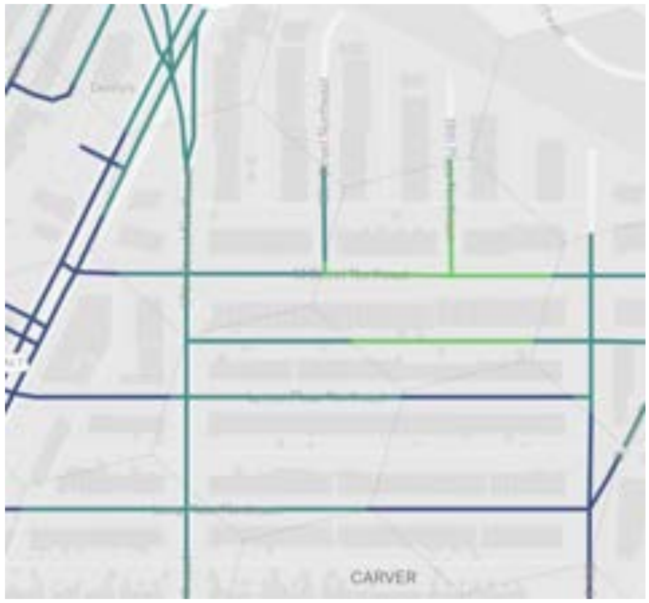


Figure 4: Road segments assigned a mean value (and therefore color coded) the same as the mean value of the hex bin containing that segment. All road segments falling within a given hex bin receive the same value.

2.2 Enhancement Event Detection Methodology

As the mobile platform moves through an emissions plume, a temporary increase in concentration may be observed over time, which we call an enhancement event. We define these enhancement events as localized elevation in concentration of a given pollutant within the plume that is measurably distinguishable from the ambient background. These individual enhancement events represent the detection of an emission event for a particular pollutant in the immediate vicinity of the source. The enhancement events benefit from simultaneous measurement of multiple pollutants, which allows for additional specificity in identifying the source of the emissions, and our multi-pass sampling approach, which supports identification of the consistency over time with which a specific location is impacted by a particular emissions source.

TVOC Methodology

TVOC enhancement events are calculated using data from our TVOC sensor, which is sensitive to a broad suite of VOC compounds. The enhancements are categorized into three different classes:

- Combustion: A TVOC peak that is measured at the same time as any peaks of Carbon Monoxide (CO), Carbon Dioxide (CO_2), or Nitric Oxide (NO) measurements;
- Evaporation: A TVOC peak that happens in the absence of peaks in any of the other pollutants Aclima measures;

- Mixed: A TVOC peak that happens in the absence of a CO, CO_2, or NO peak (see "Combustion"), but with the presence of other pollutants Aclima measures (example: Nitrogen Dioxide).

To indicate the consistency over time at a given location where enhancements are observed, we have calculated a "number of distinct days" metric to highlight areas that have seen an enhancement on more than one day. The distinct days metric is applied to the sum of peaks of all classes observed within a hexagonal cell approximately 140 m long and wide. The higher the number of distinct days, the higher the likelihood of finding a persistent source of TVOCs in the vicinity of this location.

3 Results

3.1 Hyperlocal mobile monitoring data allows for identification of air quality differences between blocks in a neighborhood

This section contains pollutant maps of the neighborhoods in DC included in the 2024 monitoring. Each pollutant is mapped separately, with segment median concentrations color-coded. Separate close-up maps of each neighborhood are provided in the appendix of this report.

There are also maps highlighting combustion-related and non-combustion TVOC hot spots (Figure 11).

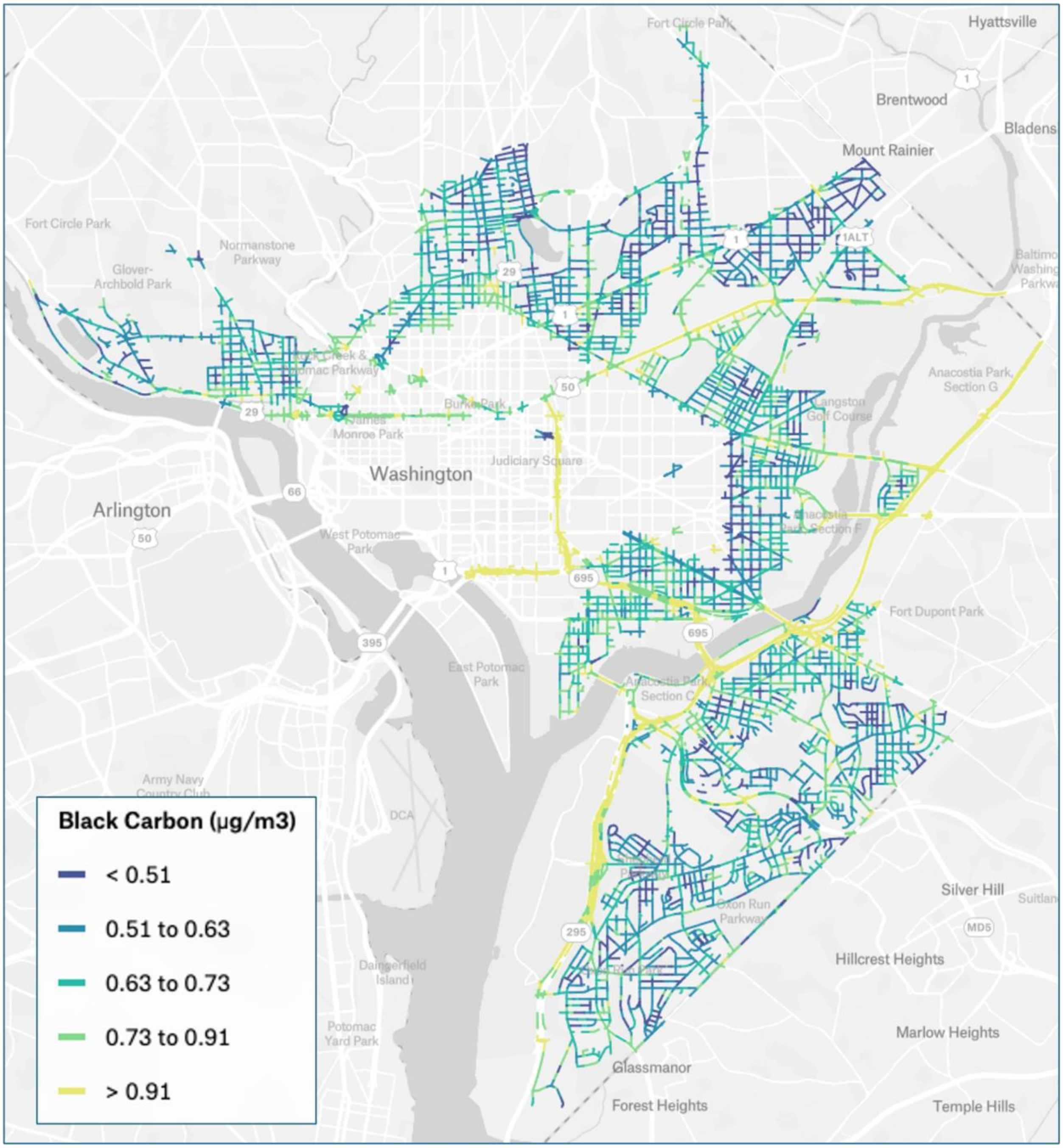


Figure 5. Segment medians of black carbon.
Note. This includes results from outside the monitored neighborhoods, due to vehicle movements between monitored areas.

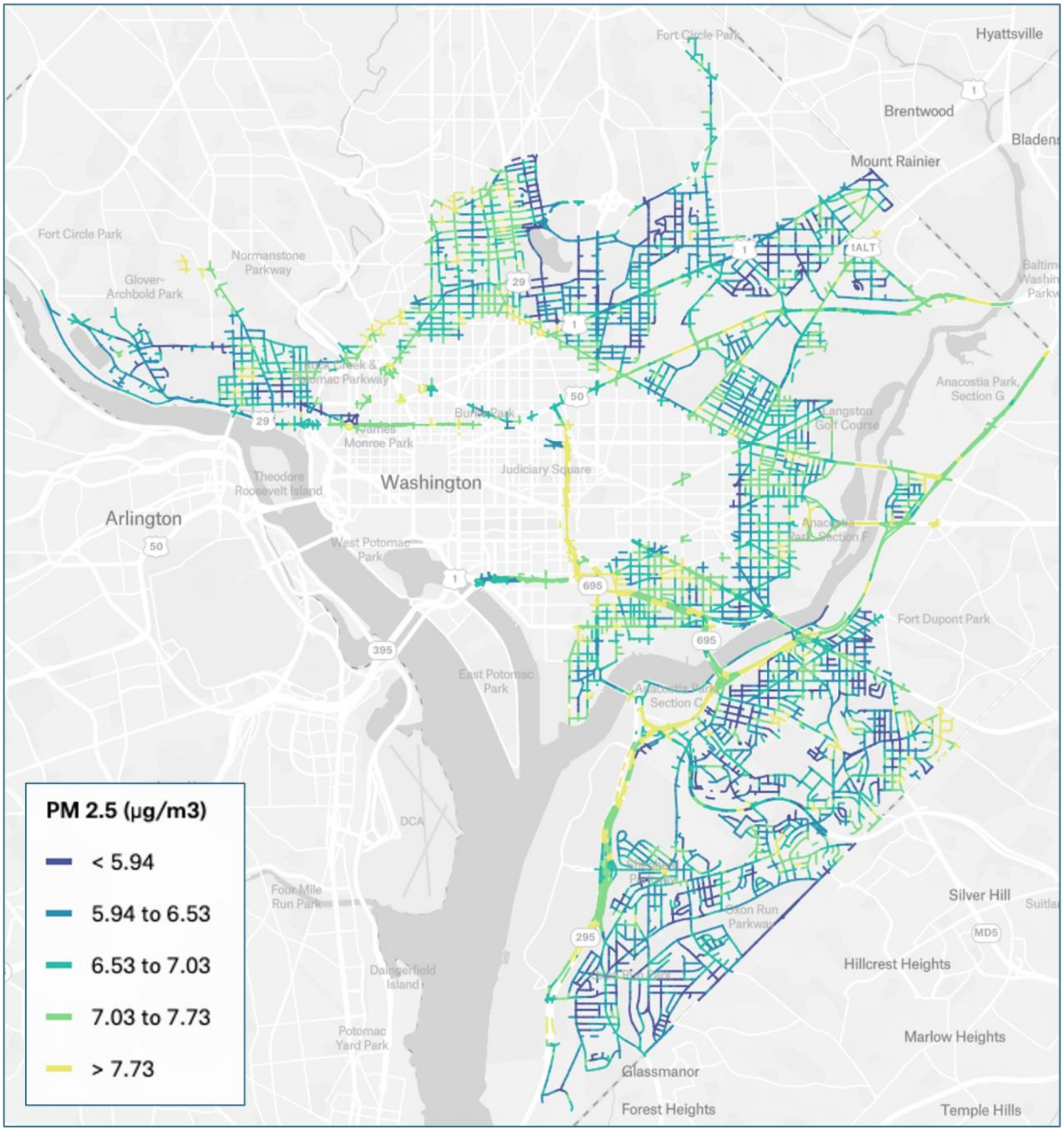


Figure 6. Segment medians of $PM_{2.5}$.
Note. This includes results from outside the monitored neighborhoods, due to vehicle movements between monitored areas.

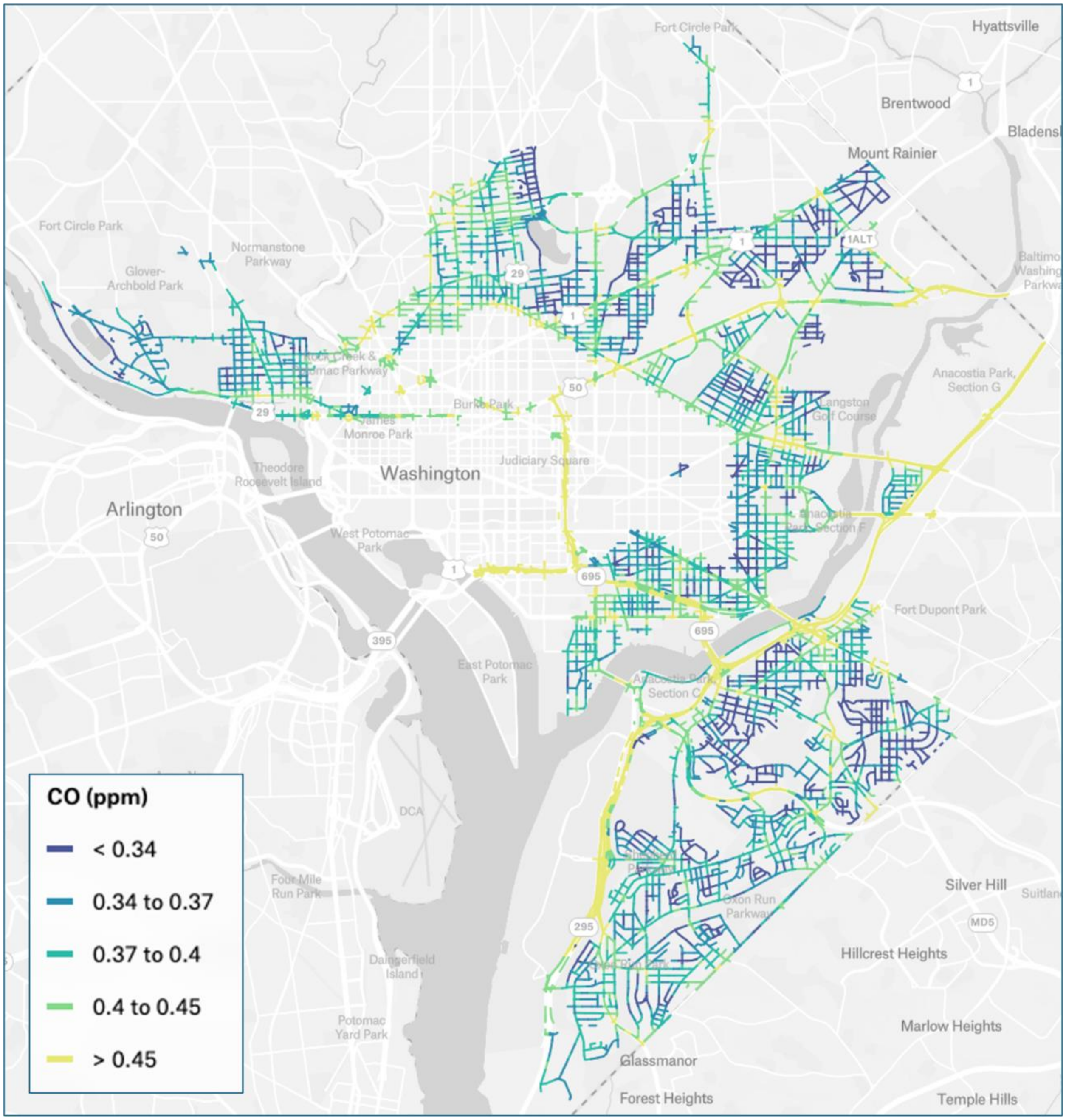


Figure 7. Segment medians of CO.
Note. This includes results from outside the monitored neighborhoods, due to vehicle movements between monitored areas.

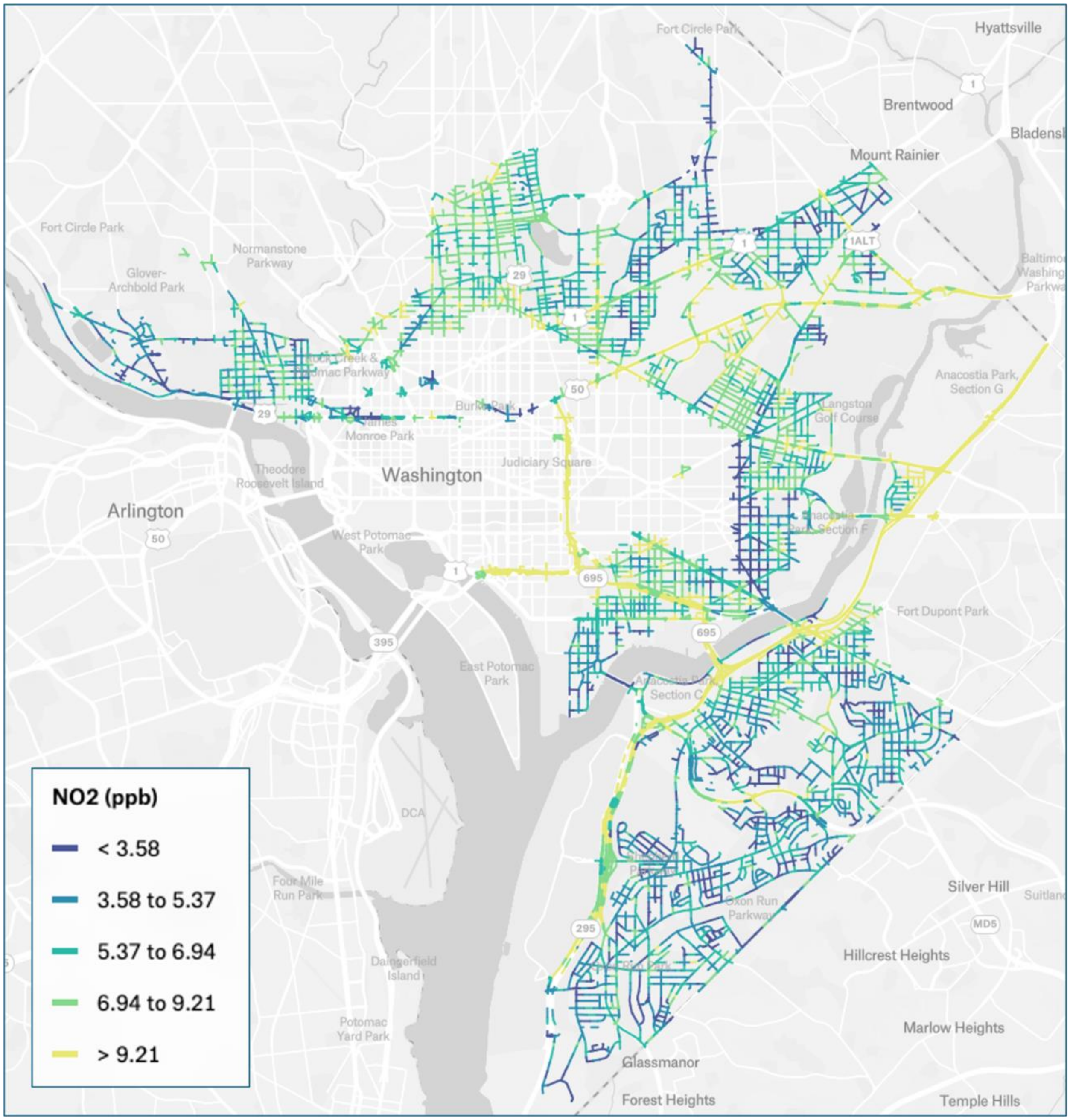


Figure 8. Segment medians of NO_2.
Note. This includes results from outside the monitored neighborhoods, due to vehicle movements between monitored areas.

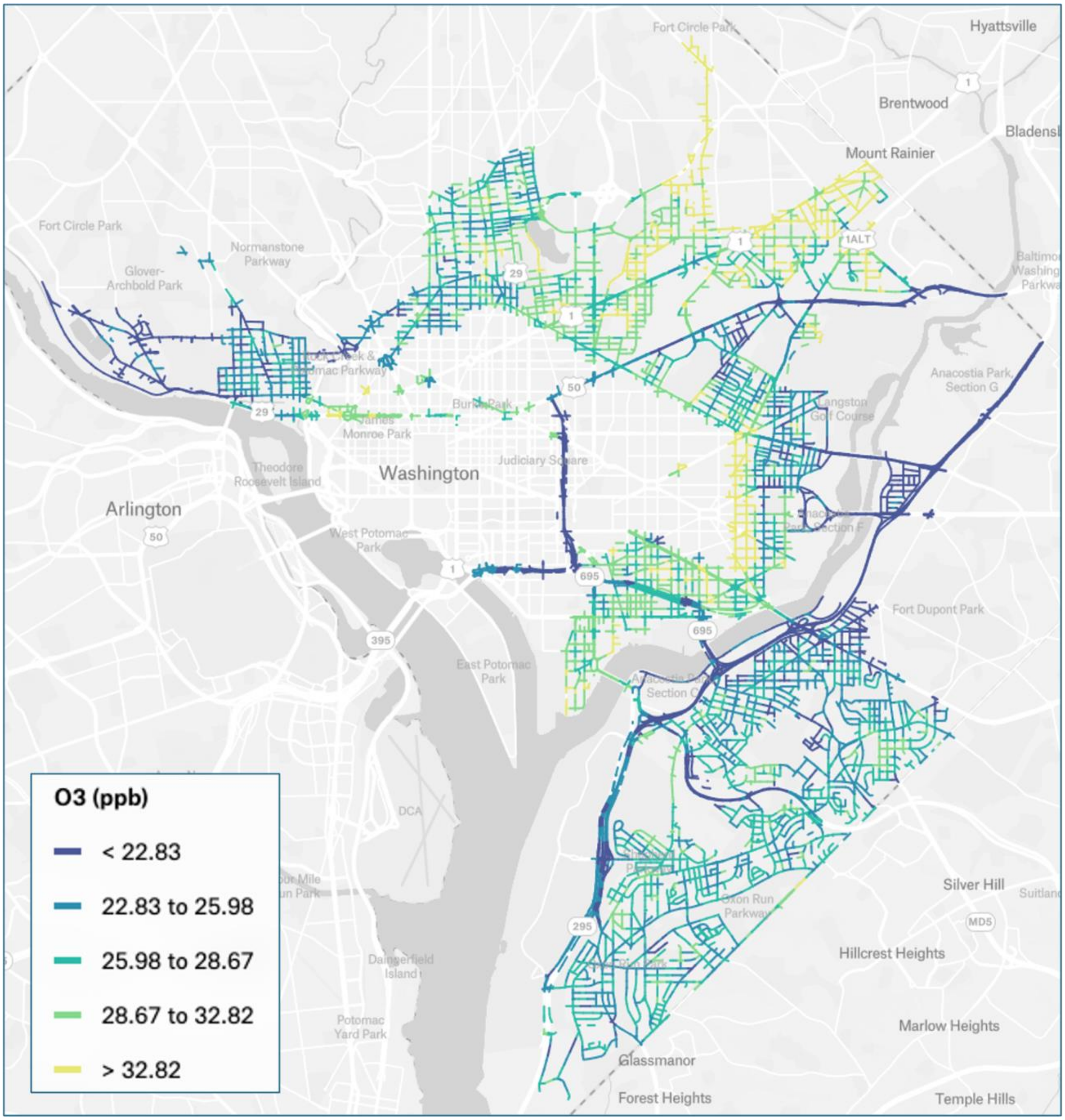


Figure 9. Segment medians of O_3.

Note. This includes results from outside the monitored neighborhoods, due to vehicle movements between monitored areas

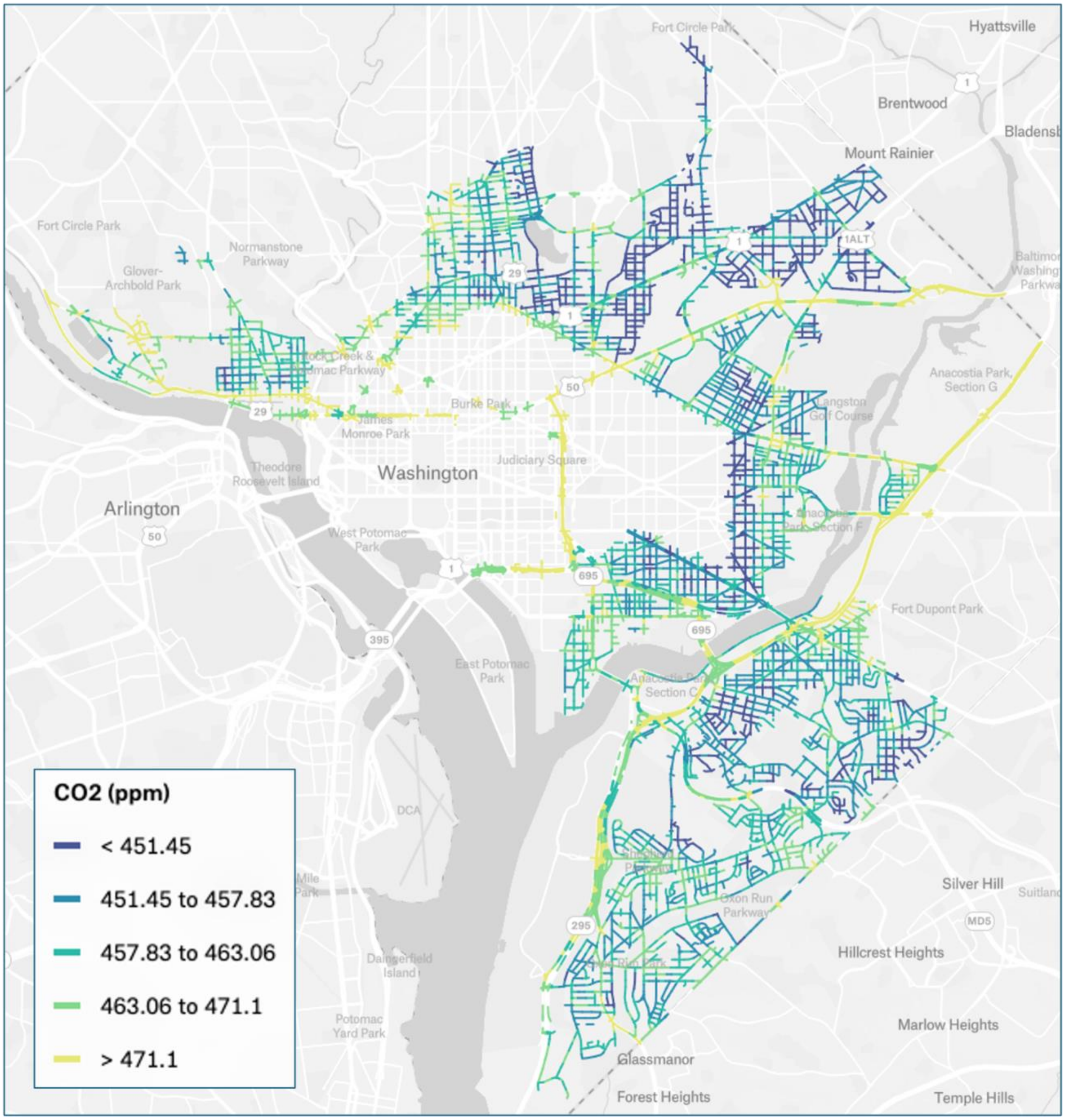


Figure 10. Segment medians of CO_2.
Note. This includes results from outside the monitored neighborhoods, due to vehicle movements between monitored areas

Figure 11 is a map of TVOC hotspots that highlights locations where repeated local enhancements of total volatile organic compounds were observed. Brentwood/Ivy City contained the most TVOC hot spots, including both combustion-related TVOCs and evaporative TVOCs from non-combustion sources.

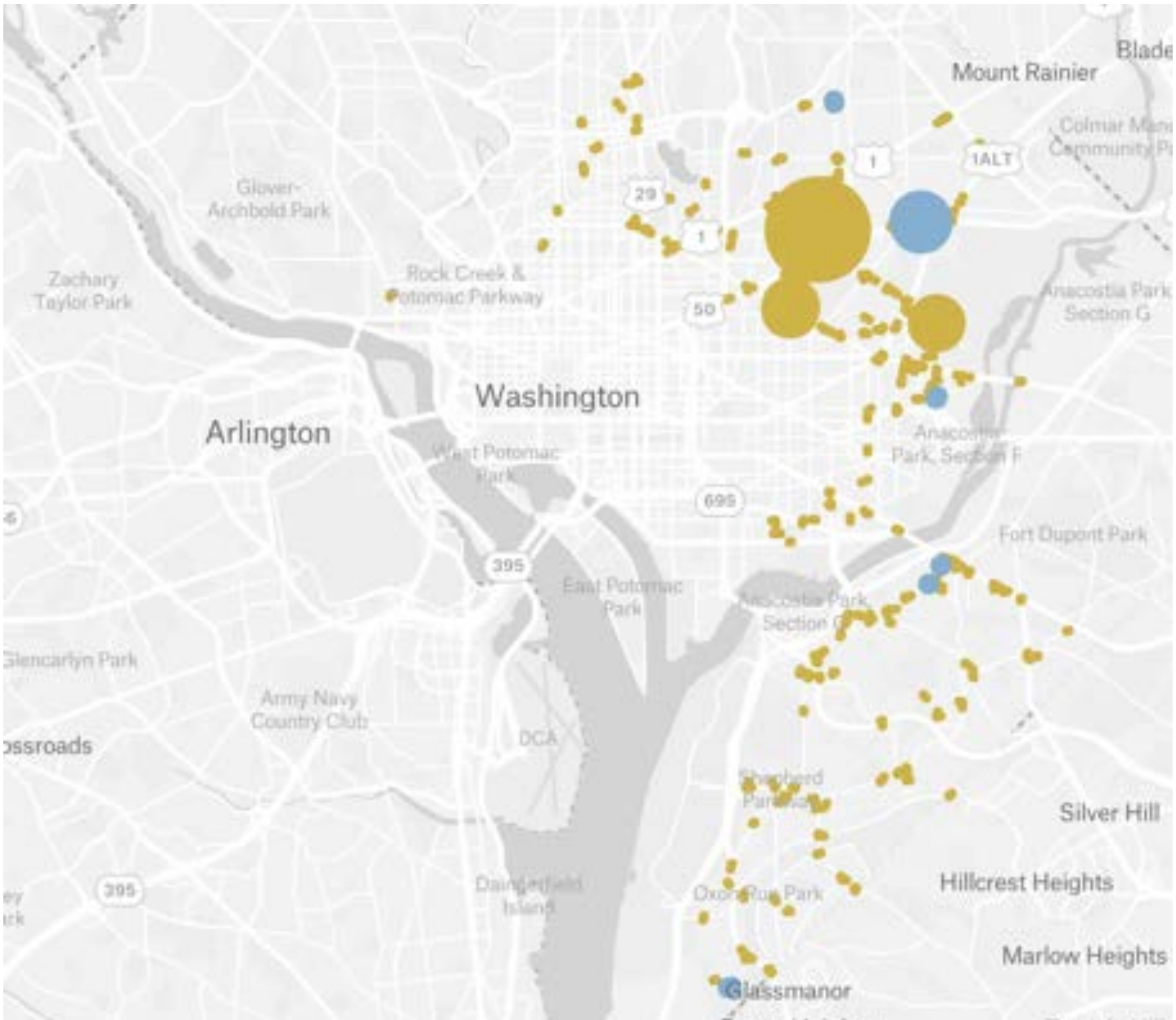
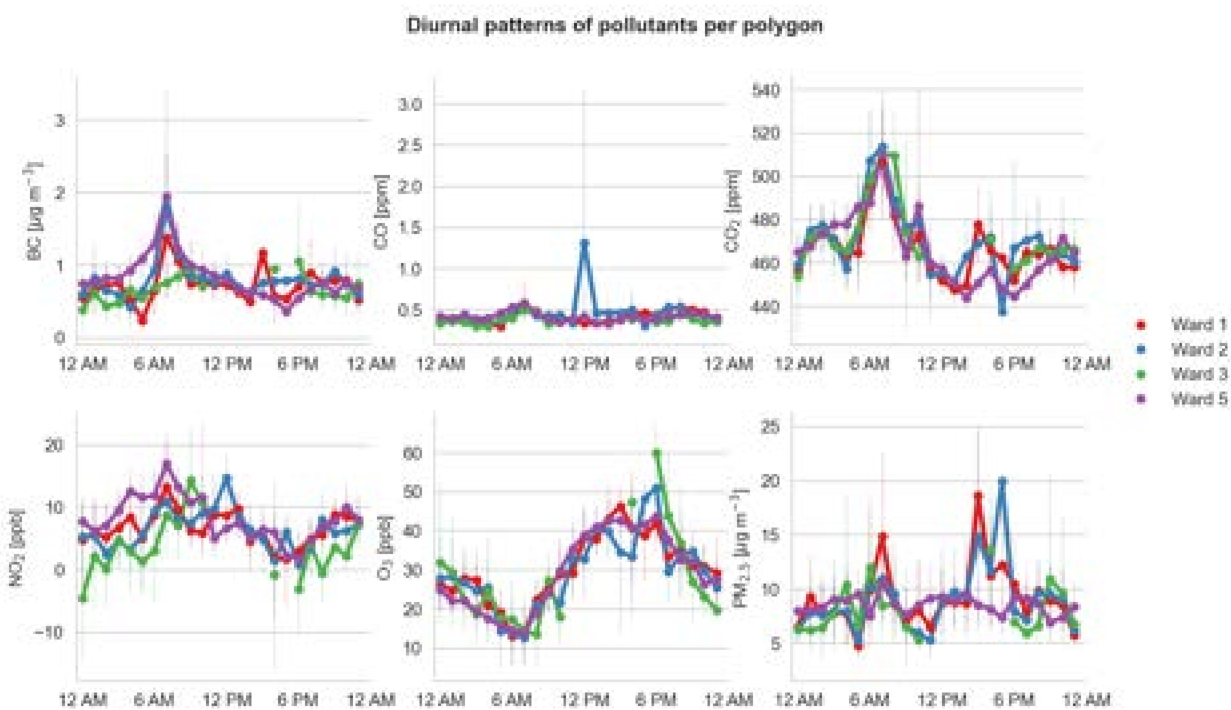


Figure 11. TVOC hot spots were detected at least three times during the study period, including combustion-related TVOCs (orange), and combined evaporative and mixed TVOCs (blue). The size of the markers indicates the strength of the TVOC peak, i.e., the concentration in ppm of the peak observed in the time series.

3.2 Diurnal patterns in pollutants

A key strength of mobile air quality monitoring is its ability to collect hyperlocal data, capturing differences in pollution levels from one city block to the next. This level of detail helps identify pollution hot spots that may be missed by fixed monitoring stations. Additionally, when mobile measurements are collected frequently enough across both time and space, it becomes possible to observe diurnal patterns — how pollution levels change throughout the day — in different neighborhoods. These patterns can reveal the influence of rush hour traffic, industrial activity, and other time-dependent sources, providing valuable insights for understanding local exposure and informing targeted pollution reduction strategies.

Figure 13 shows diurnal trends in concentrations of black carbon, CO, CO_2, NO_2, and $PM_{2.5}$ separated by Wards 1, 2, 3, and 5 and Wards 6-8. Note that there are not an equal number of data points collected in each ward at all times of day and that there is not necessarily an equal spatial distribution within each ward at all times of day (for example, high traffic roadways in certain wards may be more heavily sampled at particular times of day than at other times of day). As a result, a deeper analysis of the underlying data should be done to further explore any ward-to-ward or time-of-day differences that may be apparent in these plots before drawing final conclusions about the causes.



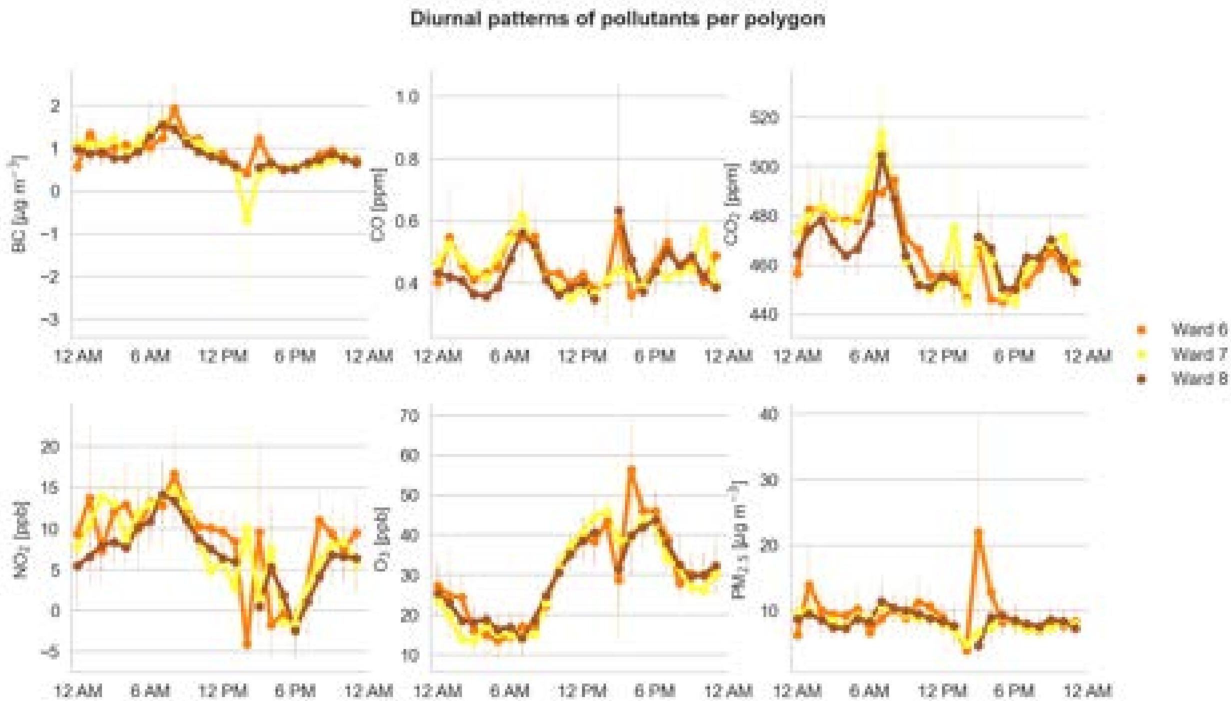


Figure 12. Hourly resolution diurnal plots for Wards 1,2,3, and 5 (top) and Wards 6-8 (bottom) by pollutant. Vertical bars indicate the 5th and the 95th confidence intervals.

3.3 Potential air quality areas of concern in the three regions

Examples of potential air quality areas of concern are included in the following sections. This is not an exhaustive list of all areas of concern that could be identified from this six-week study, but an example of analyses that can identify air pollution hotspots and potential sources.

3.3.1 Diesel impact and TVOCs in Ivy City

The section of New York Avenue, NE, runs alongside a large railyard and has some of the highest concentrations in the area of $PM_{2.5}$ and black carbon (Figure 14). Due to proximity to the railyard, pollutants measured here are likely from both road traffic and rail operations. This area was also identified as an area of concern in the two-week mobile monitoring study conducted by Aclima in 2023.

Figure 14. Segment medians of Black Carbon (top) and $PM_{2.5}$ (bottom) in the Ivy City area.

In addition to the diesel impact along New York Avenue, NE near the railyard, a TVOC hotspot was identified at and around a major intersection. This included both combustion-related TVOCs from the road traffic as well as numerous detections of evaporative TVOC plumes.

Figure 15. Hotspot of evaporative and mixed TVOCs (blue). The size of the markers indicates the strength of the TVOC peak, i.e., the concentration in ppm of the peak observed in the time series.

3.3.2 $PM_{2.5}$ and NO_2 in South Capitol Hill and Buzzard Point

South Capitol Hill and Buzzard Point both had elevated concentrations of $PM_{2.5}$.

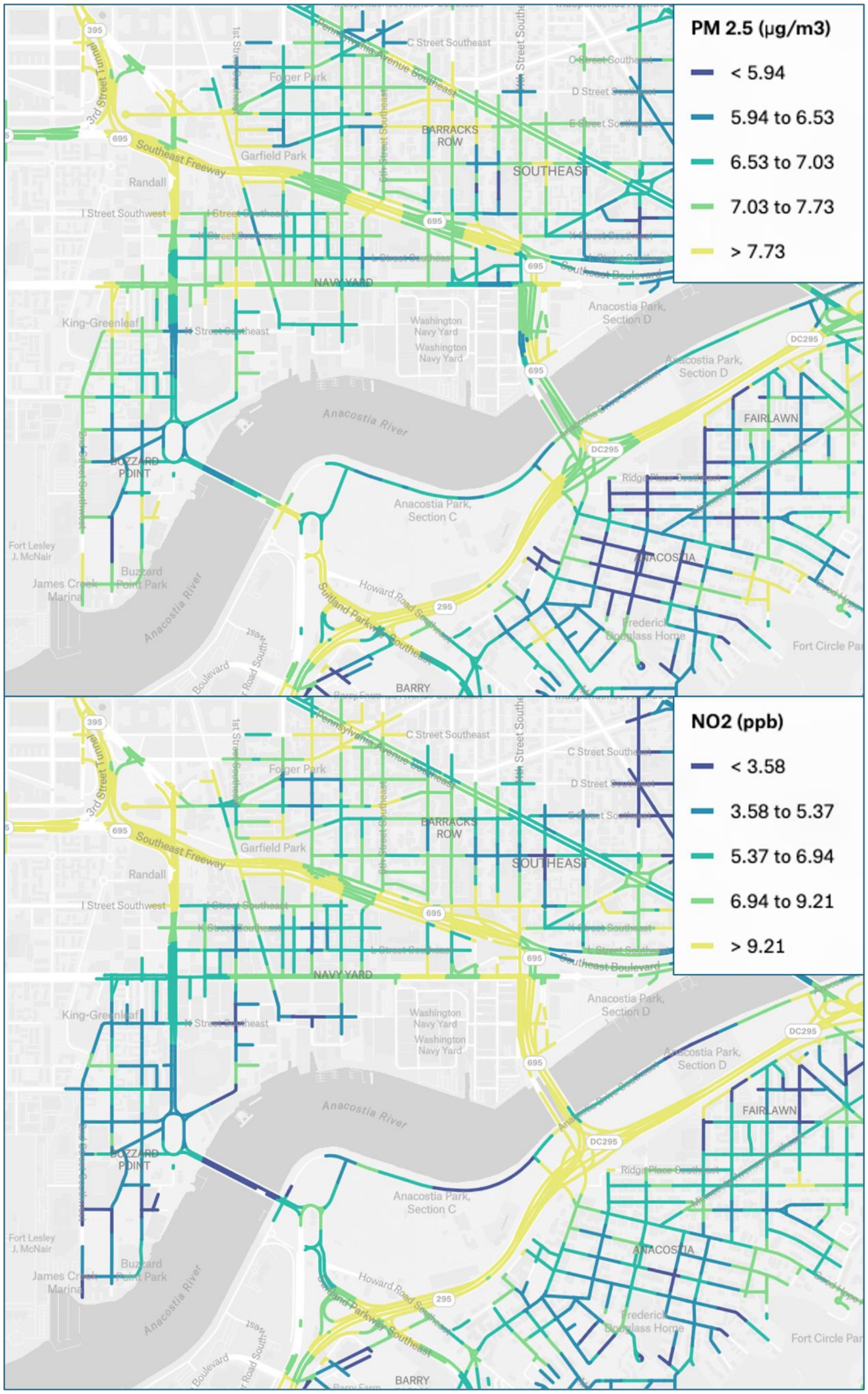


Figure 16. Segment medians of $PM_{2.5}$ (top) and NO_2 (bottom) in South Capitol Hill and Buzzard Point.

3.3.3 Diesel impact in River Terrace

Mayfair and the surrounding residential neighborhoods are impacted by proximity to the Anacostia Freeway and Benning Road. There is a strong spatial gradient in $PM_{2.5}$, BC, CO, and NO_2 that is highest on and near the two major roads and decreases in concentration with increasing distance from the major roads.

Figure 17. Segment medians of $PM_{2.5}$ (top) and BC (bottom) in River Terrace.

3.3.4 $PM_{2.5}$ in Anacostia

A $PM_{2.5}$ hotspot was identified in Anacostia on U Street, SE. No hotspots were detected in the same area for any of the other pollutants, indicating that the source is likely not combustion-related and could be due to intermittent activities such as construction. The elevated concentrations were detected on multiple blocks in either direction of the suspected source area, demonstrating the spatial impact of this source on ambient concentrations of $PM_{2.5}$.

Figure 18. Segment medians of $PM_{2.5}$ in Anacostia.

3.4 Comparison with 2-week 2023 results

Three of the neighborhoods monitored during the two-week campaign in 2023 were also monitored in this 6-week campaign. Figure 19 below shows box plots of concentrations for each of the pollutants in the three neighborhoods for the two weeks in 2023, compared to the six weeks in 2024. Figures 20-22 show the differences in median $PM_{2.5}$ and black carbon concentrations for the three neighborhoods that were monitored in both years, with blue/red colors denoting decreases/increases from 2023 to 2024.

Because the time of year sampled in 2023 (June) differed slightly from the time of year sampled in 2024 (August-September), these comparisons might also be influenced by minor seasonal variability. Moreover, we note that in June 2023, much of the eastern U.S. was experiencing emissions from massive wildfires occurring across Canada. This could explain why concentrations of black carbon and $PM_{2.5}$ were significantly higher during the 2023 measurement campaign. Ultimately, as these two monitoring periods were both snapshots in time, the change in concentration may not represent a longer-term trend. But the presence or absence of individual hotspots year to year can be useful for identifying urban sources that impact air quality on the hyperlocal scale.

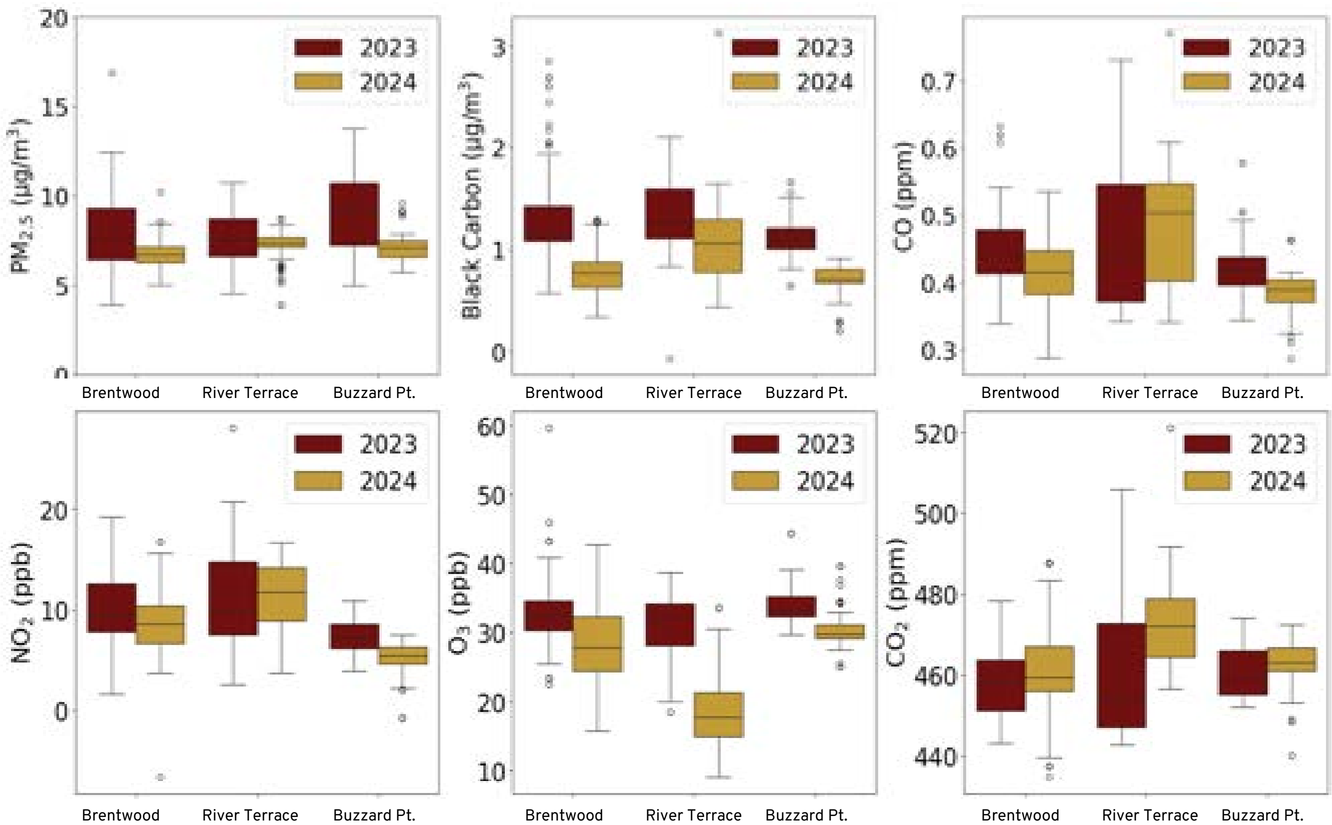


Figure 19. Box plots of segment median concentrations in River Terrace, Buzzard Point, and Ivy City/Brentwood.

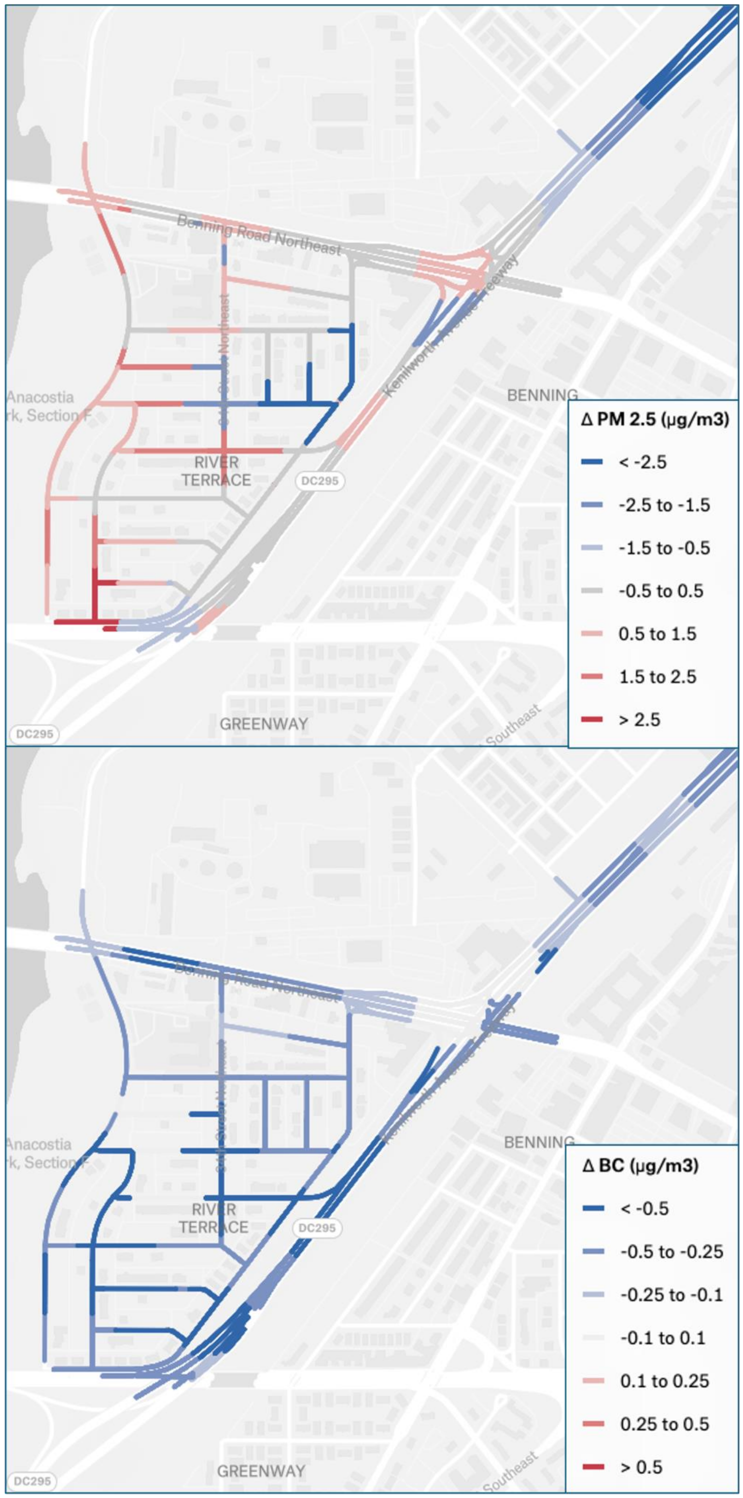


Figure 20. Segment median concentration differences in River Terrace for $PM_{2.5}$ and black carbon between 2023 and 2024. The blue color represents 2024 concentration lower than 2023 concentration and the red color represents 2024 concentration higher than 2023 concentration.

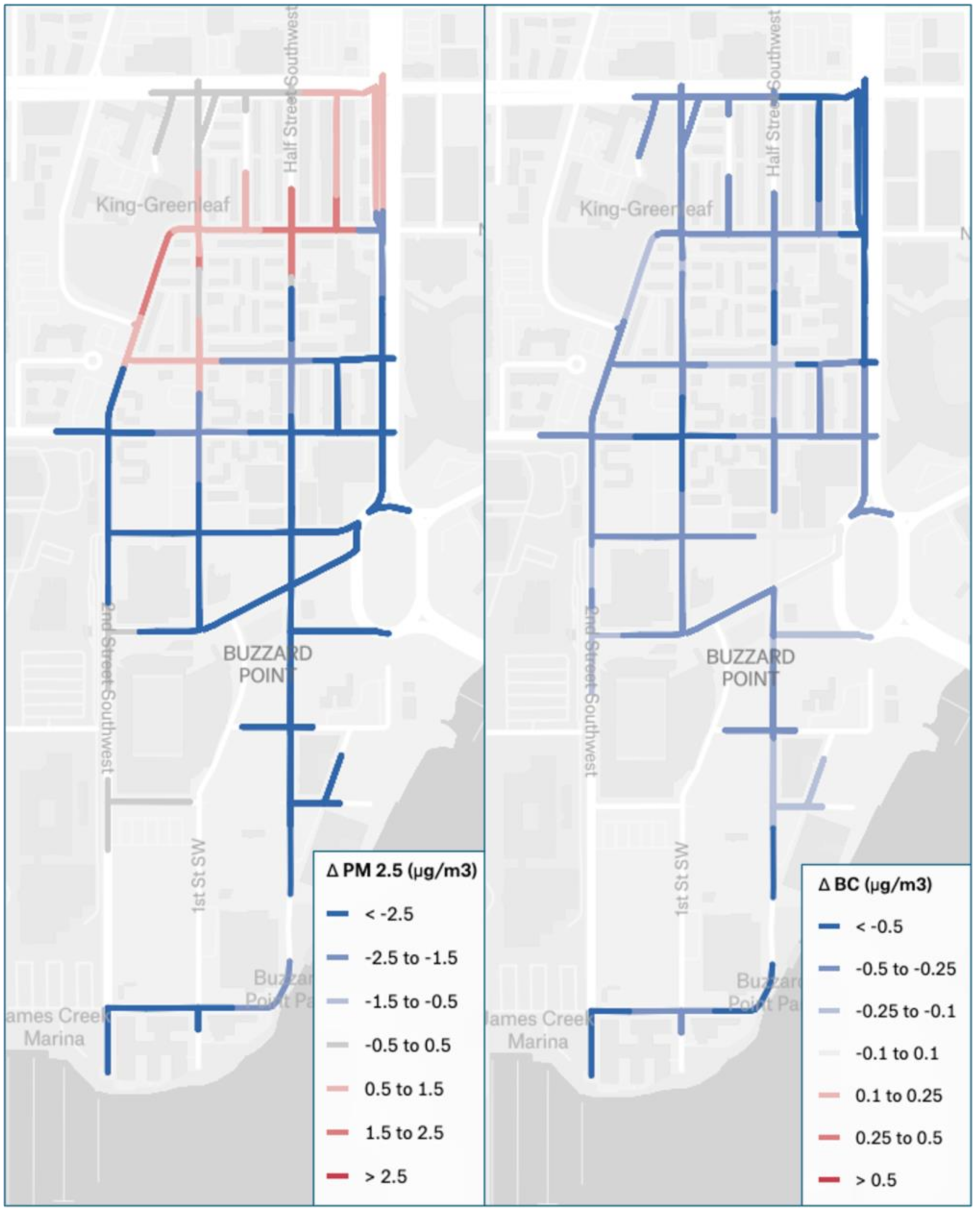


Figure 21. Segment median concentration differences in Buzzard Point for $PM_{2.5}$ and black carbon between 2023 and 2024. The blue color represents 2024 concentration lower than 2023 concentration and the red color represents 2024 concentration higher than 2023 concentration.

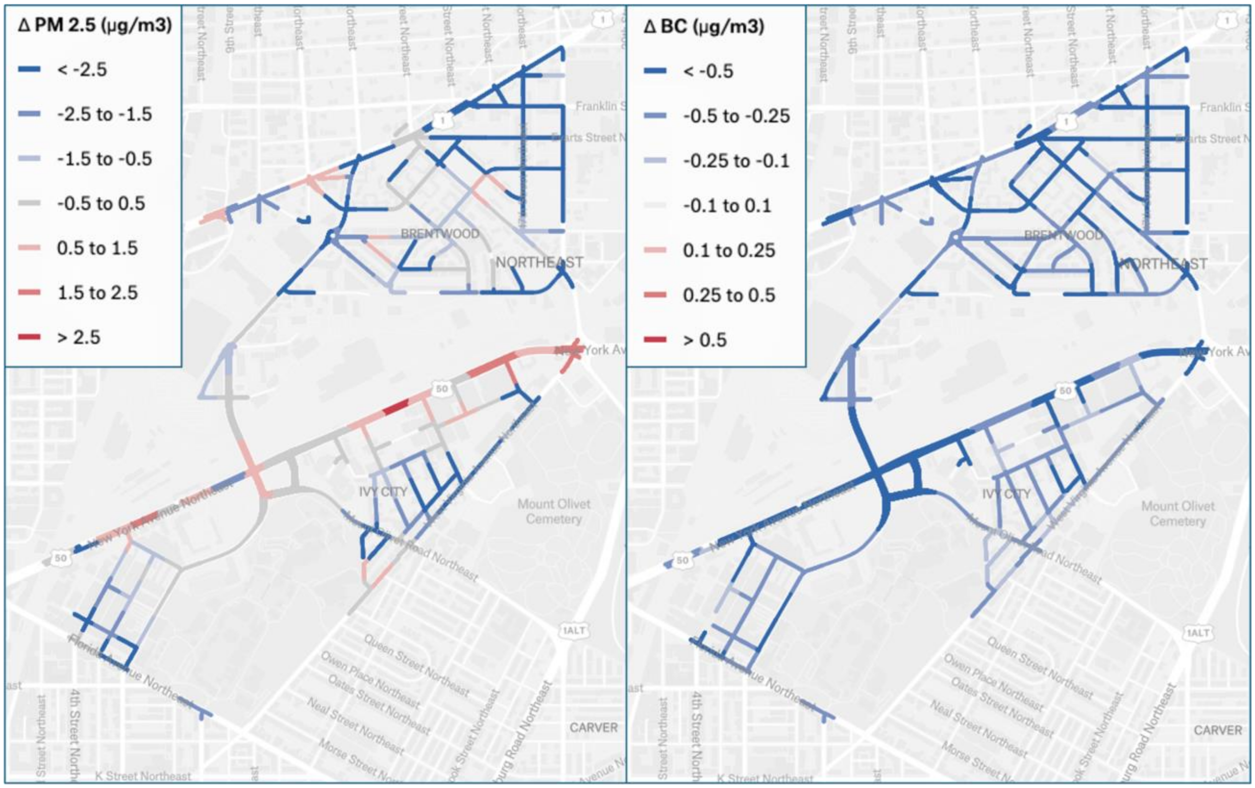


Figure 22. Segment median concentration differences in Ivy City/Brentwood for $PM_{2.5}$ and black carbon between 2023 and 2024. The blue color represents 2024 concentration lower than 2023 concentration and the red color represents 2024 concentration higher than 2023 concentration.

4 Conclusions

This six-week mobile monitoring campaign captured significant spatial variability in each of the measured pollutants, as well as identifying actionable pollution hotspots in many of the neighborhoods. One of the most important sources of pollution in urban areas, including Washington, DC, continues to be heavily trafficked roadways, and diesel emissions, in particular, can result in elevated concentrations of black carbon in areas near major roadways. Additional day-of-week, monthly, and seasonal analyses can be derived from a longer analysis campaign.

Continuous stationary monitoring captures a temporally complete but spatially limited picture of air pollution in a complex urban area. Mobile monitoring provides an important and complementary dataset to regulatory monitoring, capturing the hyperlocal differences in air pollution from block to block, identifying trends and pollution sources, and providing actionable insights to all of the diverse communities in Washington, DC.

Appendix

This section includes additional statistical analyses comparing Aclima's mobile monitoring data with nearby regulatory sites. For a more comprehensive analysis of Aclima's mobile data compared to regulatory sites, as well as a detailed description of the entirety of Aclima's QA system, please refer to Section 5.1 in the "Hyperlocal Ambient Concentration Estimate Validation and Quality Assurance System" document. Additionally, typical performance metrics for all of Aclima's sensors can be found in Table 5 of the "Mobile Ambient Air Pollution Measurement Quality Assurance System" document.

General Findings

- The stationary collocation comparison at the McMillian site found that all pollutants are within expected levels of systematic bias (quantified as MBE) between the Aclima and DOEE network. However, the range of concentrations experienced over the course of this collocation time period for pollutants such as CO, $PM_{2.5}$, and NO_2 was quite low, and as such, the bias estimated from this data set may not reflect what would have been found had the data collection period occurred at a different time period when concentrations were higher and more variable.
- There was more variability in mobile-to-stationary comparison than stationary colocation, which is expected due to spatial variability that exists even within a 250m radius of the source and with on-road measurements of pollutants. This is shown in the low R^2 values and high MBE values in the mobile-to-stationary comparisons. Generally, higher and more variable concentrations are observed in the on-road mobile measurements than at fixed regulatory sites. This is observed in particular for $PM_{2.5}$ and CO.
- Overall, both the stationary and mobile comparisons demonstrated that the AMN captured trends over time in each pollutant.

A.1 Mobile monitoring comparison with regulatory monitoring sites

This analysis allows for a device-level comparison of the mobile sensors to regulatory measurements and is primarily intended to determine whether any systematic bias is present between the mobile measurements and the existing regulatory network. This mobile-to-stationary comparison is different from traditional collocations as defined by the EPA (which requires measurements within 10m horizontally and 3m vertically according to 40 CFR 58), and, therefore, the comparison metrics should not be interpreted directly as performance metrics of Aclima's mobile sensors. There are a number of factors that can influence these comparisons, including some factors that cannot be controlled and can vary from site to site and over time, such as hyperlocal variability in concentrations around the sites and the range of concentrations observed over the full collection time period (in this case, limited to 2 weeks). These factors typically impact precision based metrics such as RMSE, MAE, and R^2; however, we have found that with a suitable number of comparison data points collected over enough distinct hourly time periods, these mobile to stationary comparisons can often be a good indicator of the presence of systematic bias or drift over time (estimated as mean bias error or MBE) in measurement between Aclima's mobile measurements and the local regulatory measurements.

This data set was compiled using all 1-second data points collected within a 250m radius of any regulatory site and aggregated to an hourly time scale to align with the hourly measurements of each regulatory site. There is no minimum completion threshold applied to the mobile data, so there is a variable number of data points aggregated for the comparison, and in many cases, as little as a few minutes may be used as a comparison point to an hourly average. From these hourly measurement pairs, a series of comparison metrics and figures is generated to give the hourly results. Additionally, the hourly measurement pairs are aggregated to daily time scales, from which a second set of daily metrics and figures is generated. Tables A.1-3 below show the comparison metrics for all regulatory sites and Aclima's mobile dataset within a 250m radius, combined by pollutant.

Data from four EPA monitoring sites were used for the analysis. The list of sites and available pollutants are summarized in Table A1.

Table A1: List of sites and available pollutants

Regulatory Site	Available pollutants
DC Near Road	CO, NO_2, $PM_{2.5}$
King Greenleaf Rec C	$PM_{2.5}$
McMillan Reservoir	Black Carbon, CO, NO_2, O_3, $PM_{2.5}$
River Terrace	NO_2, O_3, $PM_{2.5}$

Table A2: Hourly comparison metrics across all sites for each pollutant

Pollutant	MBE	MAE	R^2	precision
Black Carbon (1 site)	0.11 μg/m³	0.28 μg/m³	0.37	0.31 μg/m³
CO (2 sites)	0.17 ppm	0.19 ppm	0.18	0.19 ppm
NO_2 (3 sites)	0.86 ppb	6.32 ppb	0.4	6.96 ppb
O_3 (2 sites)	0.47 ppb	3.86 ppb	0.89	4.07 ppb
$PM_{2.5}$ (4 sites)	1.99 μg/m³	3.25 μg/m³	0.36	3.17 μg/m³

Table A3: Hourly comparison metrics for individual sites for each pollutant

Pollutant	Regulatory site	MBE	MAE	R^2	Precision
Black Carbon	McMillan Reservoir	+0.11 μg/m³	0.28 μg/m³	0.37	0.31 μg/m³
CO	DC Near Road	+0.26 ppm	0.28 ppm	0.17	0.23 ppm
CO	McMillan Reservoir	+0.04 ppm	0.08 ppm	0.21	0.08 ppm
NO_2	DC Near Road	+1.86 ppb	7.8 ppb	0.35	9.04 ppb
NO_2	McMillan Reservoir	+0.09 ppb	4.5 ppb	0.17	4.76 ppb
NO_2	River Terrace	+0.16 ppb	6.15 ppb	0.27	6.37 ppb
O_3	McMillan Reservoir	-0.69 ppb	3.28 ppb	0.91	3.55 ppb
O_3	River Terrace	+1.94 ppb	4.59 ppb	0.86	4.71 ppb
$PM_{2.5}$	DC Near Road	+3.17 μg/m³	4.03 μg/m³	0.1	3.81 μg/m³
$PM_{2.5}$	King Greenleaf Rec C	+2.46 μg/m³	3.00 μg/m³	0.73	2.31 μg/m³
$PM_{2.5}$	McMillan Reservoir	+0.95 μg/m³	3.16 μg/m³	0.39	3.51 μg/m³
$PM_{2.5}$	River Terrace	+0.94 μg/m³	2.29 μg/m³	0.6	2.45 μg/m³

Table A4: Daily aggregated comparison metrics across all sites, for each pollutant

Pollutant	MBE	MAE	R^2	precision
Black Carbon (1 site)	0.16 μg/m³	0.24 μg/m³	0.33	0.32 μg/m³
CO (2 sites)	0.16 ppm	0.18 ppm	0.08	0.18 ppm
NO_2 (3 sites)	1.34 ppb	5.46 ppb	0.41	5.4 ppb
O_3 (2 sites)	-0.1 ppb	8.77 ppb	0.41	9.34 ppb
$PM_{2.5}$ (4 sites)	2.3 μg/m³	2.79 μg/m³	0.59	2.97 μg/m³

Table A5: Daily comparison metrics for individual sites for each pollutant

Pollutant	Regulatory site	MBE	MAE	R2	Precision
Black Carbon	McMillan Reservoir	+0.16 μg/m³	0.24 μg/m³	0.33	0.32 μg/m³

CO	DC Near Road	+0.29 ppm	0.3 ppm	0.01	0.21 ppm
CO	McMillan Reservoir	+0.04 ppm	0.07 ppm	0.09	0.07 ppm
NO_2	DC Near Road	+2.56 ppb	6.59 ppb	0.34	6.68 ppb
NO_2	McMillan Reservoir	+0.42 ppb	4.25 ppb	0.03	4.54 ppb
NO_2	River Terrace	+0.96 ppb	5.56 ppb	0.27	6.04 ppb
O_3	McMillan Reservoir	+1.18 ppb	7.45 ppb	0.55	8.6 ppb
O_3	River Terrace	-1.72 ppb	10.44 ppb	0.11	11.28 ppb
$PM_{2.5}$	DC Near Road	+3.44 μg/m³	3.58 μg/m³	0.57	3.85 μg/m³
$PM_{2.5}$	King Greenleaf Rec C	+2.74 μg/m³	3.1 μg/m³	0.72	2.77 μg/m³
$PM_{2.5}$	McMillan Reservoir	+1.35 μg/m³	2.03 μg/m³	0.69	2.78 μg/m³
$PM_{2.5}$	River Terrace	+1.61 μg/m³	2.41 μg/m³	0.67	3.12 μg/m³

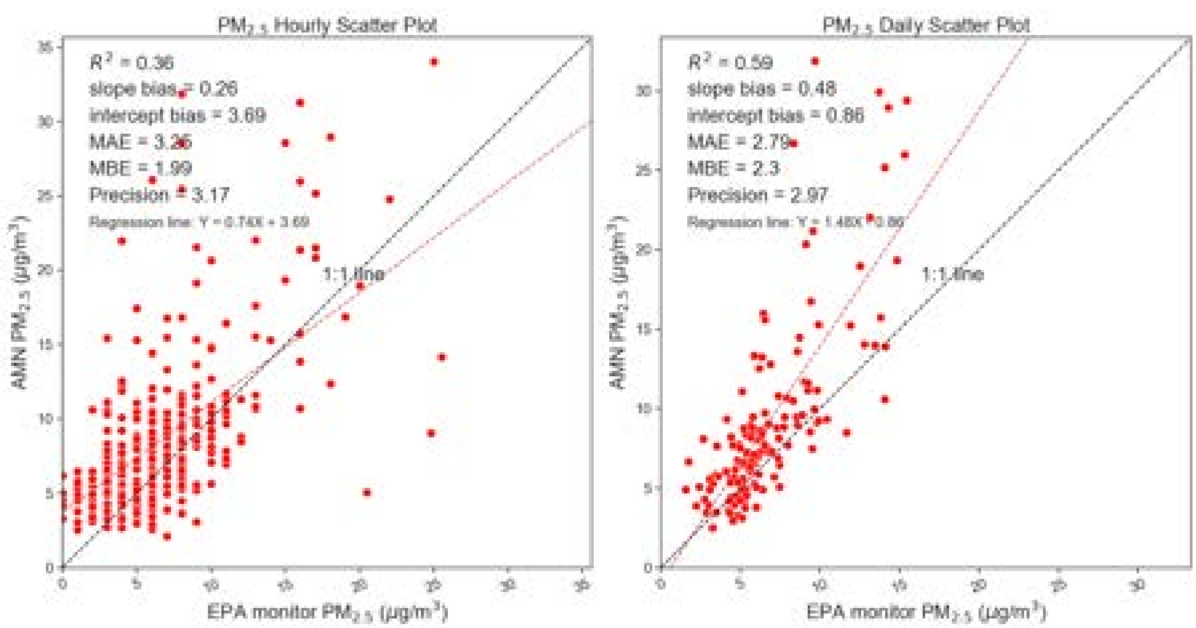


Figure A1: Comparison of hourly (left) and daily (right) mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for $PM_{2.5}$ [μg/m3], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level performance.

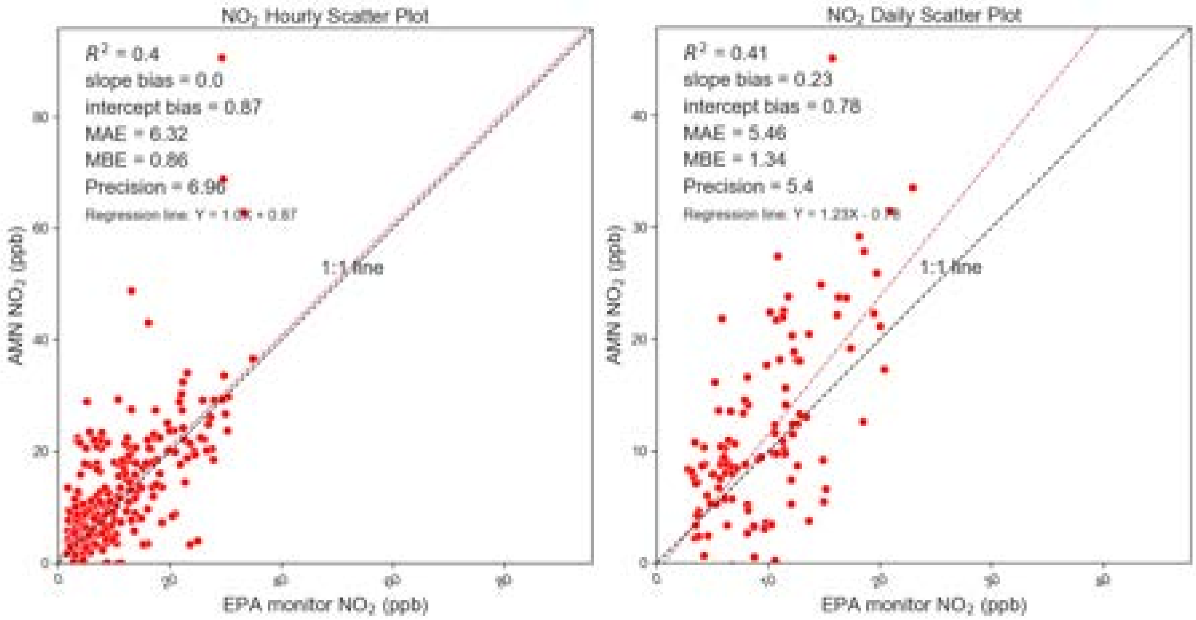


Figure A2: Comparison of hourly (left) and daily (right) mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for NO_2 [ppb], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level performance.

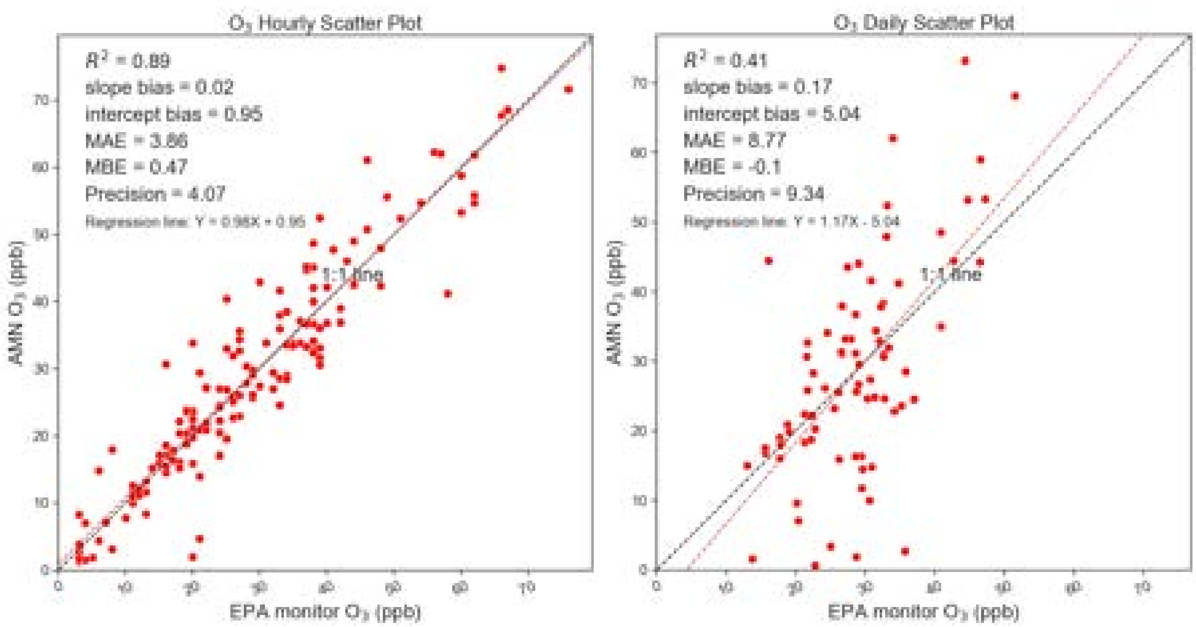


Figure A3: Comparison of hourly (left) and daily (right) mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for O_3 [ppb], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level performance.

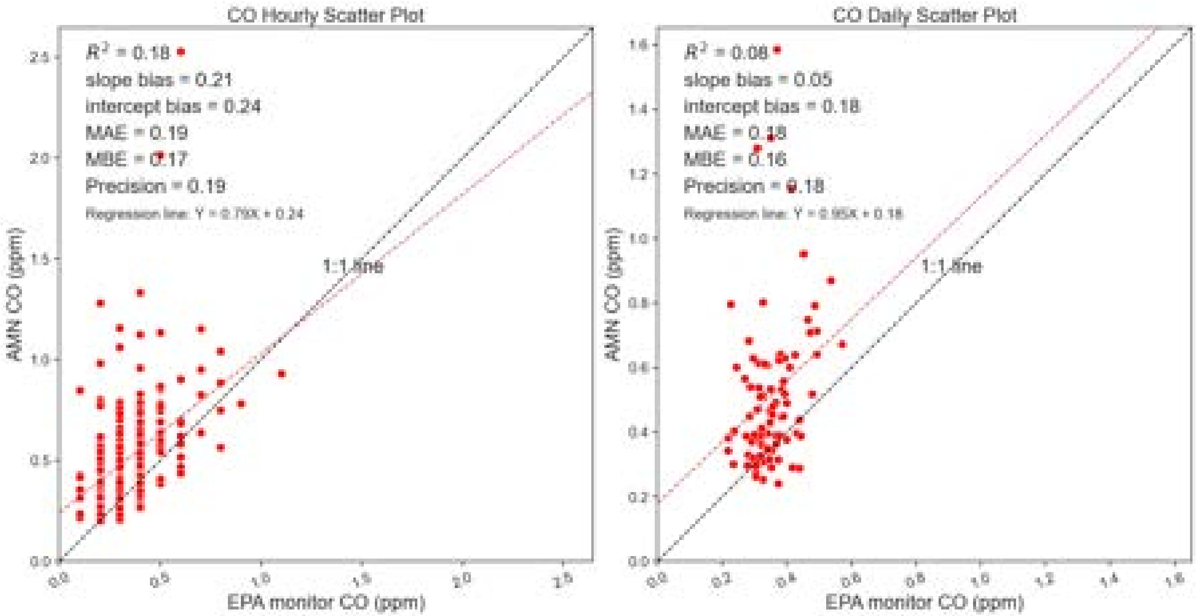


Figure A4: Comparison of hourly (left) and daily (right) mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for CO [ppm], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level performance.

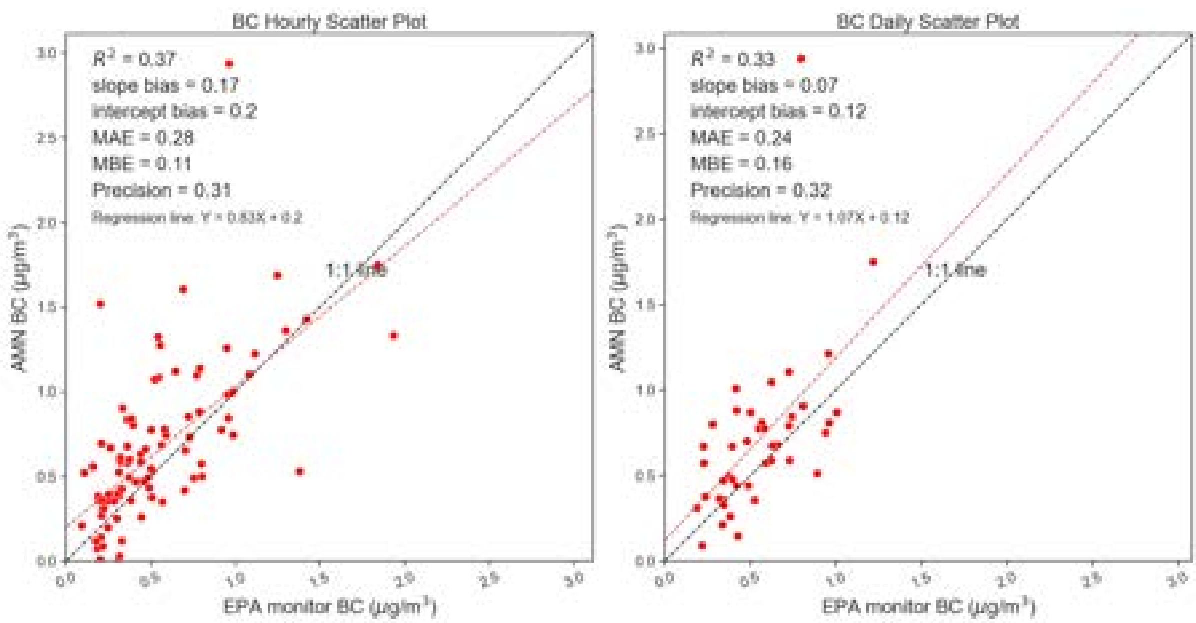


Figure A5: Comparison of hourly (left) and daily (right) mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for black carbon [μg/m3], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level performance.

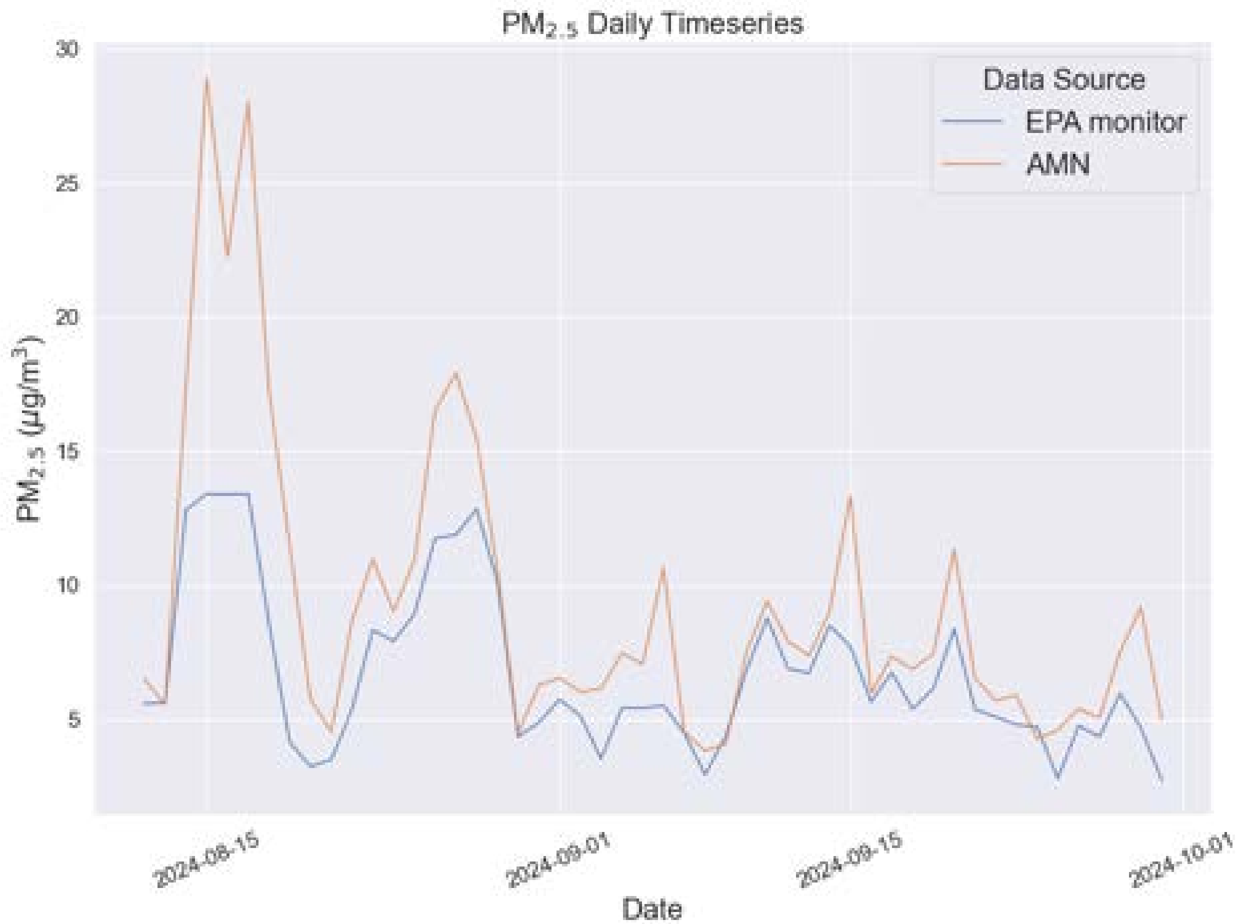


Figure A6: Daily time series showing the comparisons between daily mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for $PM_{2.5}$ [μg/m3].

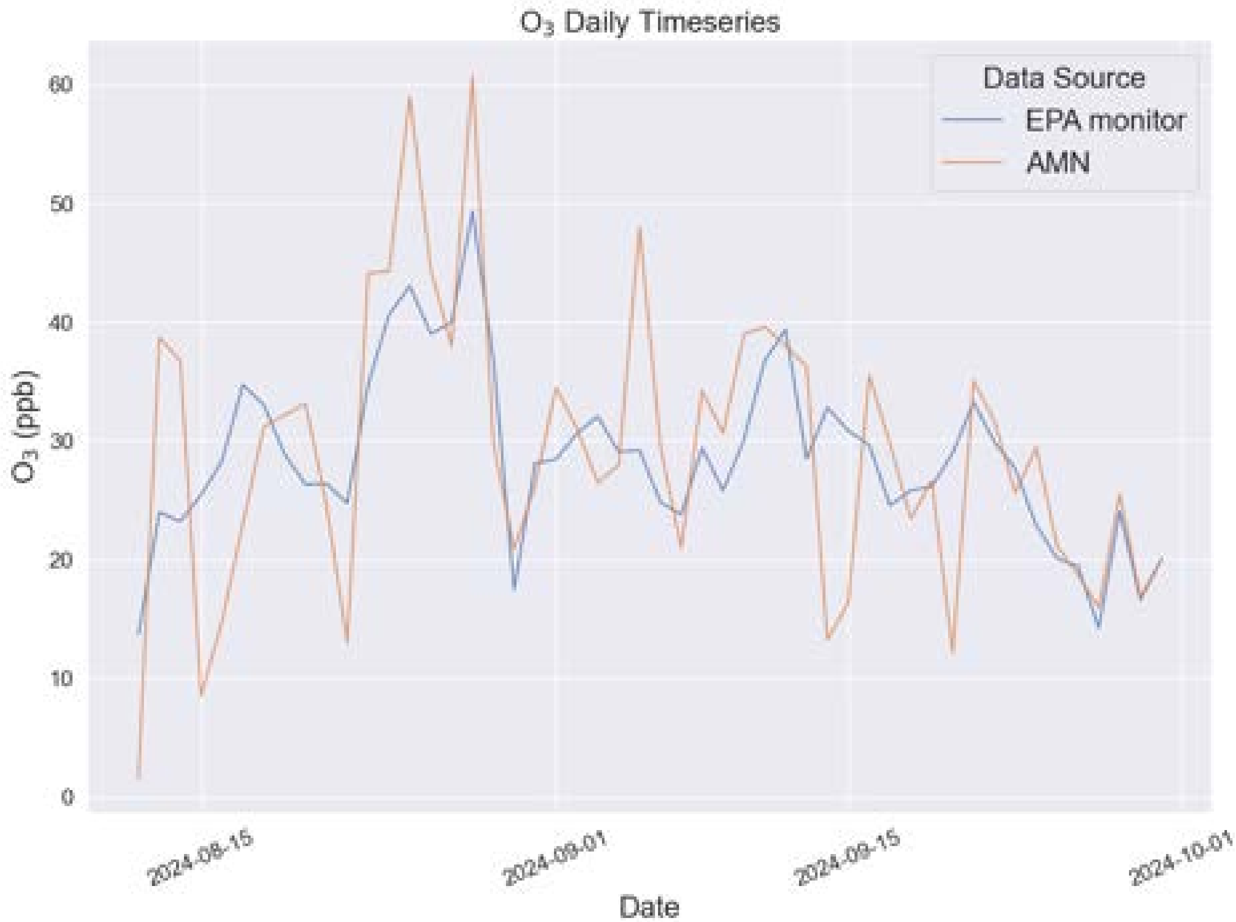


Figure A7: Daily time series showing the comparisons between daily mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for O_3 [ppb].

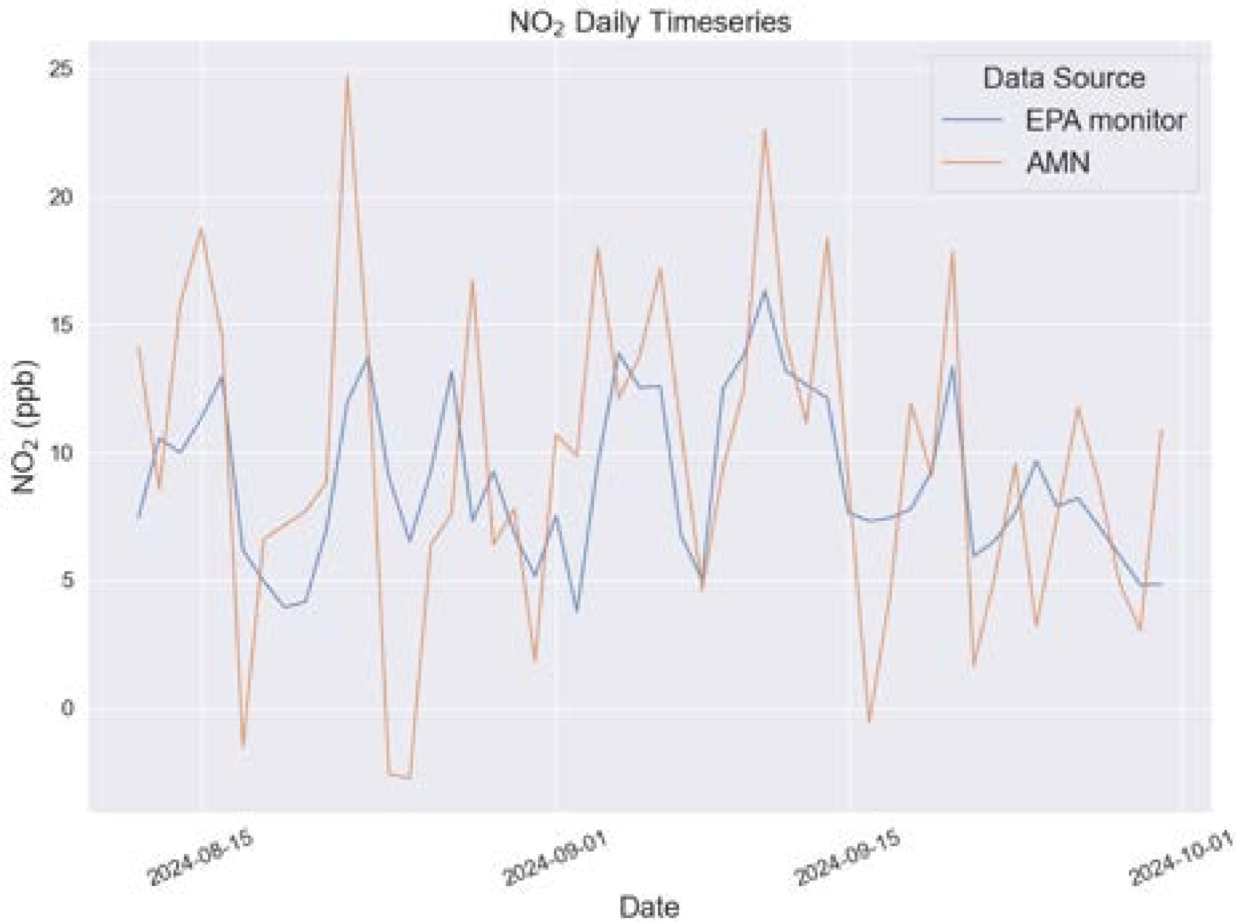


Figure A8: Daily time series showing the comparisons between daily mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for NO_2 [ppb]. Note that the NO_2 sensor started developing drift during the latter part of the 2 week campaign.

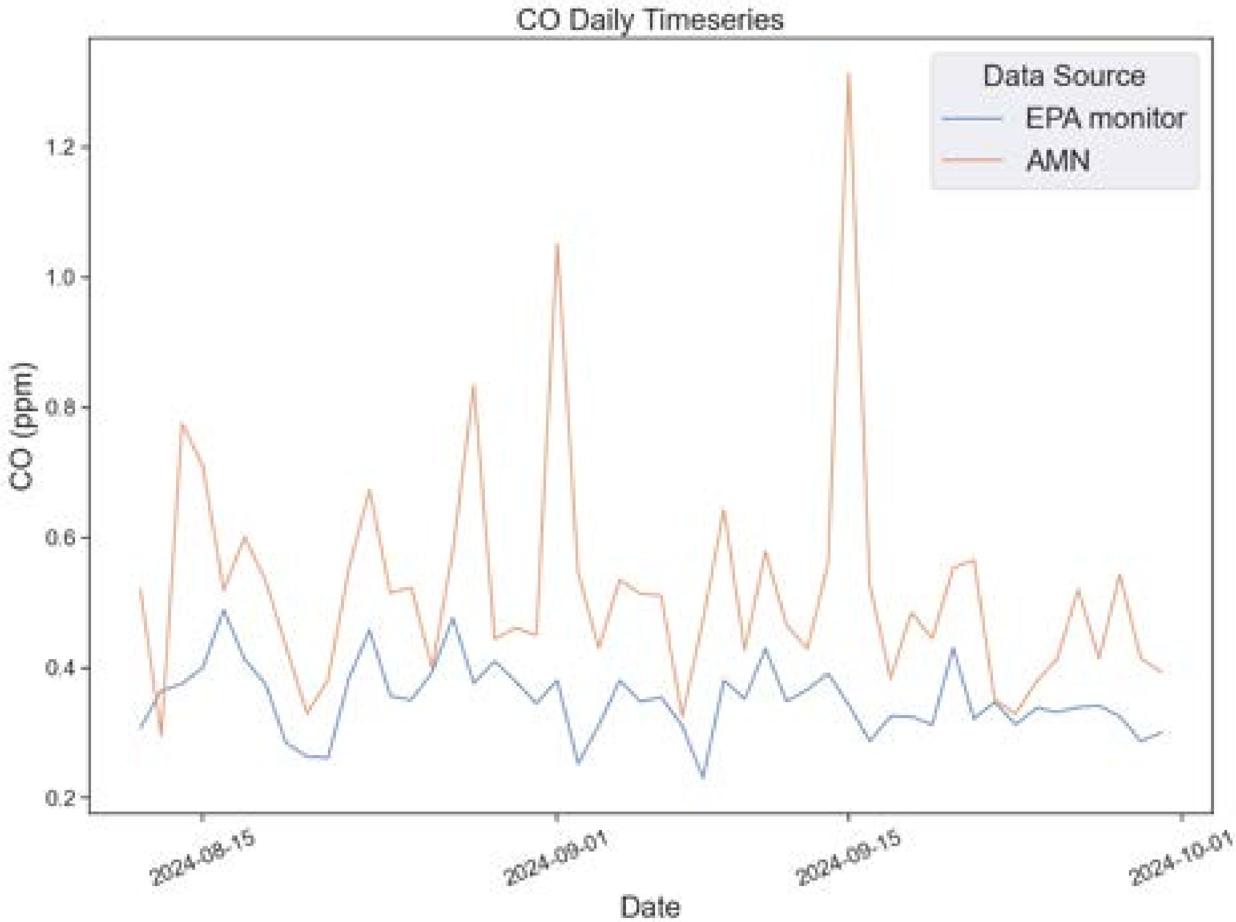


Figure A9: Daily time series showing the comparisons between daily mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for CO [ppm].

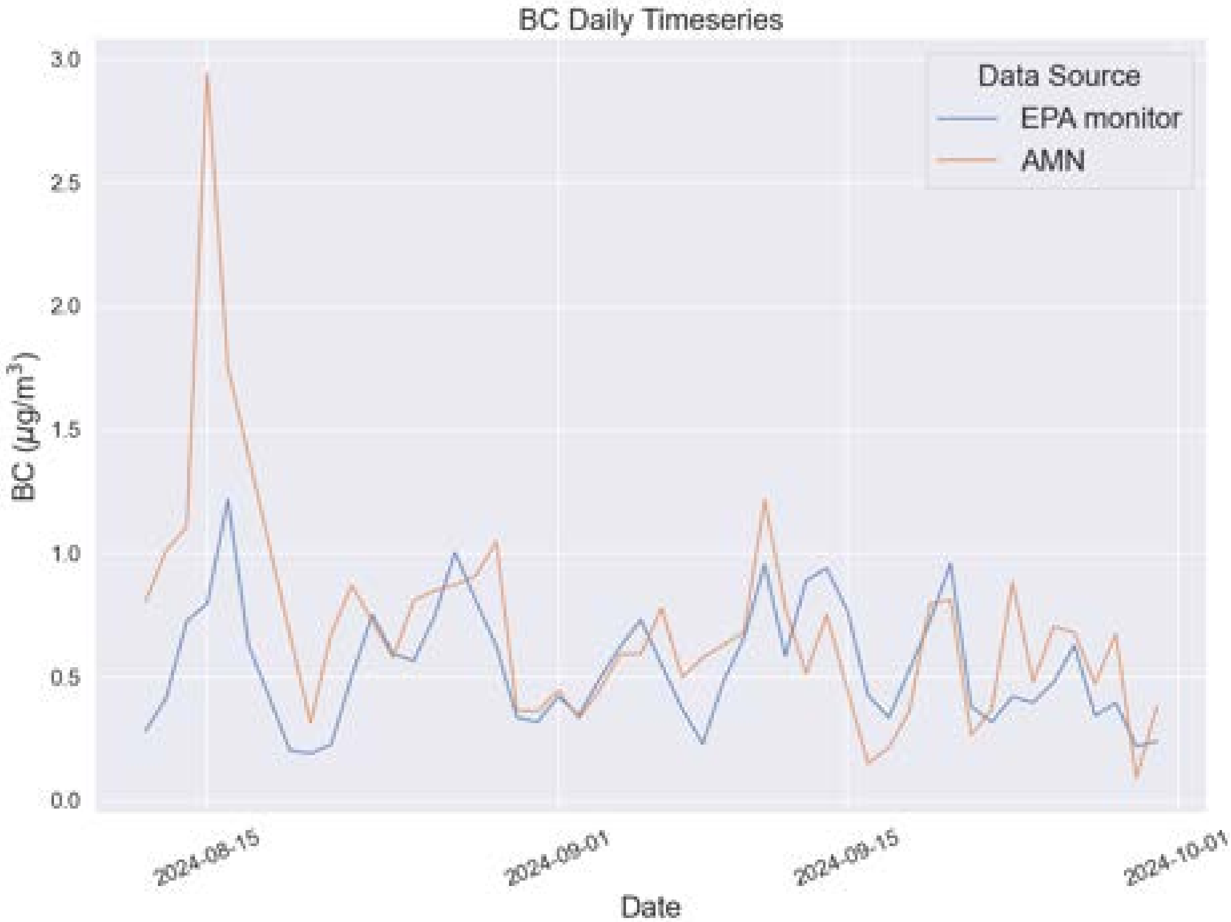


Figure A10: Daily time series showing the comparisons between daily mean Aclima mobile sensor measurements within a 250m radius circle centered at all available stationary regulatory sites to the corresponding collocated data at those regulatory sites for black carbon [µg/m3].

A.2 Stationary Comparison

Figure A1: Location of Aclima vehicle near the McMillan monitoring site.

In addition to the in-motion comparisons done between Aclima mobile measurements and the regulatory sites, we also conducted a five day stationary co-location with one of Aclima's mobile platforms at the DOEE's McMillan monitoring site.

Table A1. Hourly comparison metrics for McMillan Reservoir site for each pollutant.

Pollutant	MBE	MAE	R^2	precision
Black Carbon	0.04 μg/m³	0.13 μg/m³	0.63	0.14 μg/m³
CO	-0.04 ppm	0.07 ppm	0.08	0.07 ppm
NO_2	3.04 ppb	4.83 ppb	0.02	5.84 ppb
O_3	-2.38 ppb	3.91 ppb	0.55	4.47 ppb
$PM_{2.5}$	1.00 μg/m³	2.34 μg/m³	0.28	2.31 μg/m³

Table A3. Daily aggregated comparison metrics for McMillan Reservoir site for each pollutant

Daily	MBE	MAE	R^2	precision

Black Carbon	0.03 µg/m³	0.05 µg/m³	0.93	0.07 µg/m³
CO	-0.03 ppm	0.05 ppm	0.20	0.07 ppm
NO_2	3.06 ppb	3.06 ppb	0.93	1.62 ppb
O_3	-2.59 ppb	2.59 ppb	0.79	2.91 ppb
$PM_{2.5}$	0.79 µg/m³	1.33 µg/m³	0.37	2.24 µg/m³

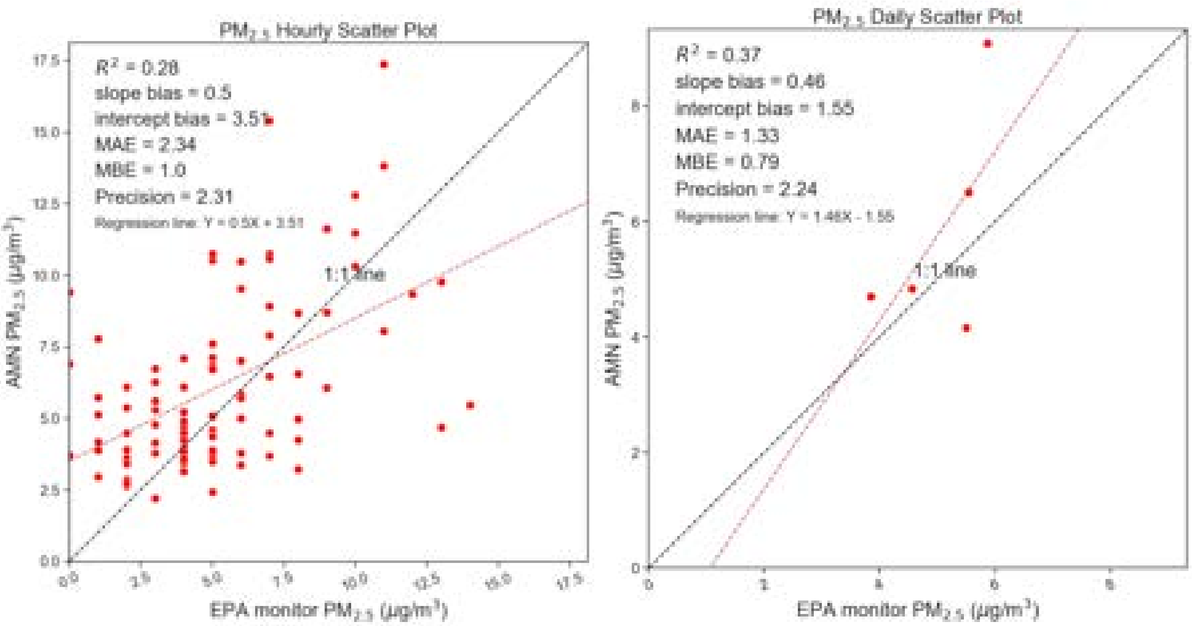


Figure A1: Comparison of hourly (left) and daily (right) mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for $PM_{2.5}$ [µg/m3], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level comparisons.

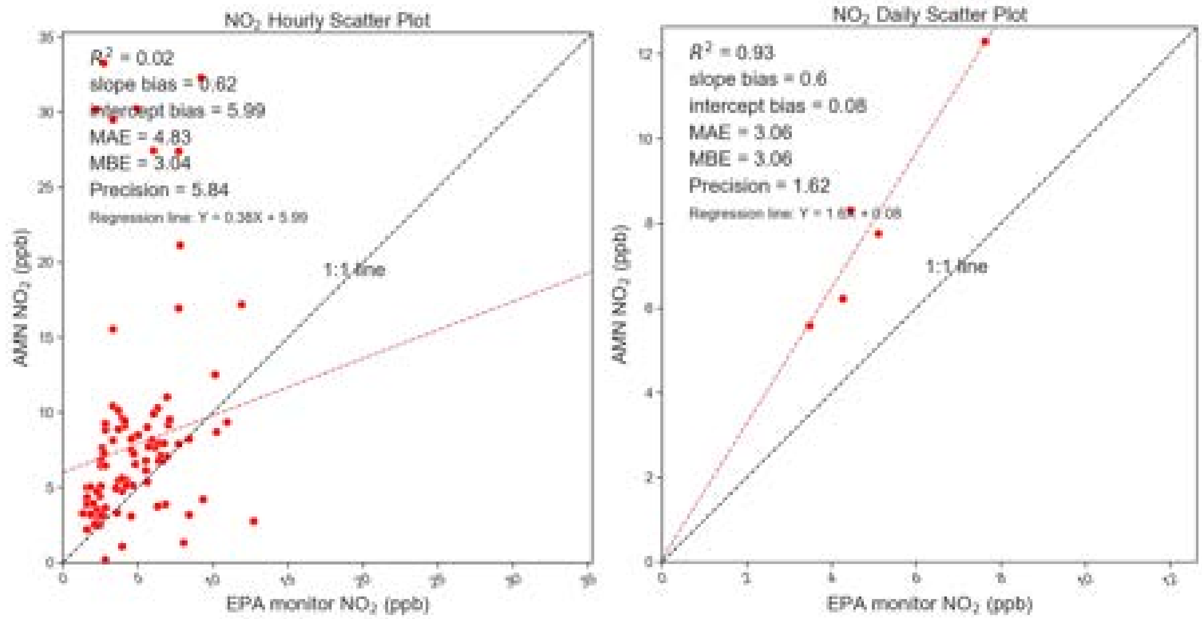


Figure A2: Comparison of hourly (left) and daily (right) mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for for NO_2 [ppb], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level comparisons.

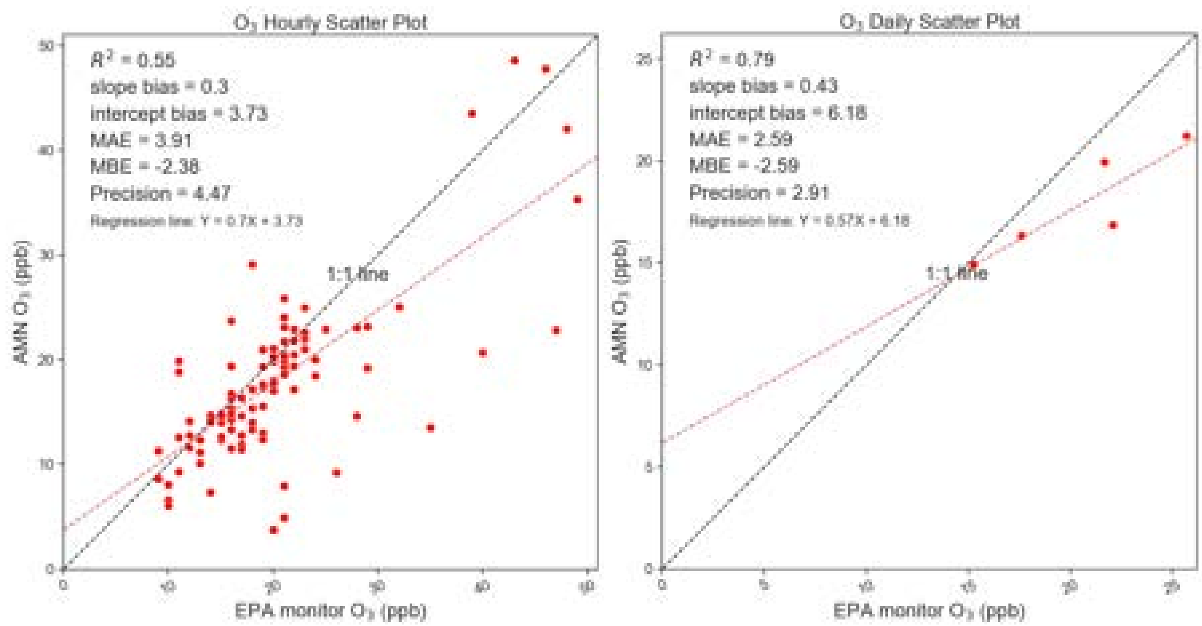


Figure A3: Comparison of hourly (left) and daily (right) mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for for O_3 [ppb], including comparison metrics (including R2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level comparisons.

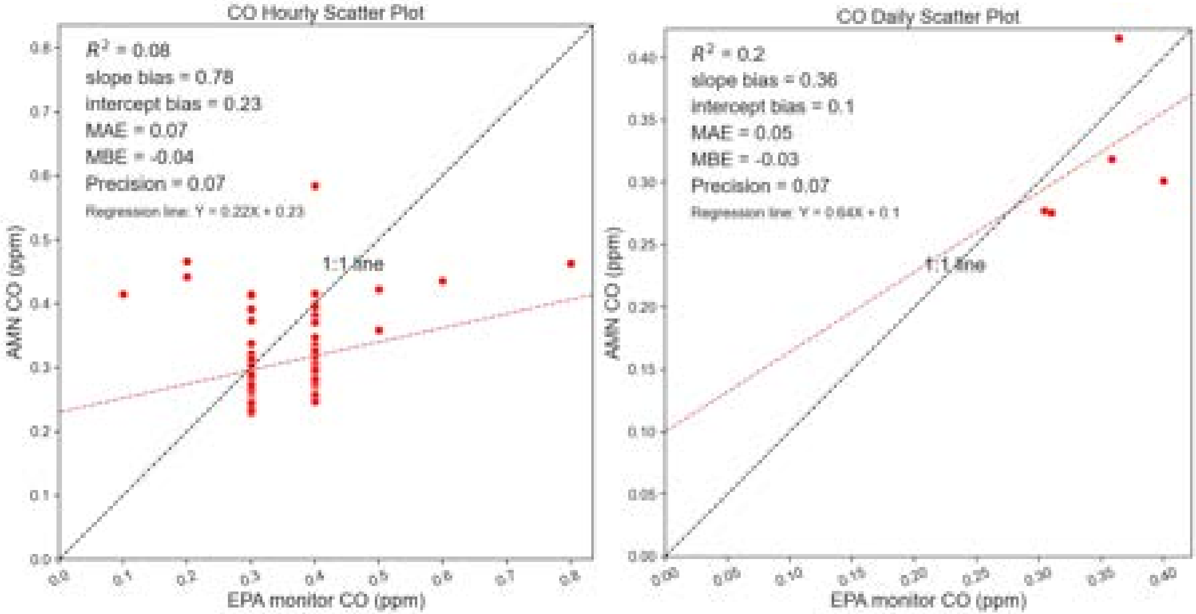


Figure A4: Comparison of hourly (left) and daily (right) mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for for CO [ppm], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level comparisons.

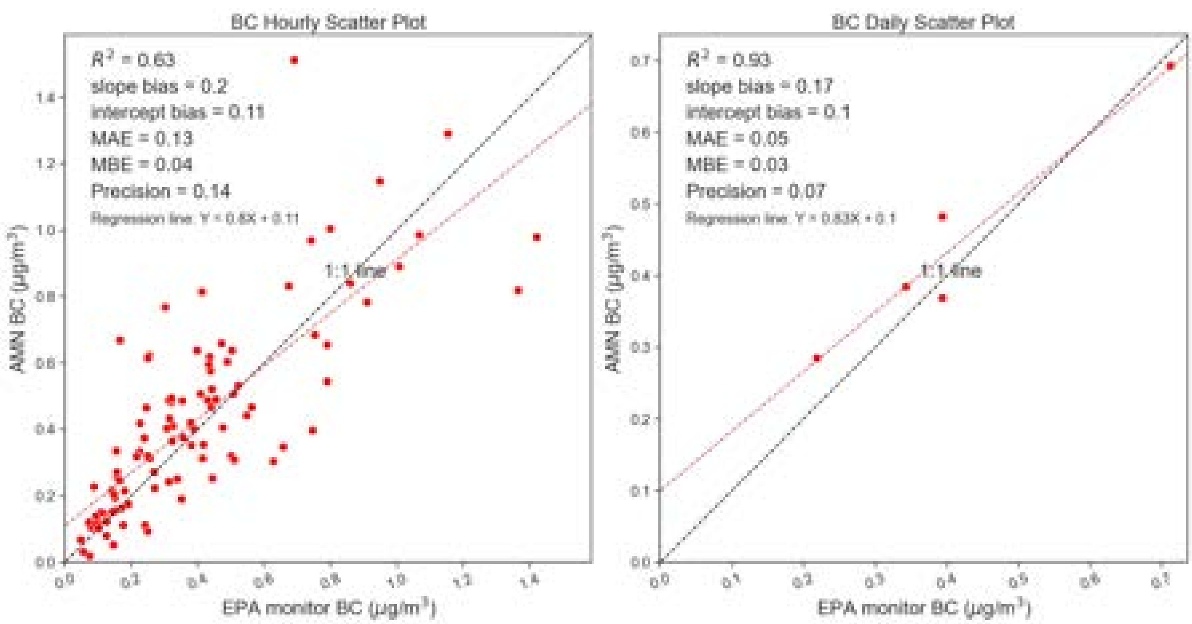


Figure A5: Comparison of hourly (left) and daily (right) mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for black carbon [µg/m3], including comparison metrics (including R^2, slope error, intercept error, MAE, MBE, and precision) that represent Aclima AMN 1-hr or 24-hr device-level comparisons.

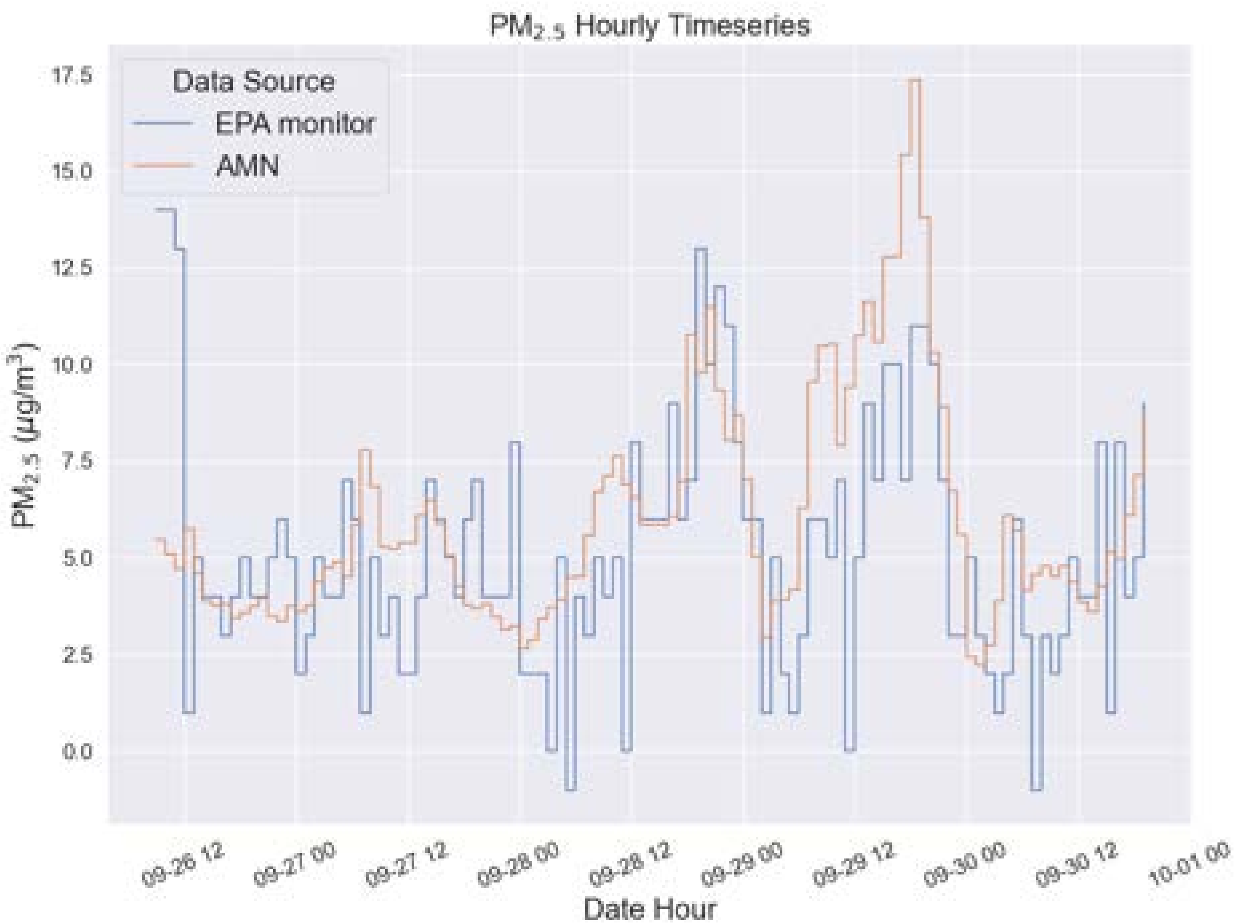


Figure A6: Hourly time series showing the comparisons between hourly mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for $PM_{2.5}$ [μg/m3].

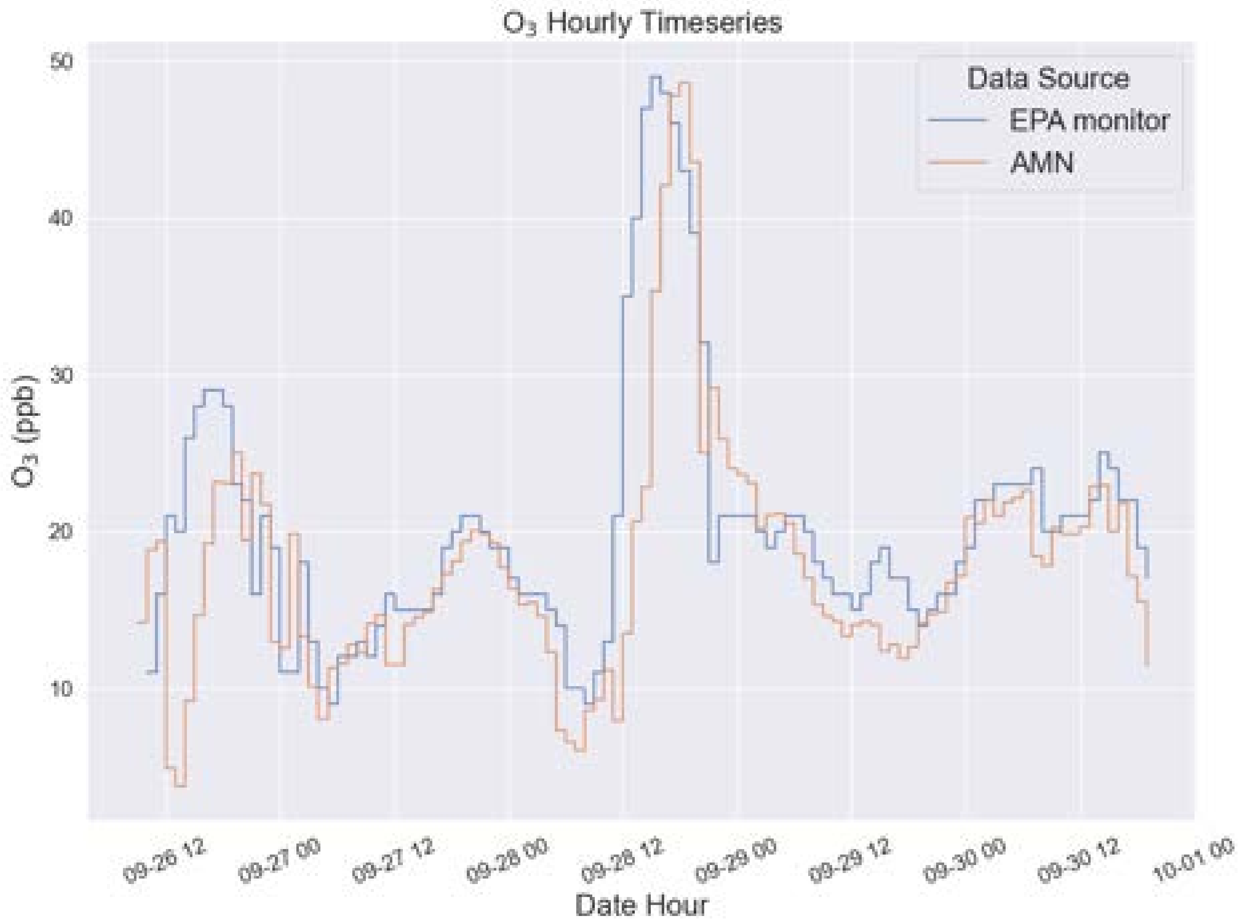


Figure A7: Hourly time series showing the comparisons between hourly mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for O_3 [ppb].

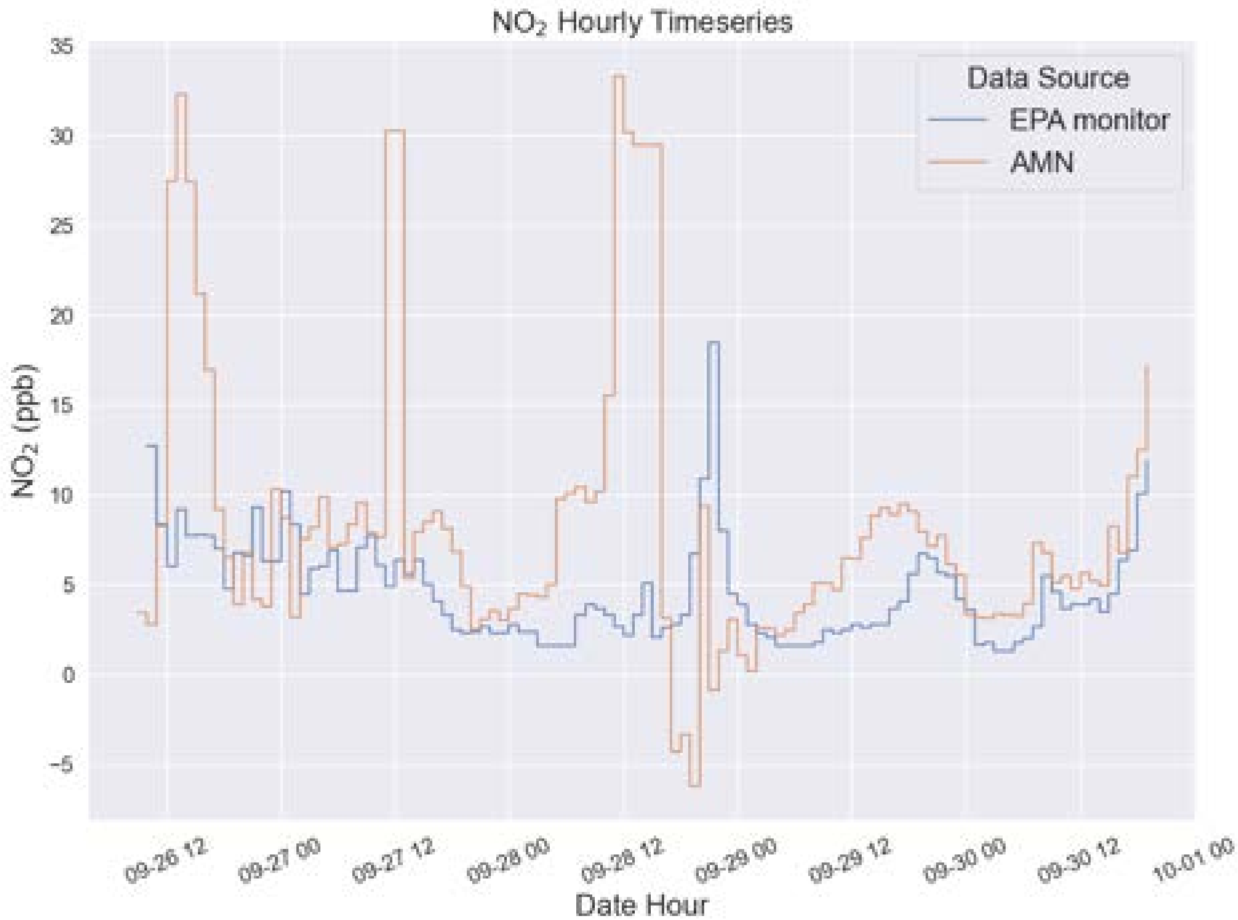


Figure A8: Hourly time series showing the comparisons between hourly mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for NO_2 [ppb]. Note that the NO_2 sensor started developing drift during the latter part of the 2-week campaign.

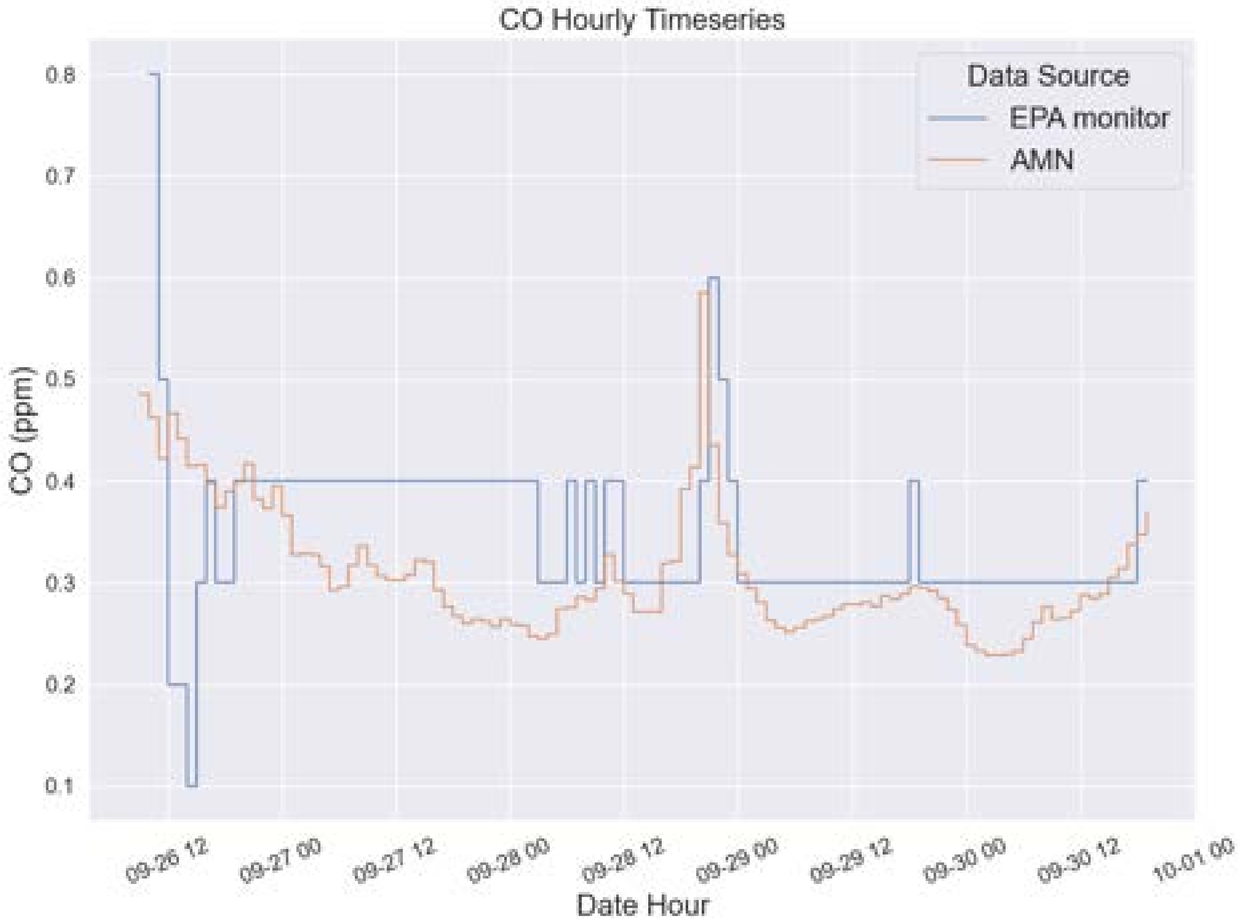


Figure A9: Hourly time series showing the comparisons between hourly mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for CO [ppm].

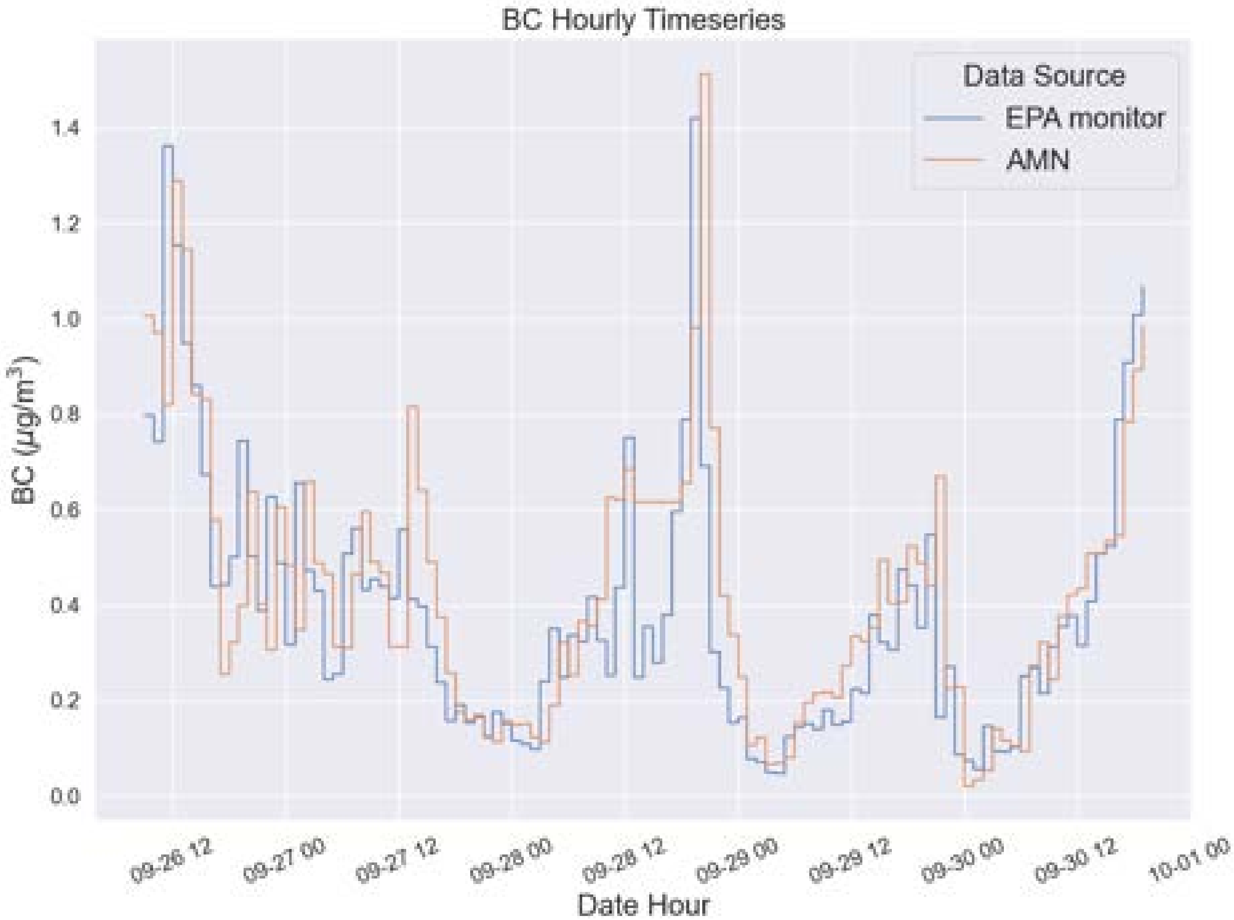


Figure A10: Hourly time series showing the comparisons between hourly mean Aclima stationary measurements to the corresponding collocated data at those regulatory sites for Black Carbon [μg/m3].

A.3 H3 Hex binning for determining unique days of observations

The following figure is an example of the use of H3 hex binning for determining the number of unique days of TVOC observations in an area for the TVOC analysis. The three colors indicate three TVOC classes (red = combustion, blue = evaporation, green = mixed).

Figure A11: Example of the use of H3 hex binning for determining the number of unique days of TVOC observations. The three colors indicate three TVOC classes (red = combustion, blue = evaporation, green = mixed).

A.4 Additional pollutant maps

A.4.1 Ward 1

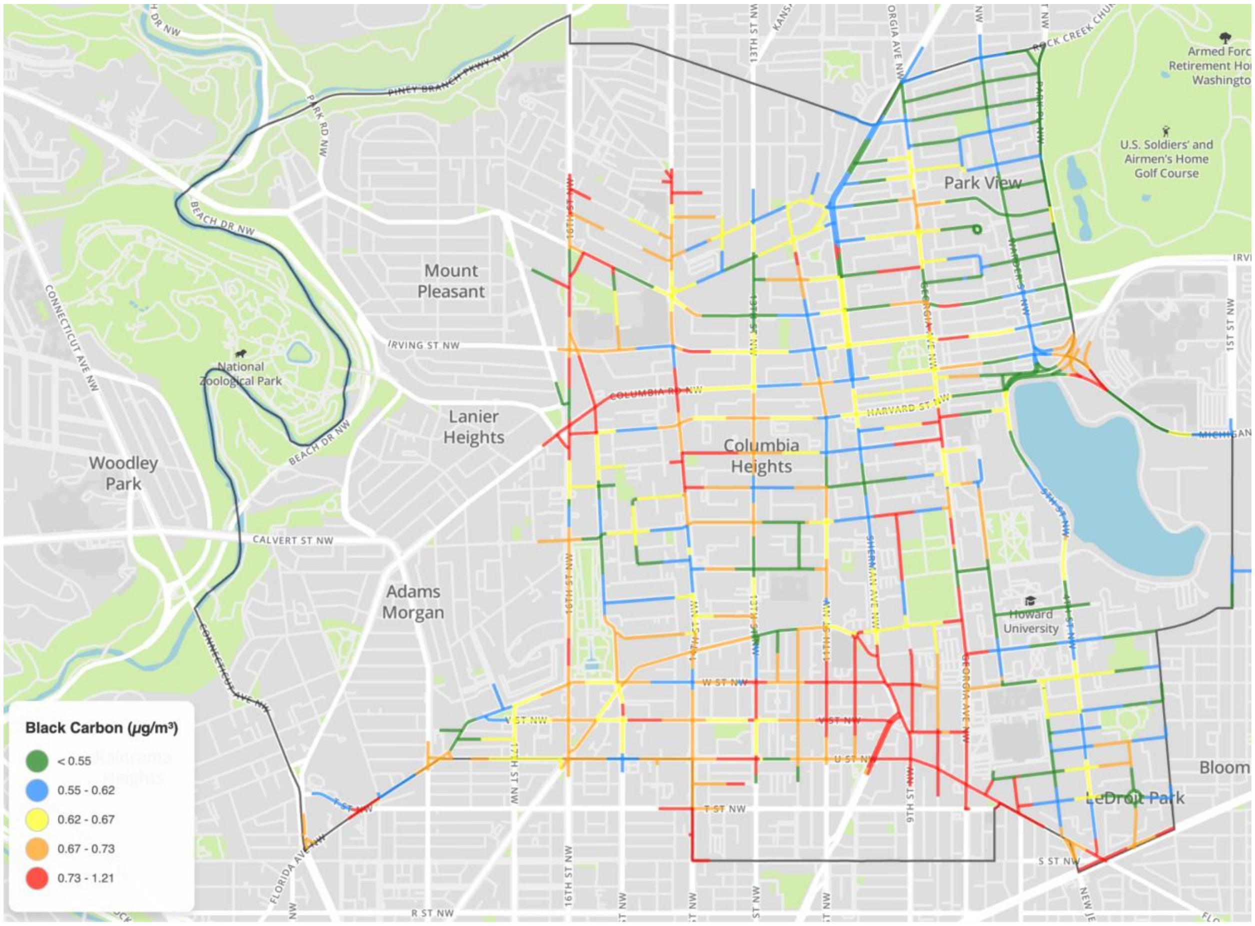


Figure A12: Black Carbon line medians for Ward 1

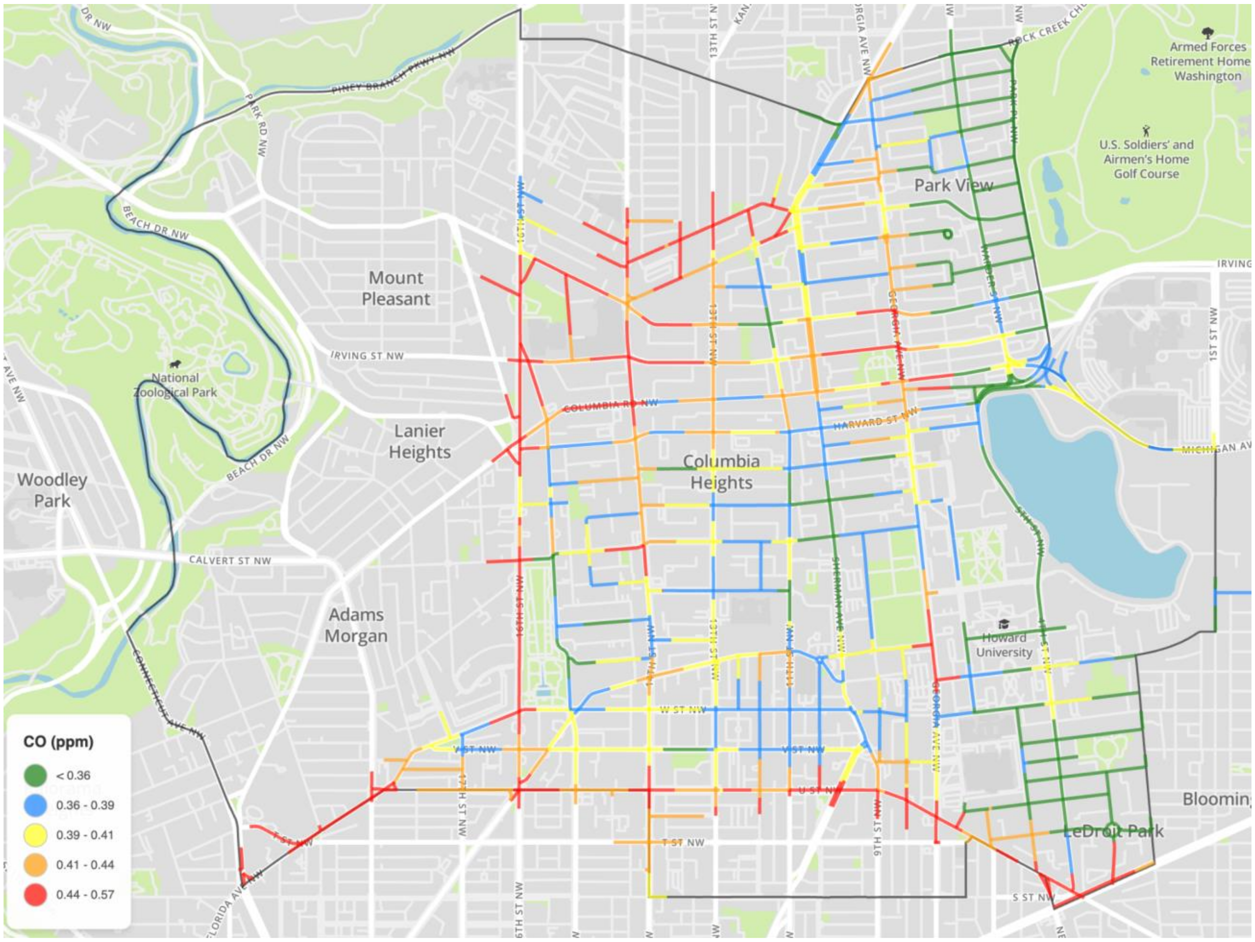


Figure A13: Carbon Monoxide line medians for Ward 1

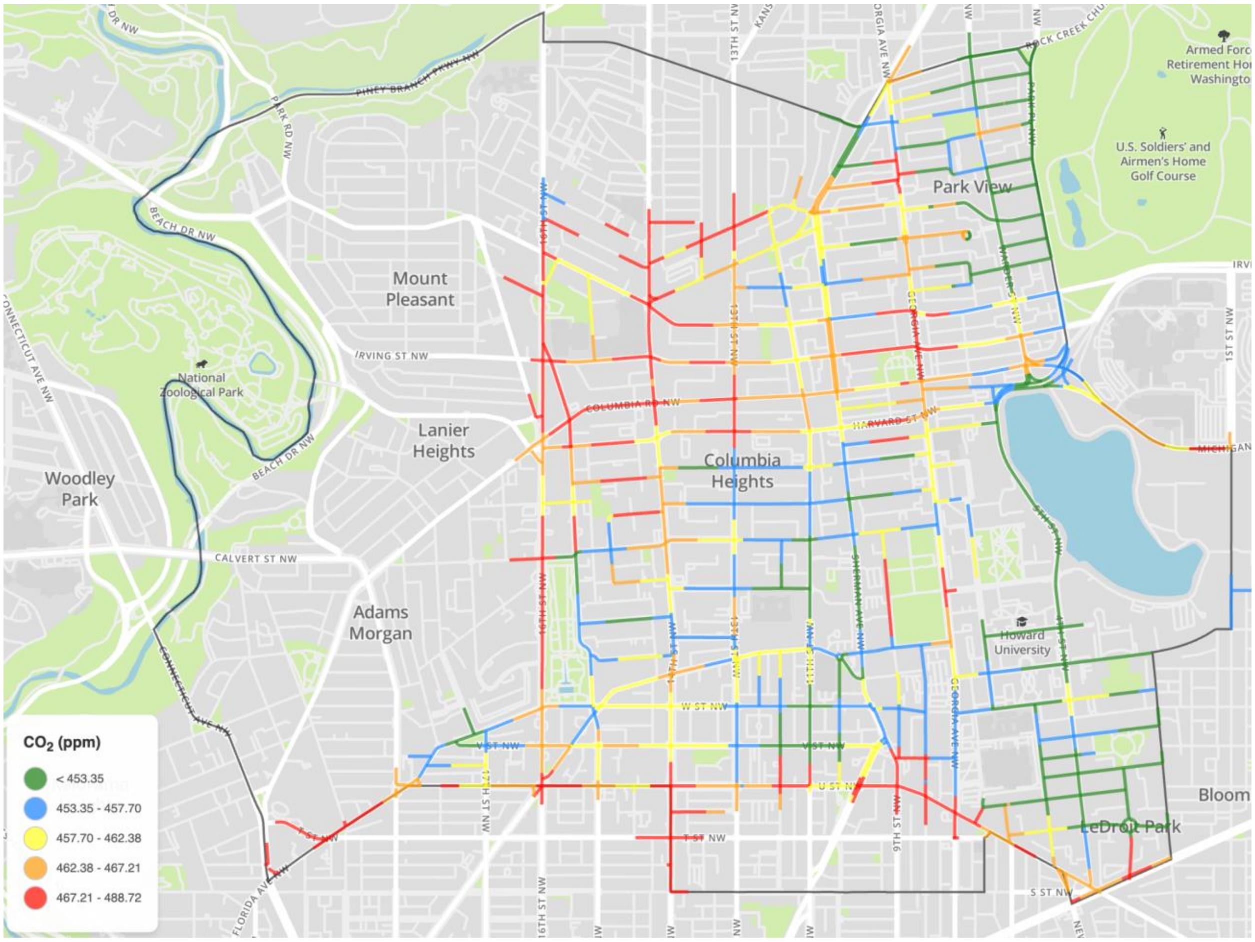


Figure A14: Carbon Dioxide line medians for Ward 1

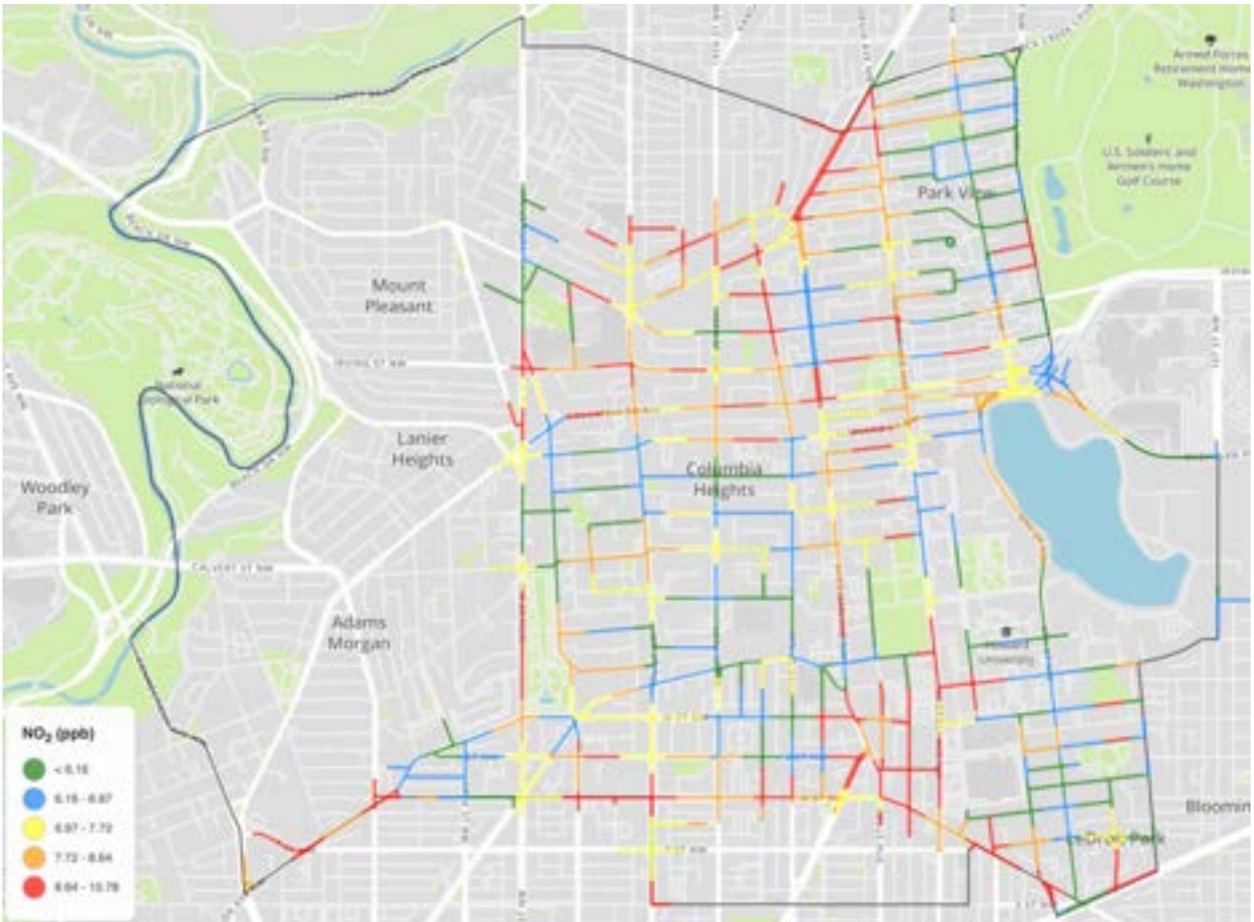


Figure A15: Nitrogen Dioxide line medians for Ward 1

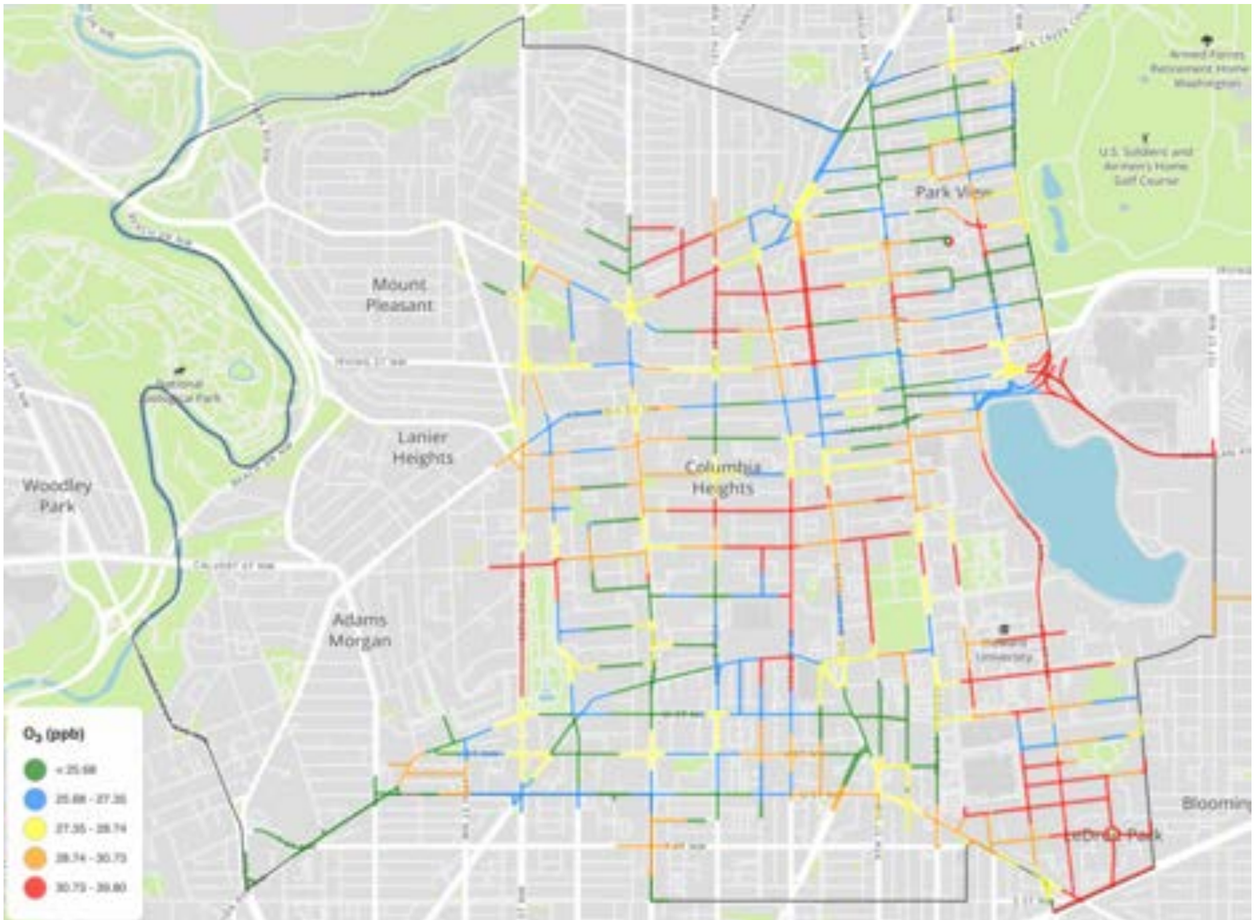


Figure A16: Ozone line medians for Ward 1

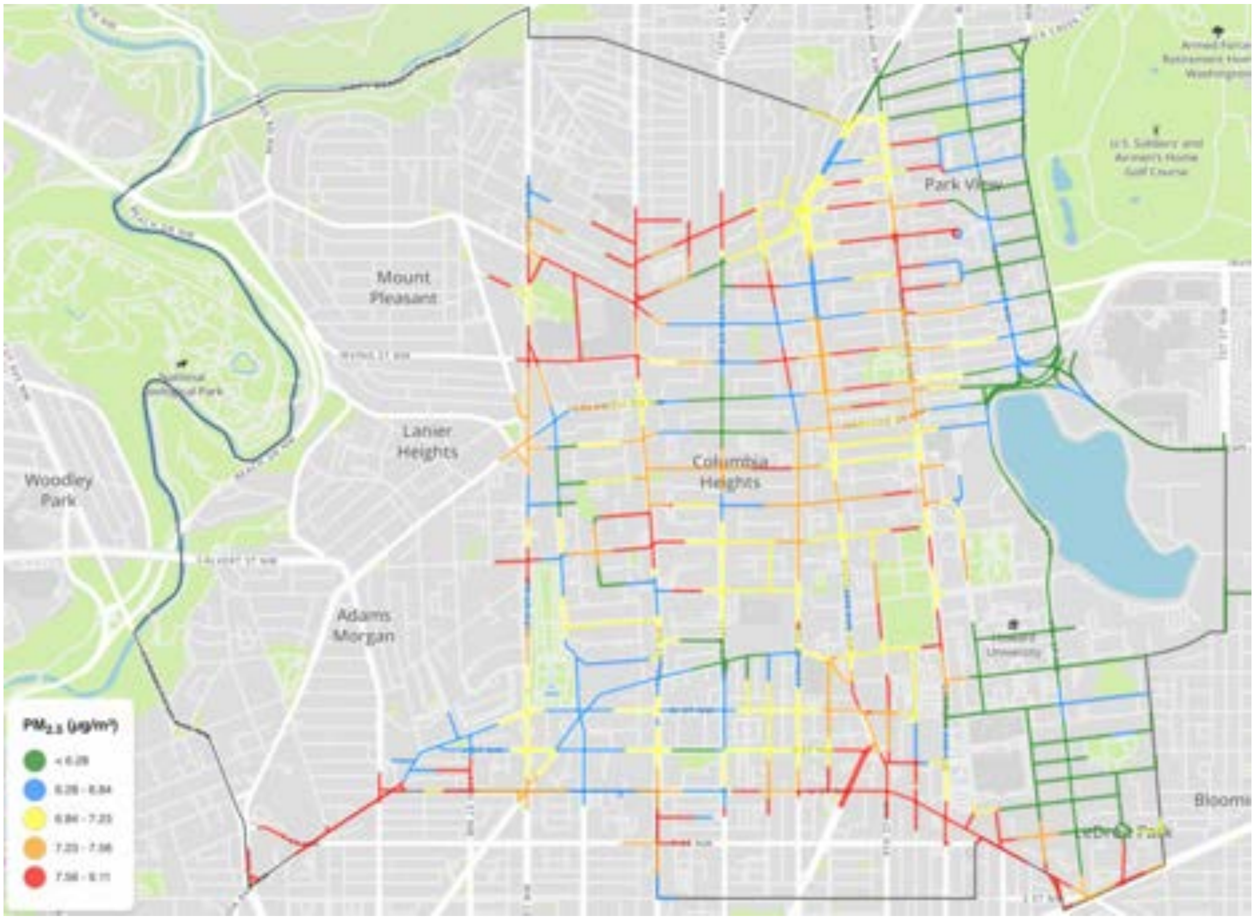


Figure A17: Particulate Matter$_{2.5}$ line medians for Ward 1

A.4.2 Ward 2

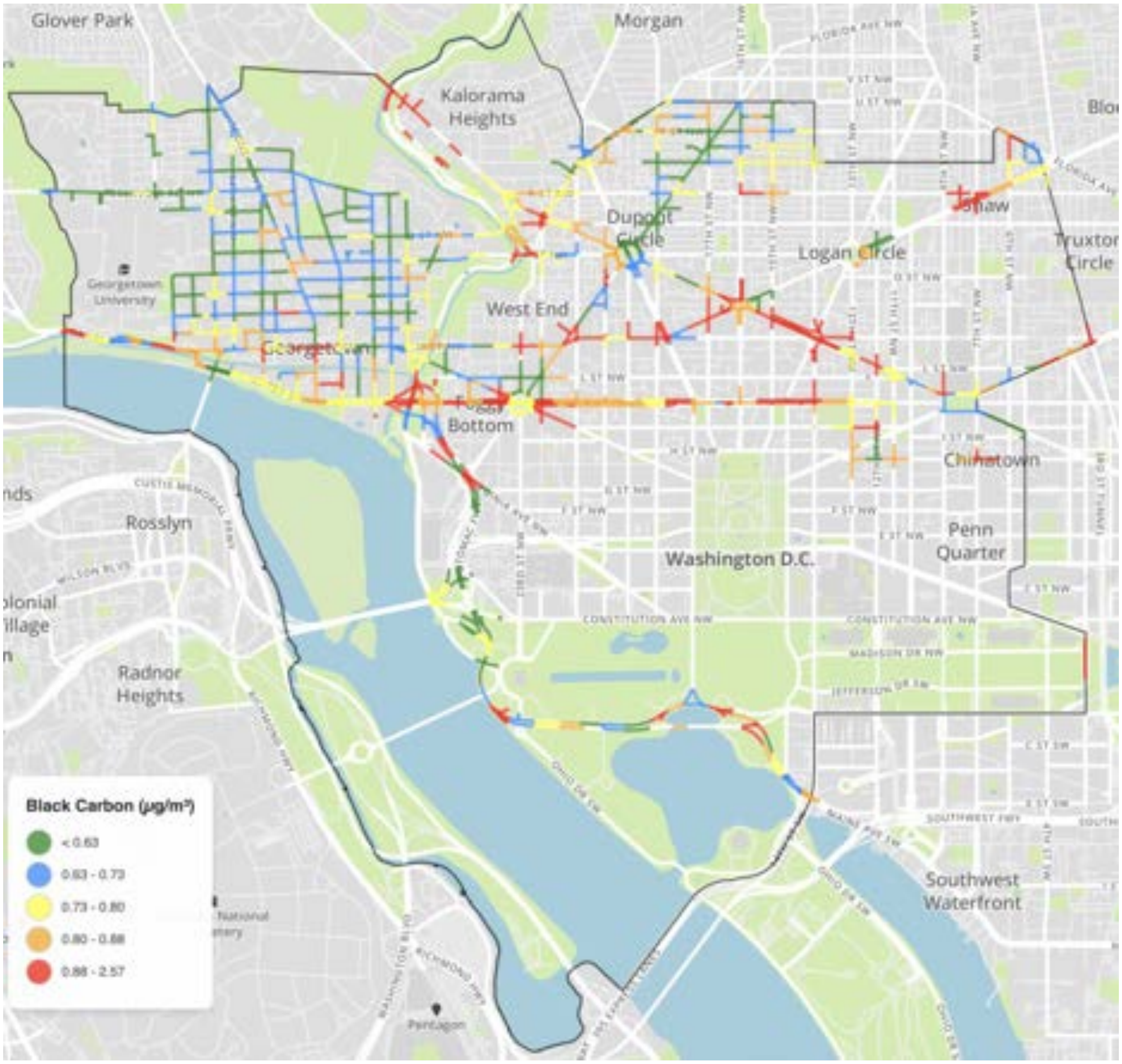


Figure A18: Black Carbon line medians for Ward 2

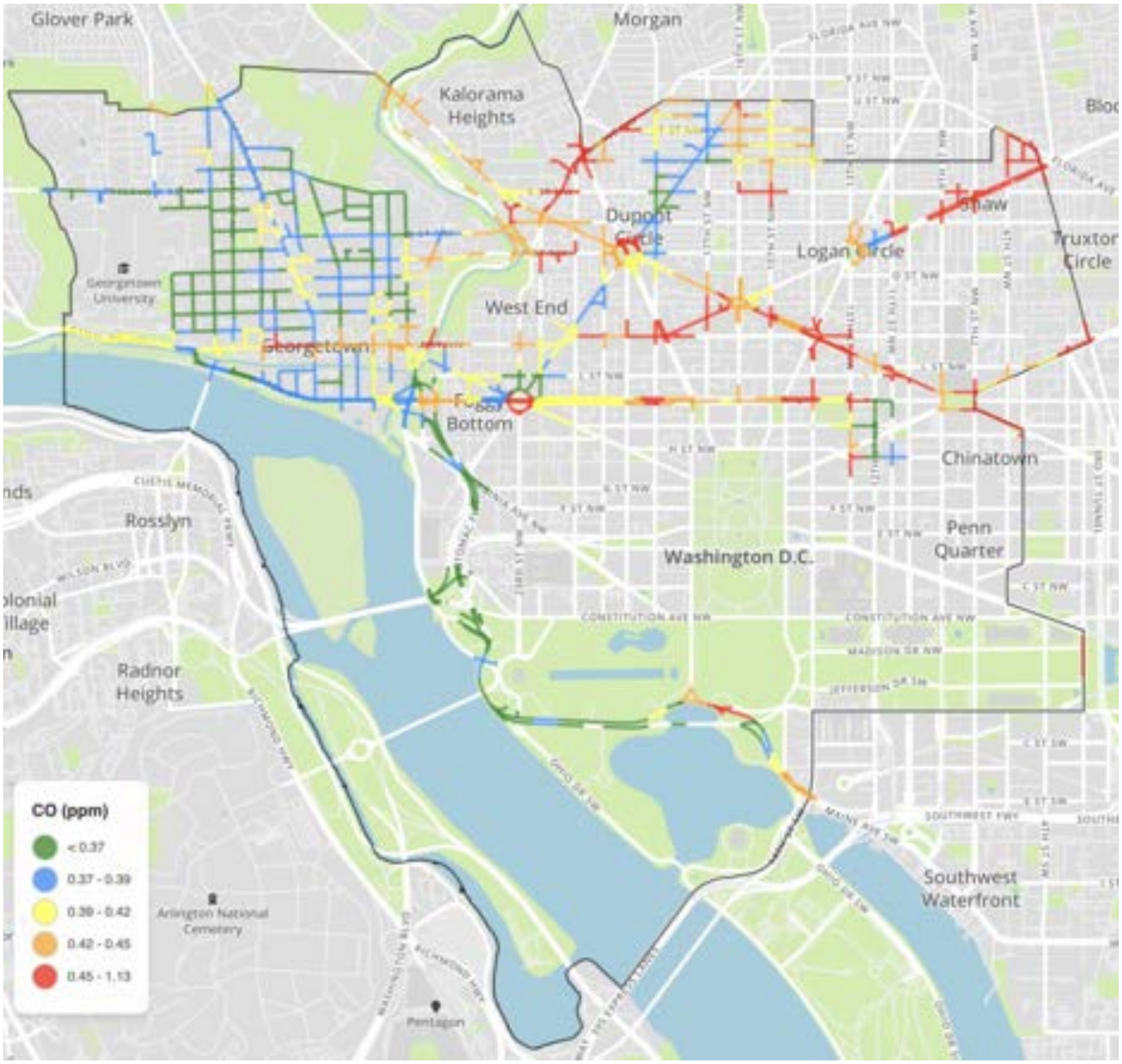


Figure A19: Carbon Monoxide line medians for Ward 2

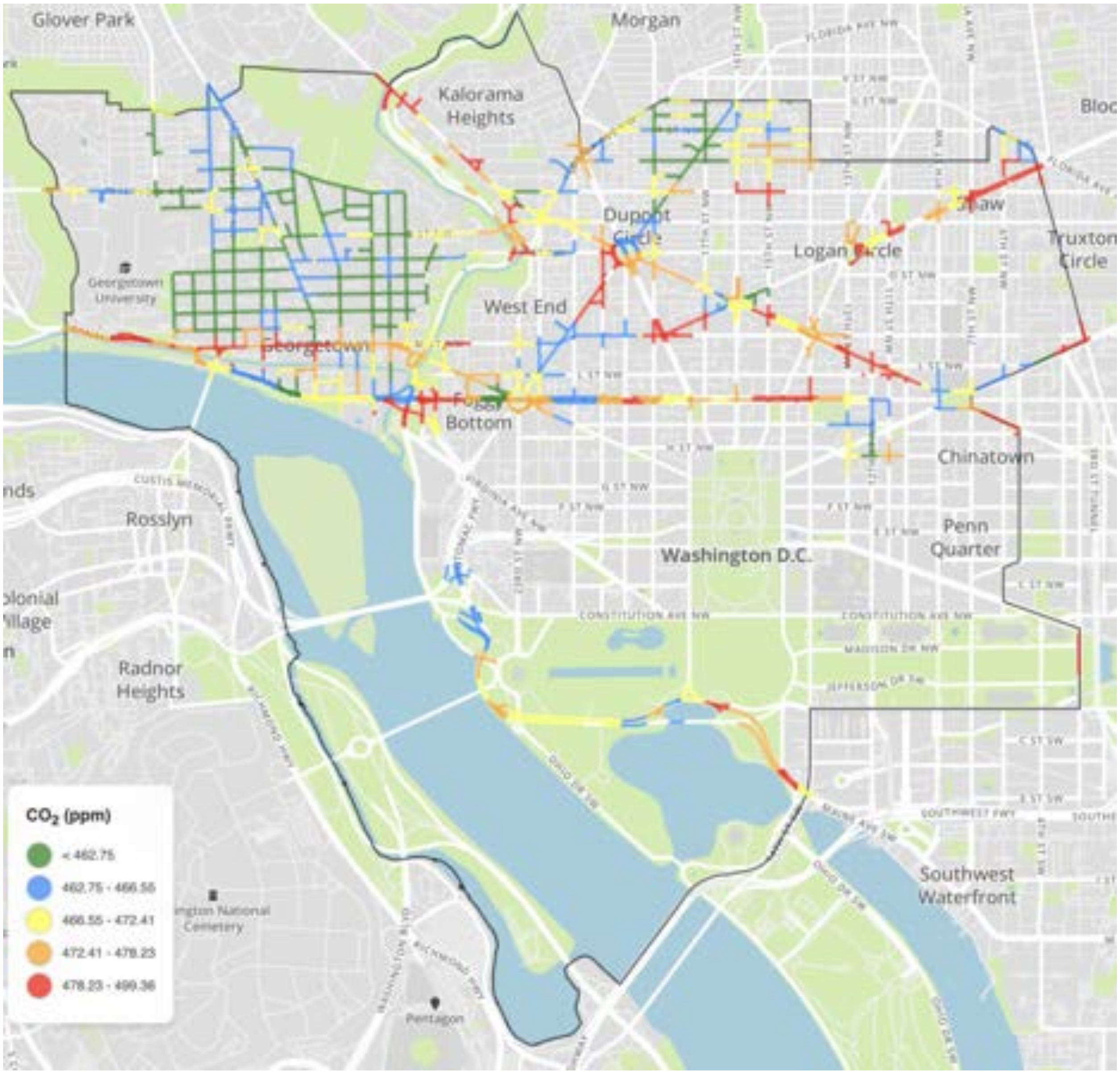


Figure A20: Carbon Dioxide line medians for Ward 2

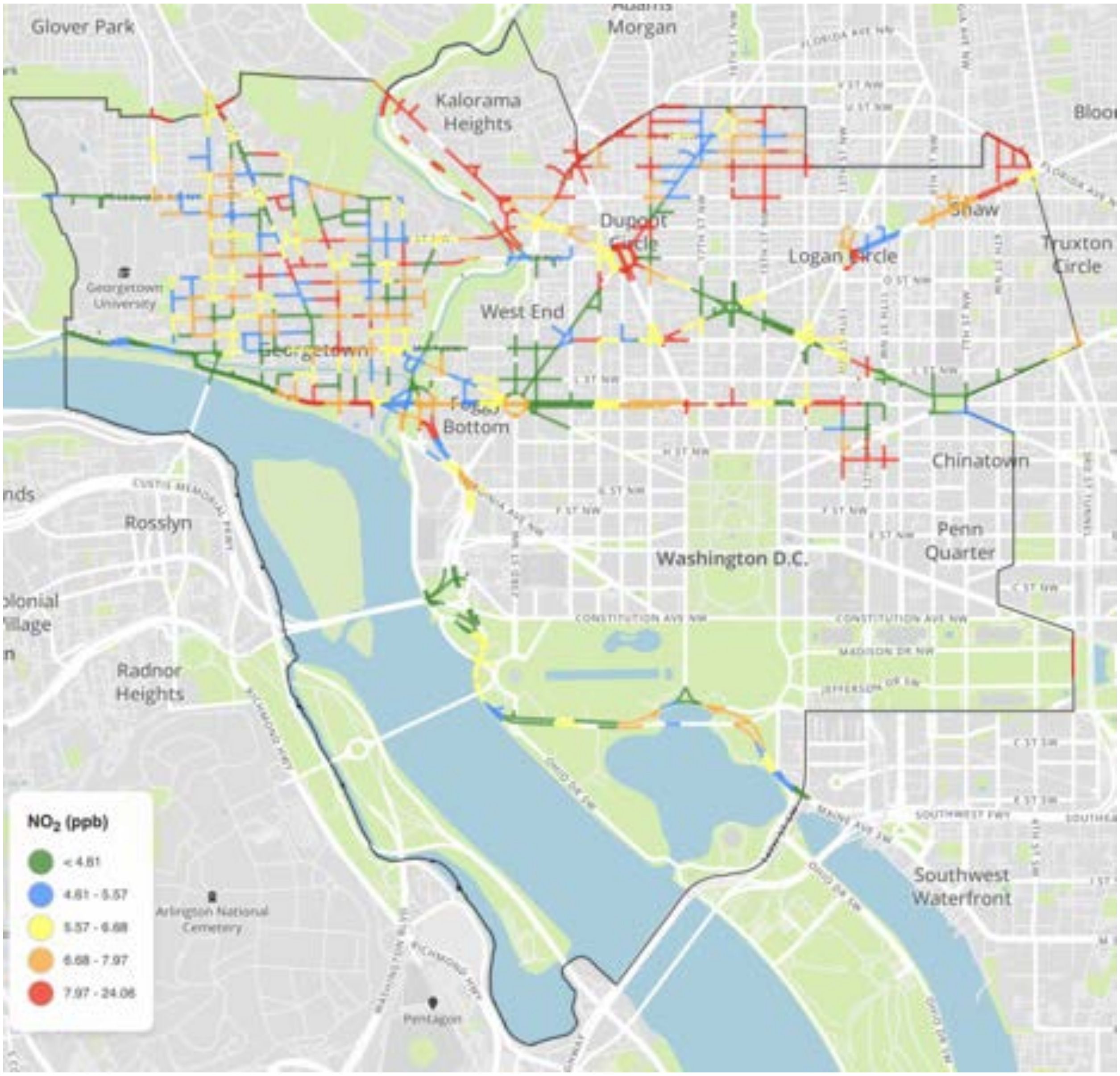


Figure A21: Nitrogen Dioxide line medians for Ward 2

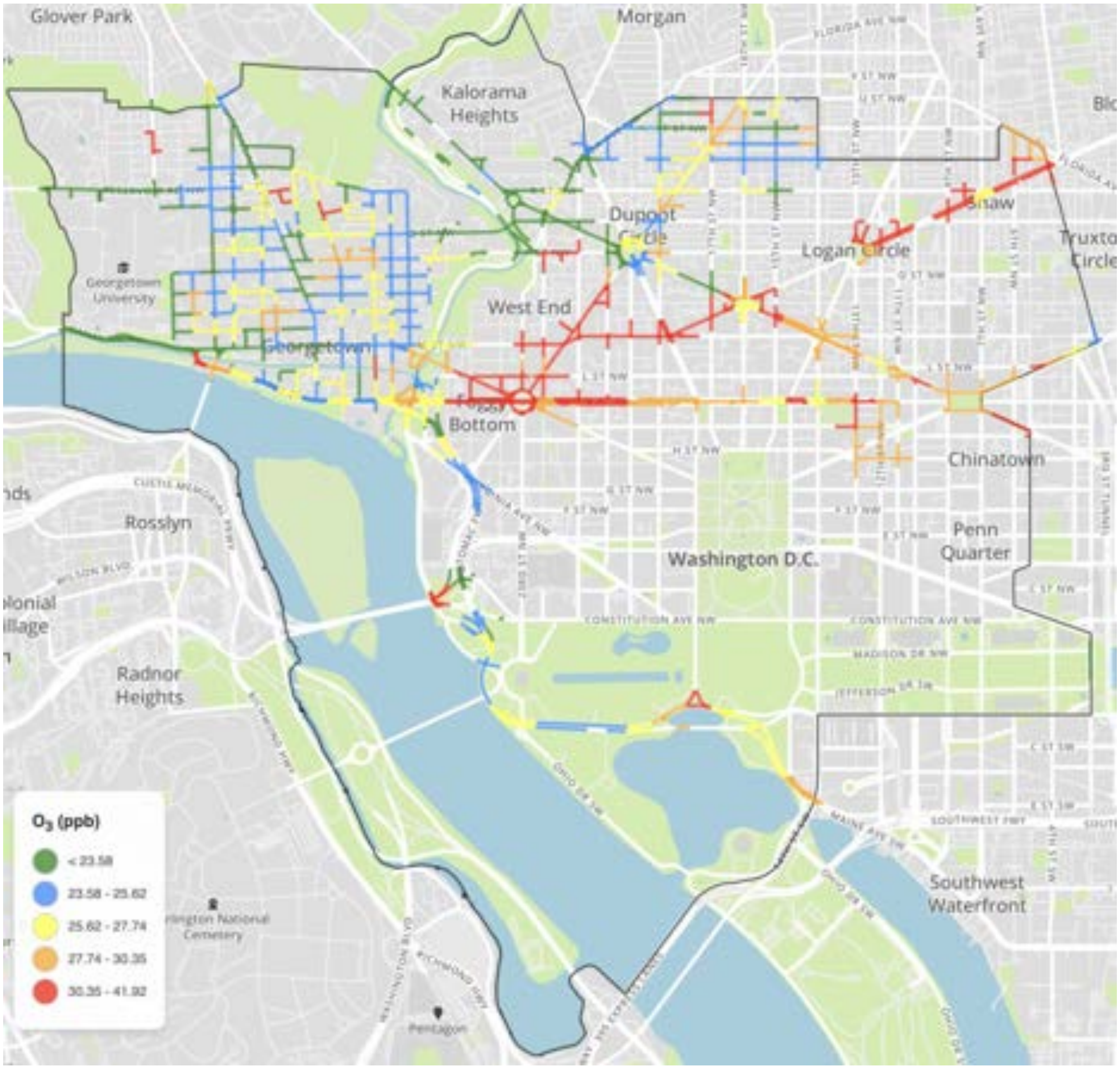


Figure A22: Ozone line medians for Ward 2

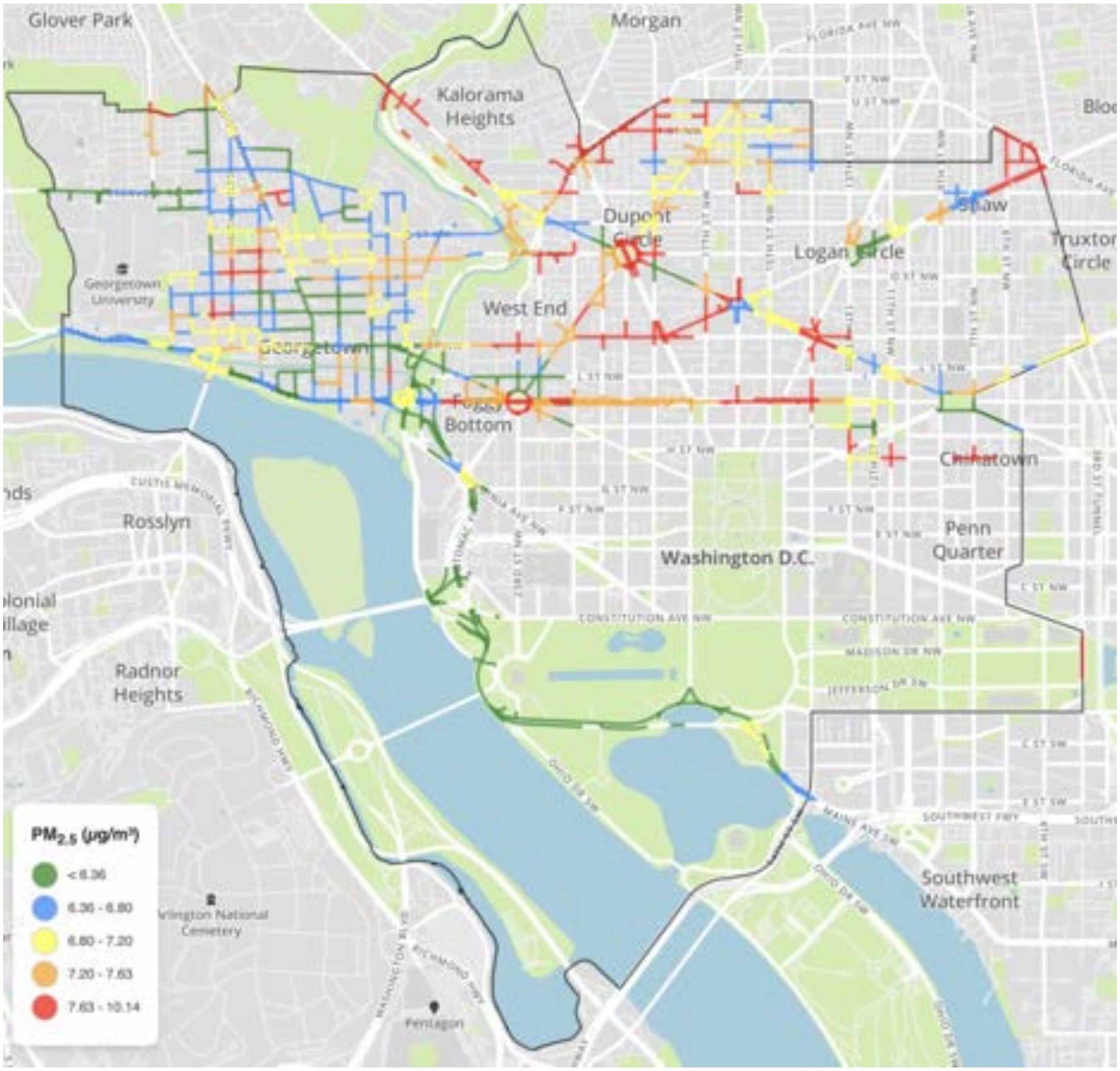


Figure A23: Particulate Matter$_{2.5}$ line medians for Ward 2

A.4.3 Ward 3

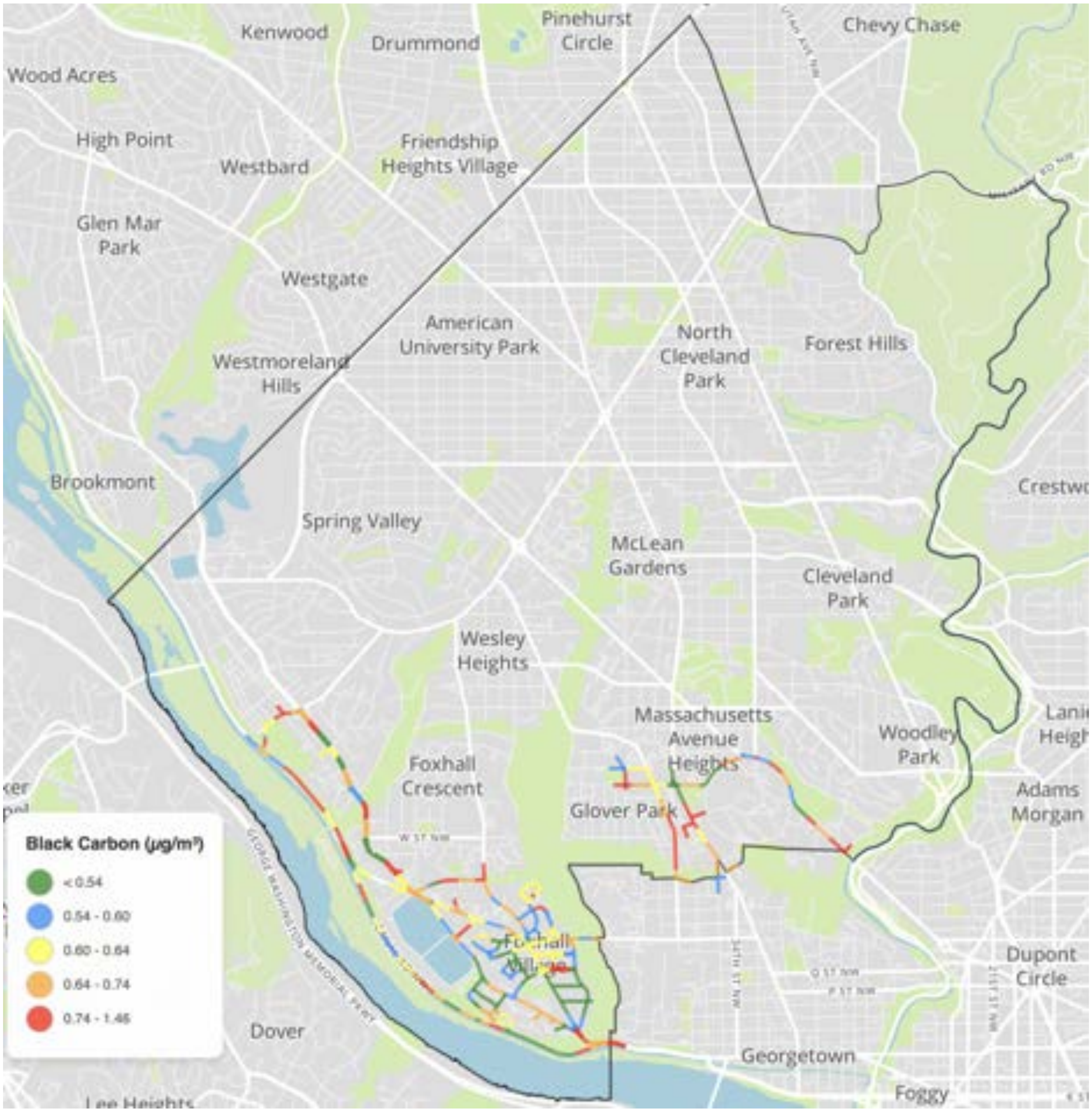


Figure A24: Black Carbon line medians for Ward 3

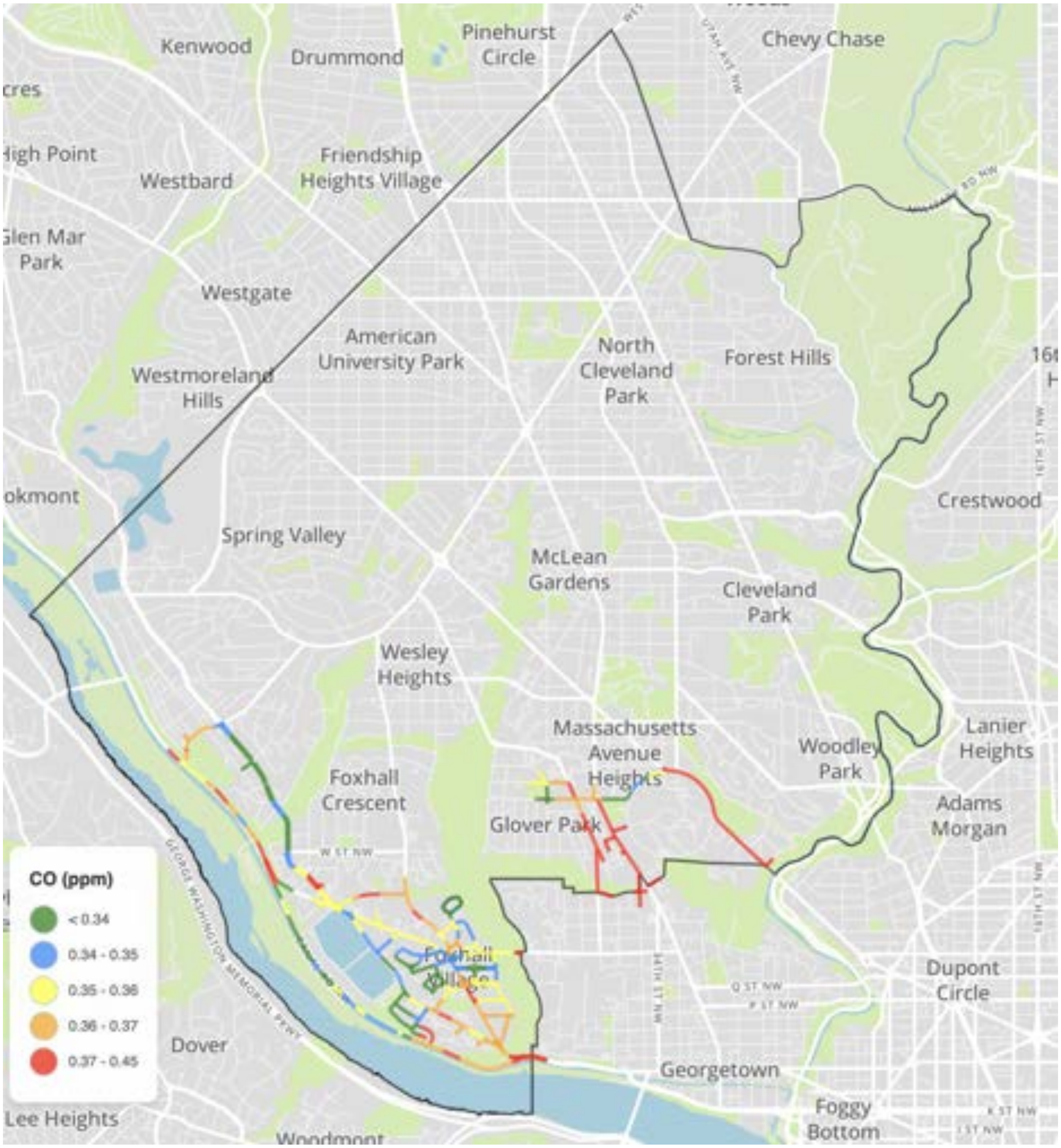


Figure A25: Carbon Monoxide line medians for Ward 3

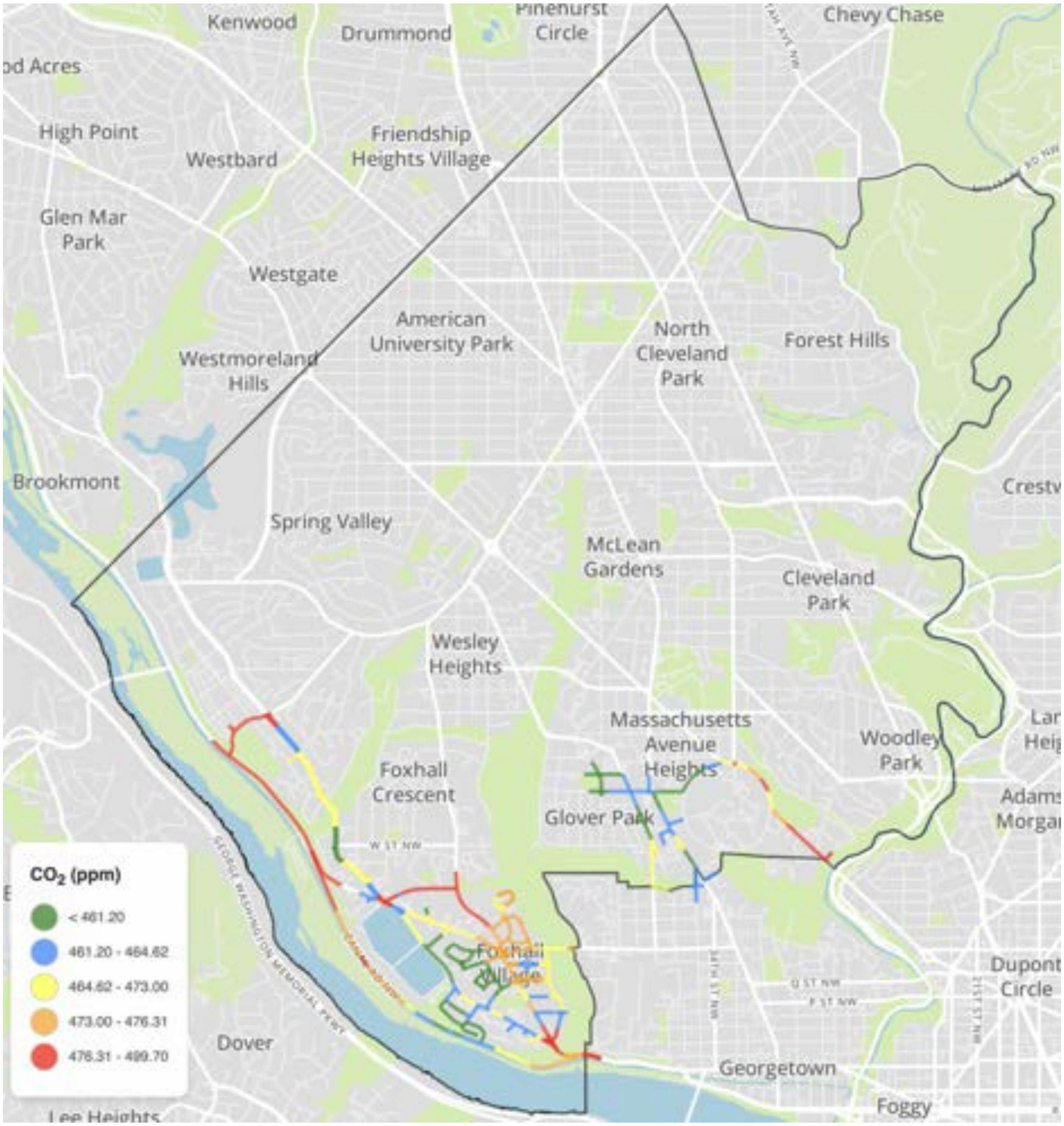


Figure A26: Carbon Dioxide line medians for Ward 3

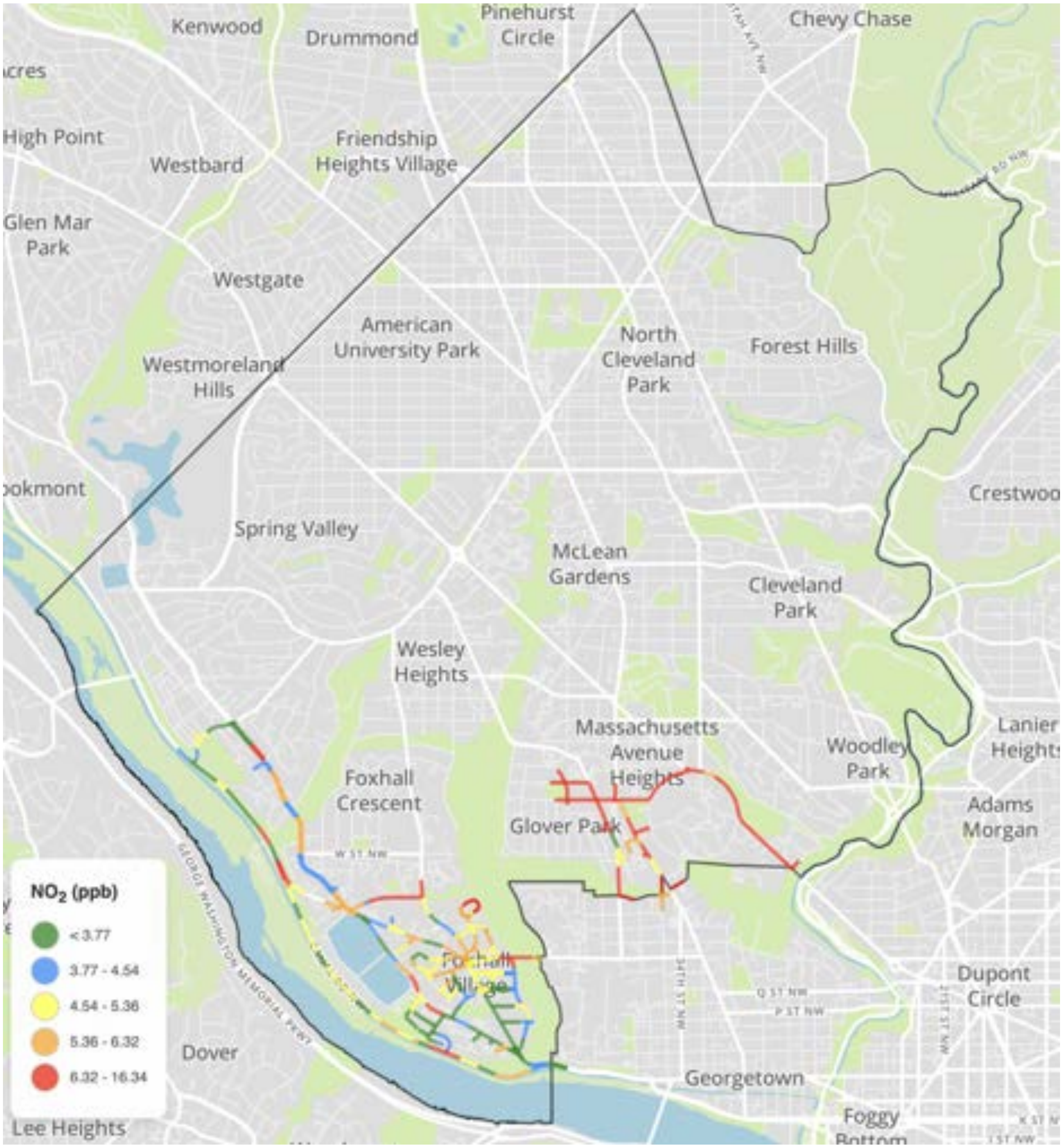


Figure A27: Nitrogen Dioxide line medians for Ward 3

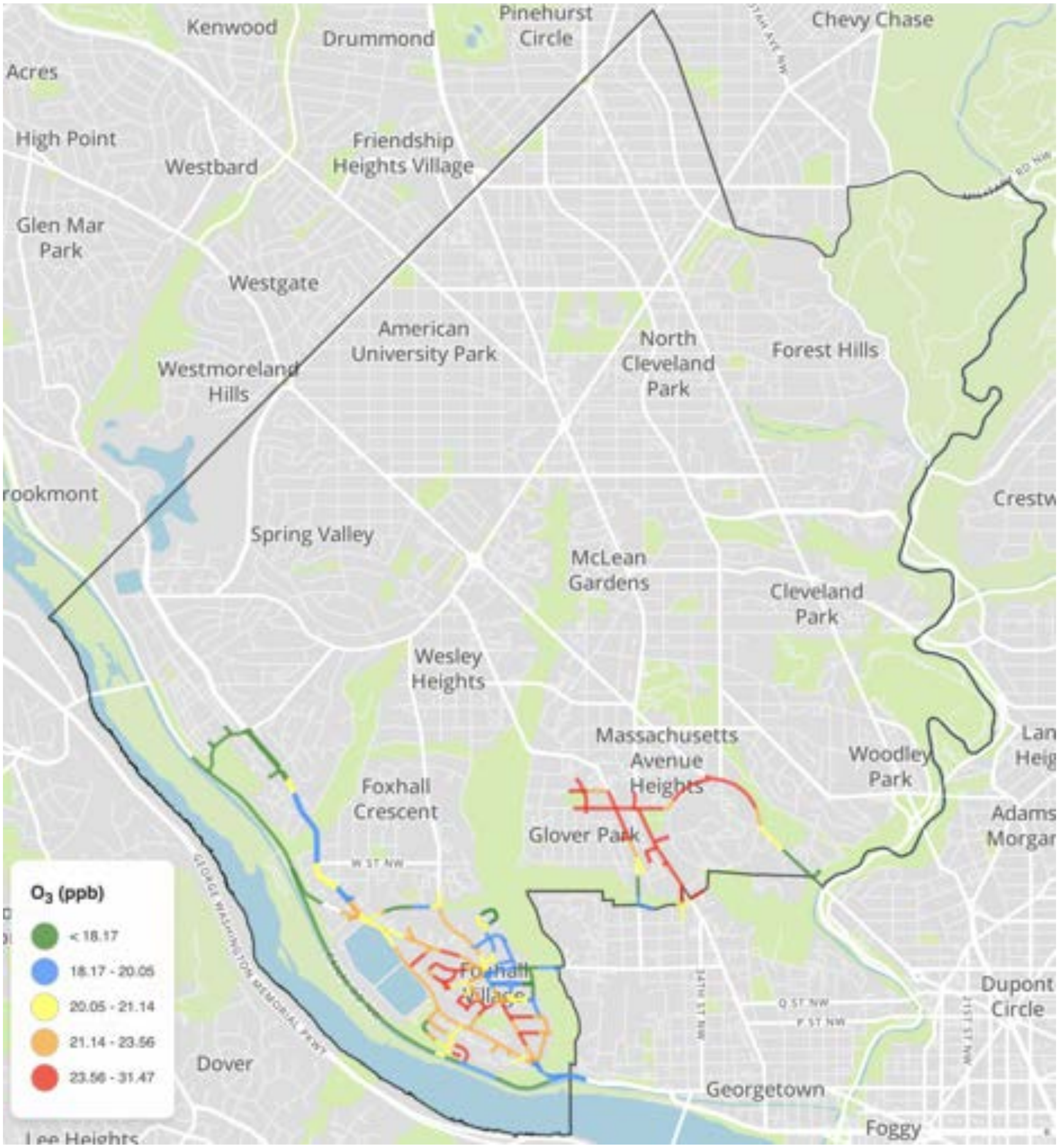


Figure A28: Ozone line medians for Ward 3

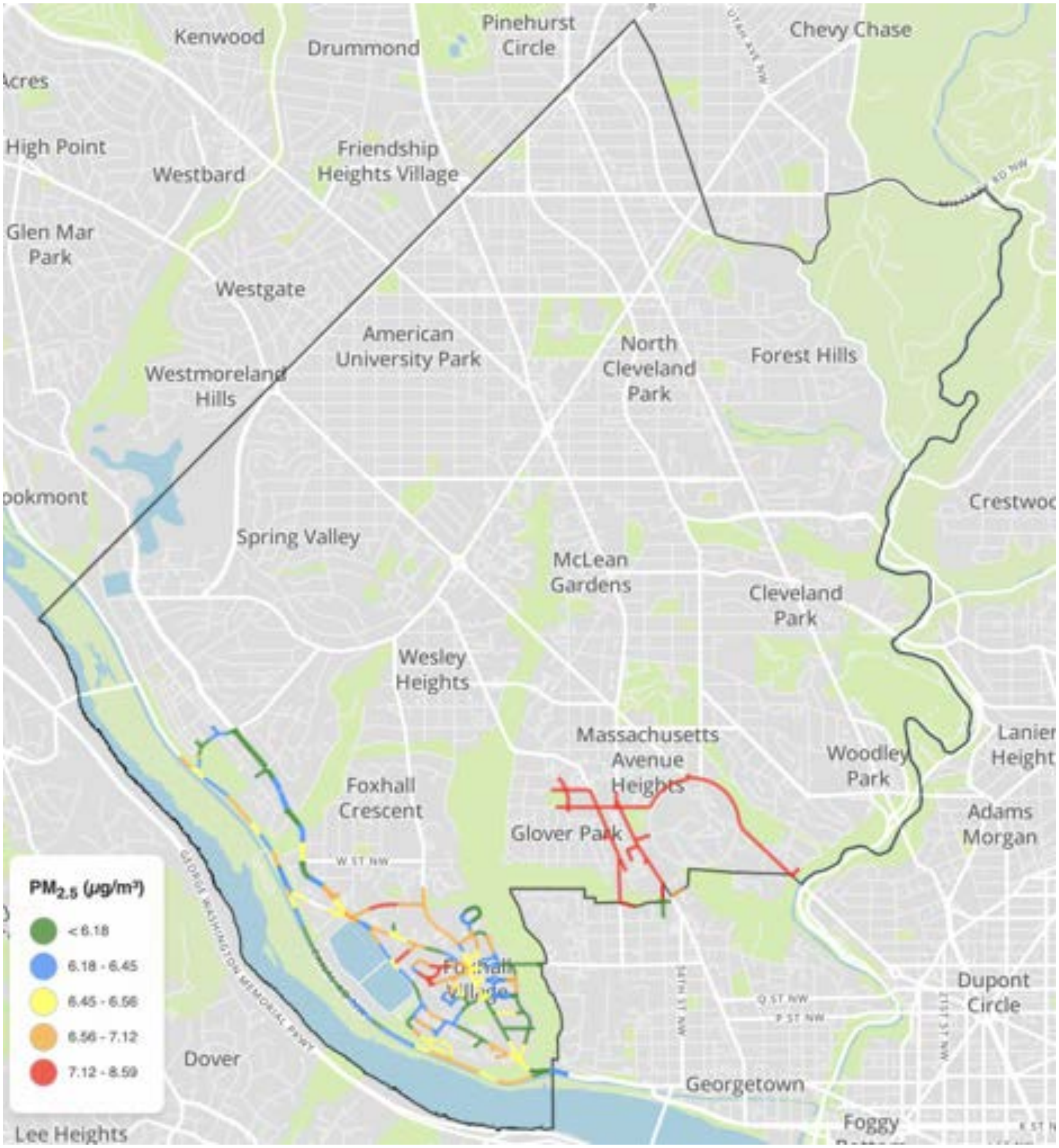


Figure A29: Particulate Matter$_{2.5}$ line medians for Ward 3

A.4.4 Ward 5

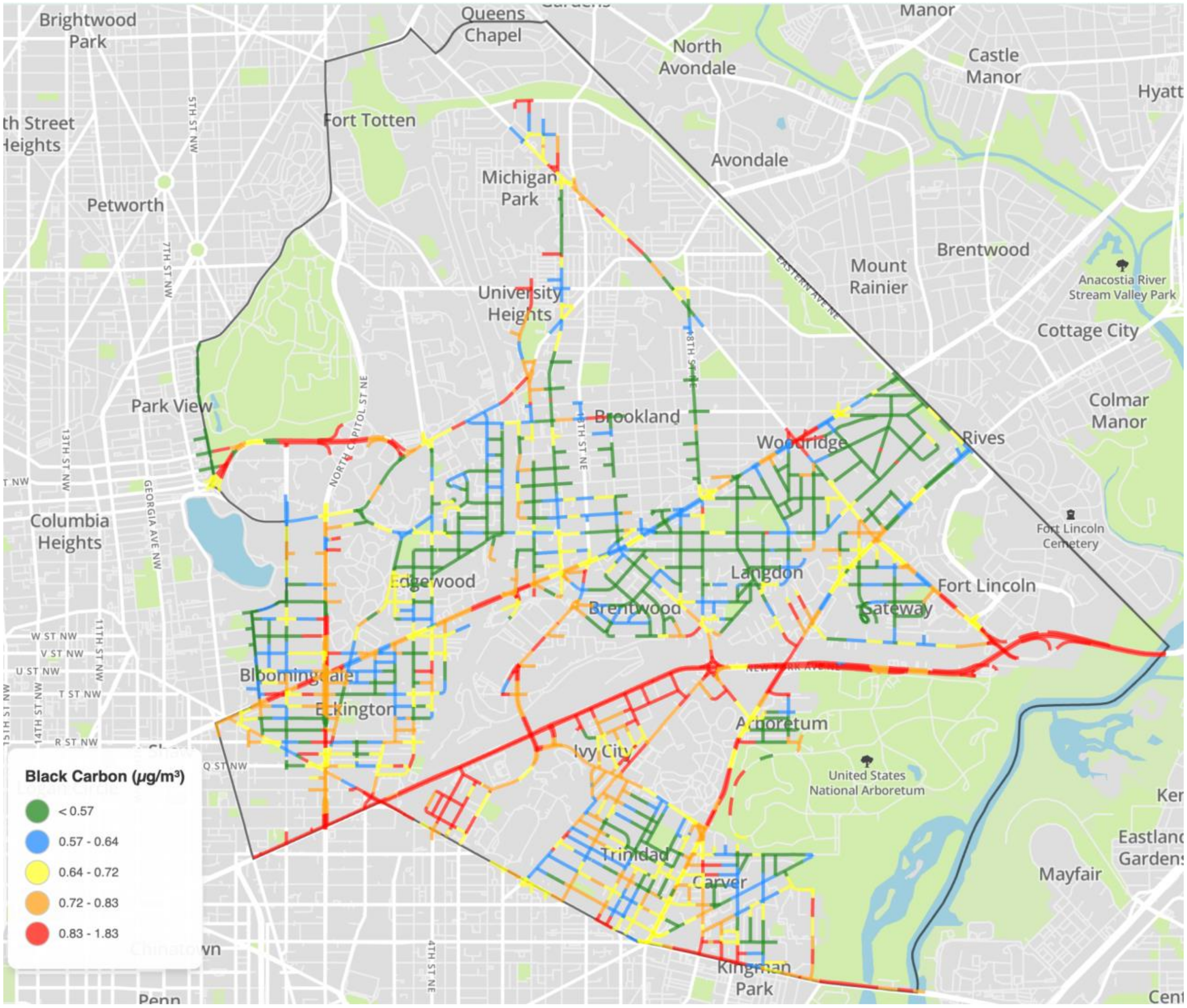


Figure A30: Black Carbon line medians for Ward 5

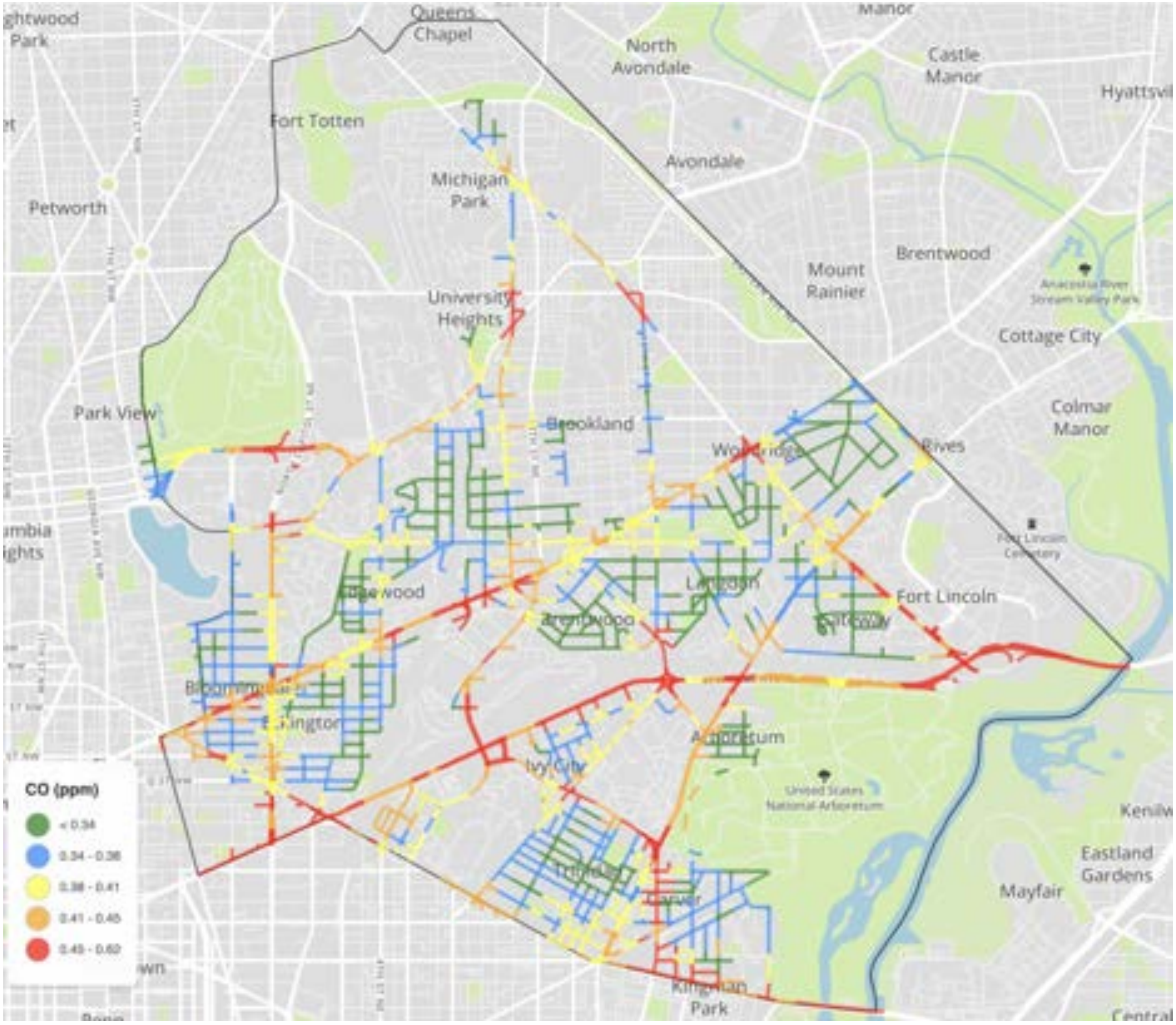


Figure A31: Carbon Monoxide line medians for Ward 5

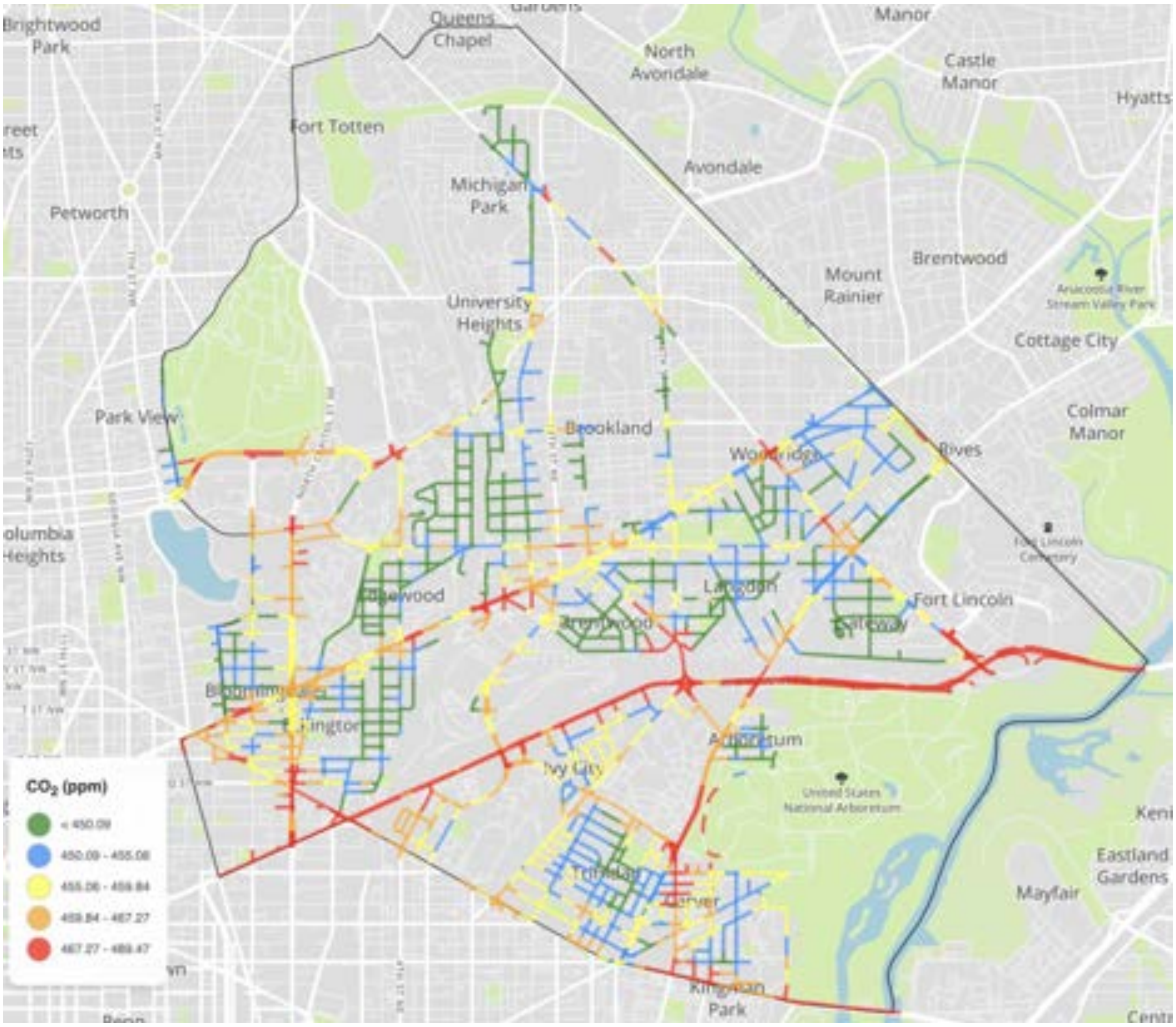


Figure A32: Carbon Dioxide line medians for Ward 5

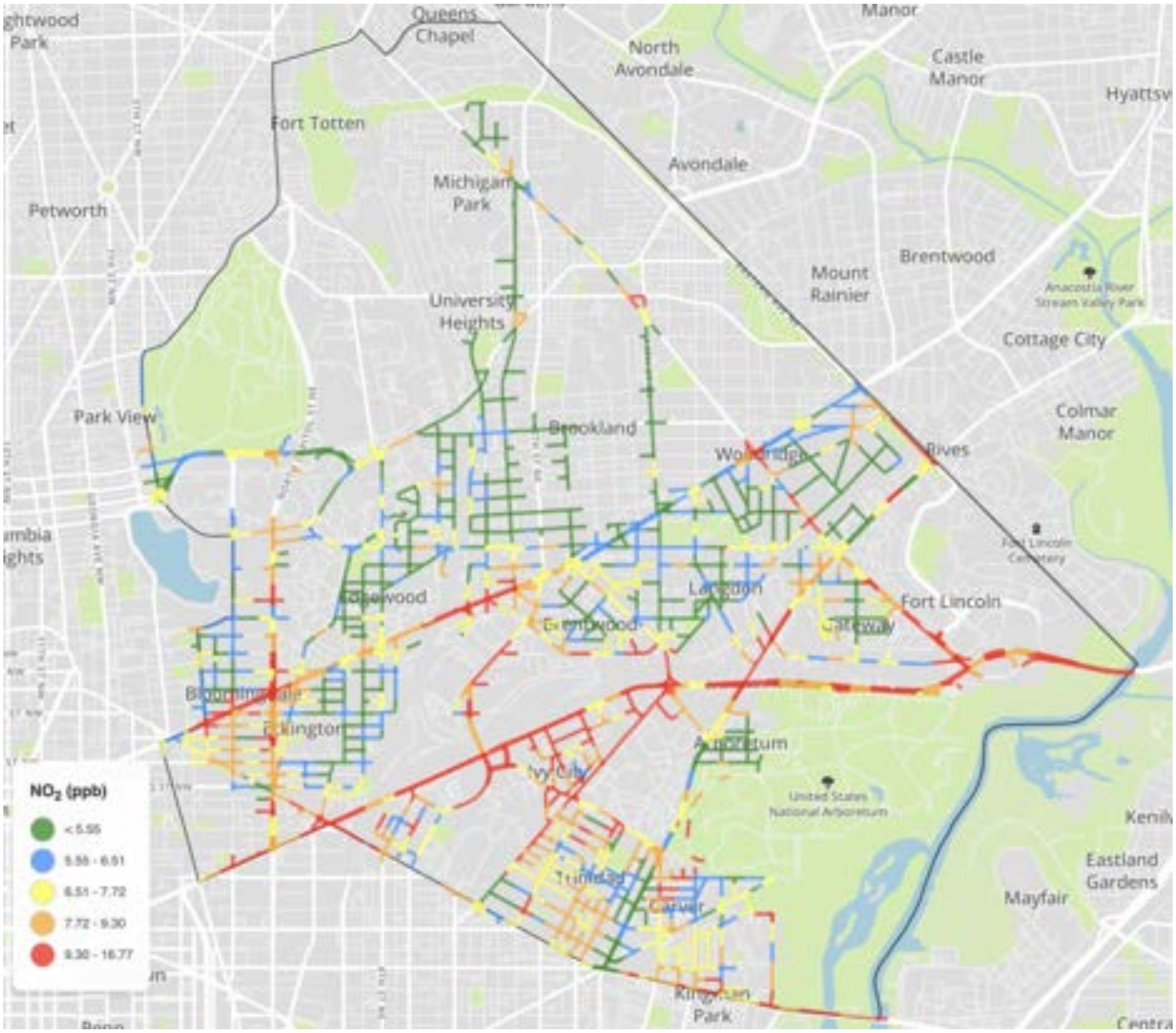


Figure A33: Nitrogen Dioxide line medians for Ward 5

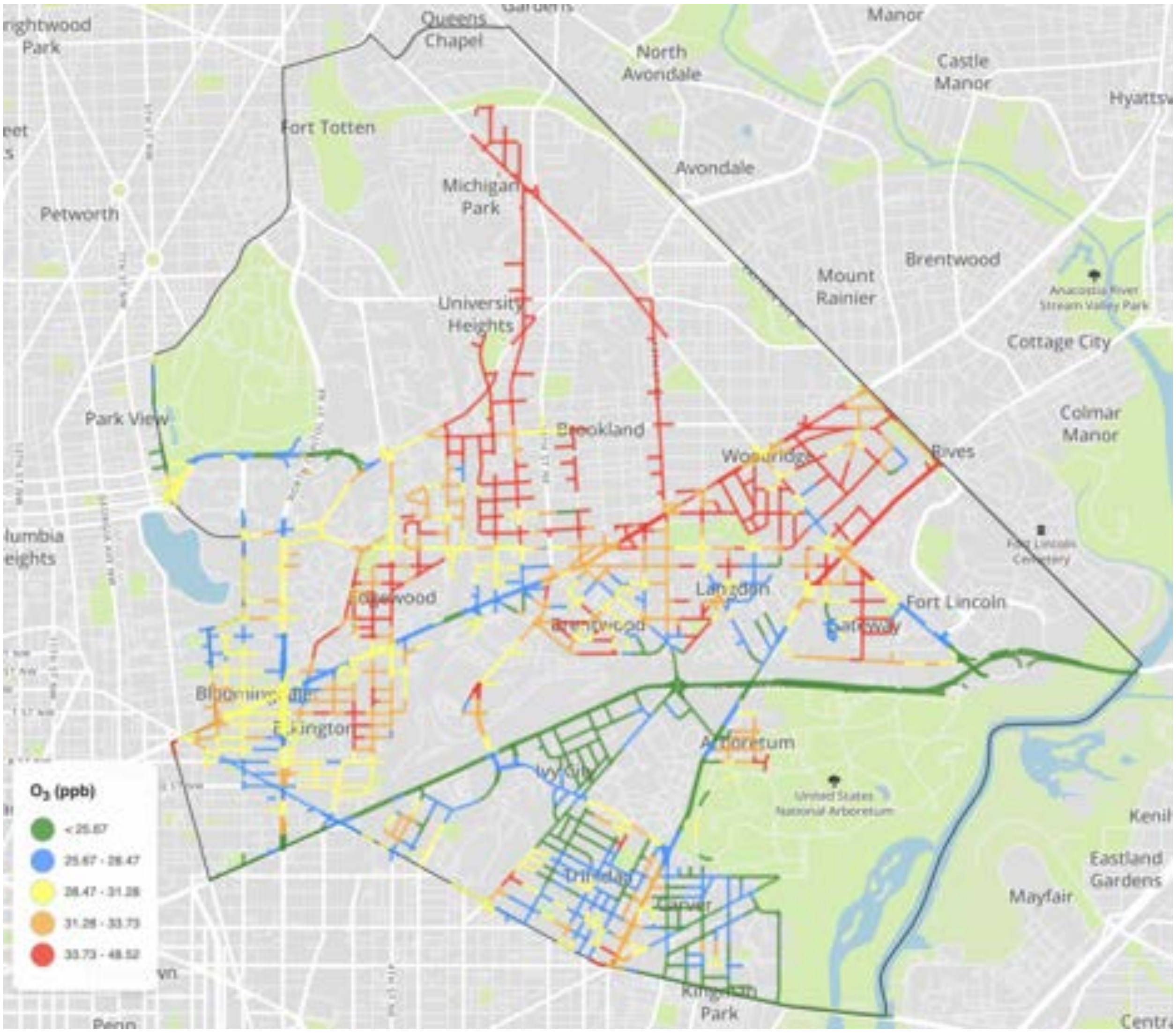


Figure A34: Ozone line medians for Ward 5

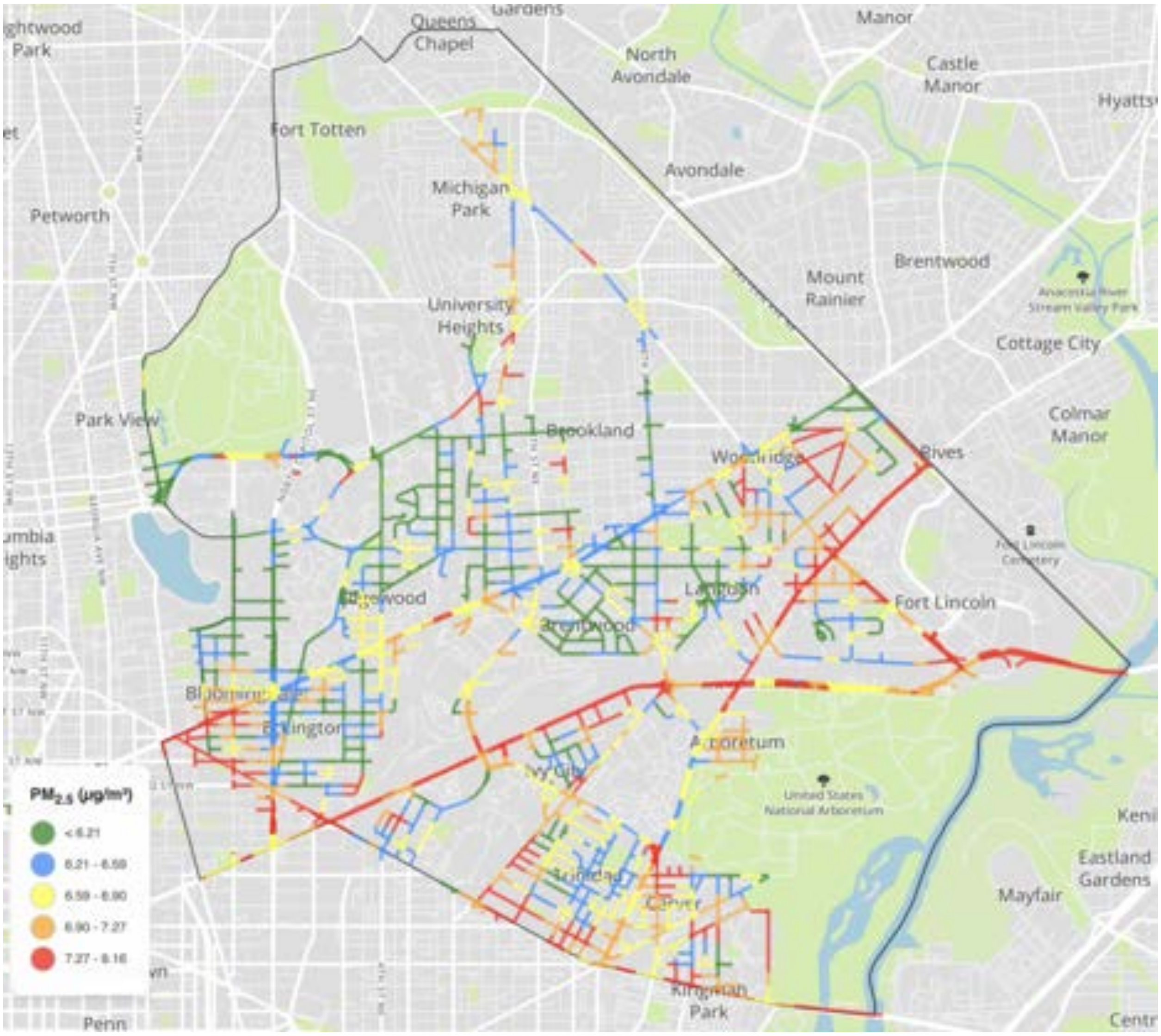


Figure A35: Particulate Matter$_{2.5}$ line medians for Ward 5

A.4.5 Ward 6

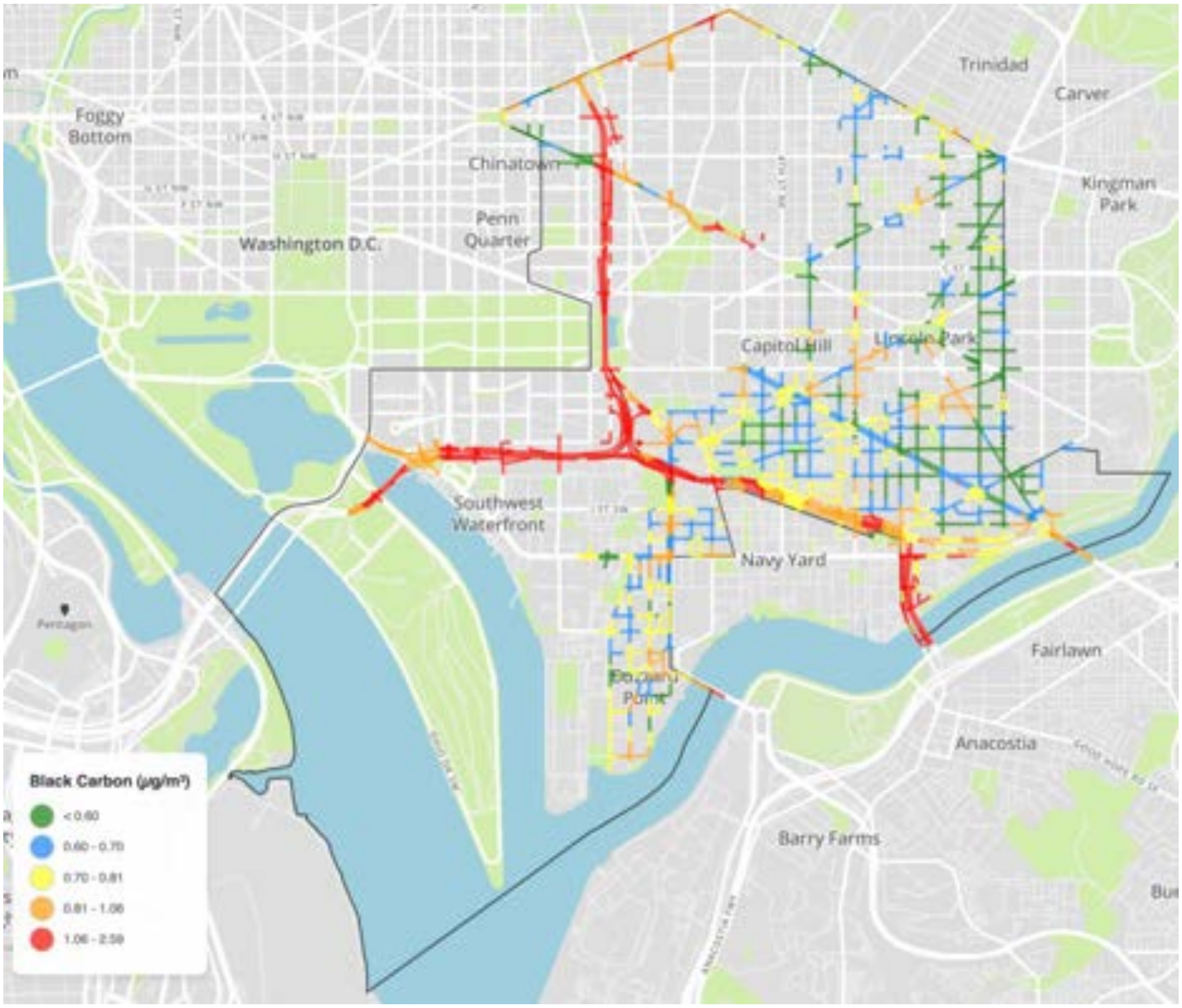


Figure A36: Black Carbon line medians for Ward 6

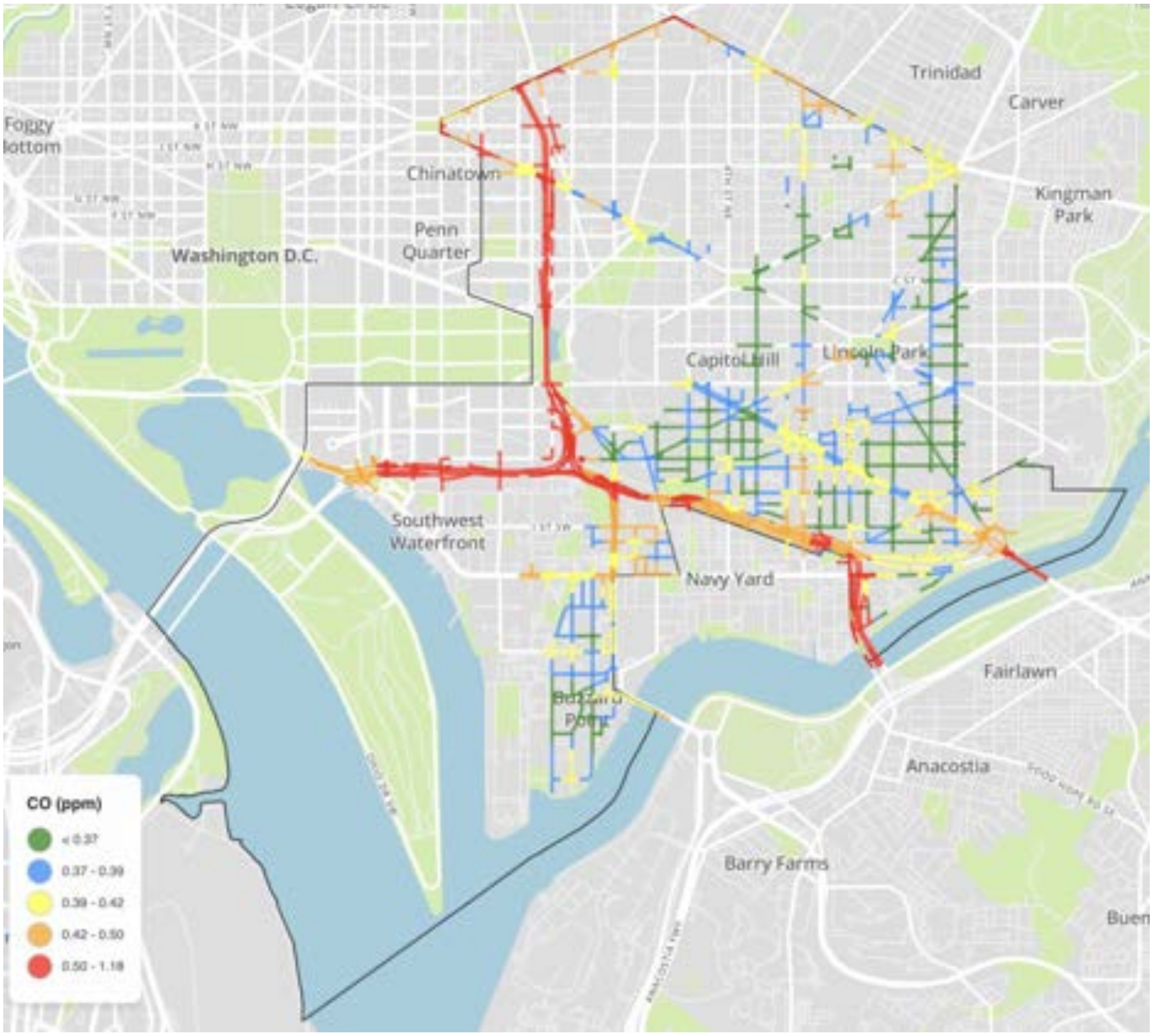


Figure A37: Carbon Monoxide line medians for Ward 6

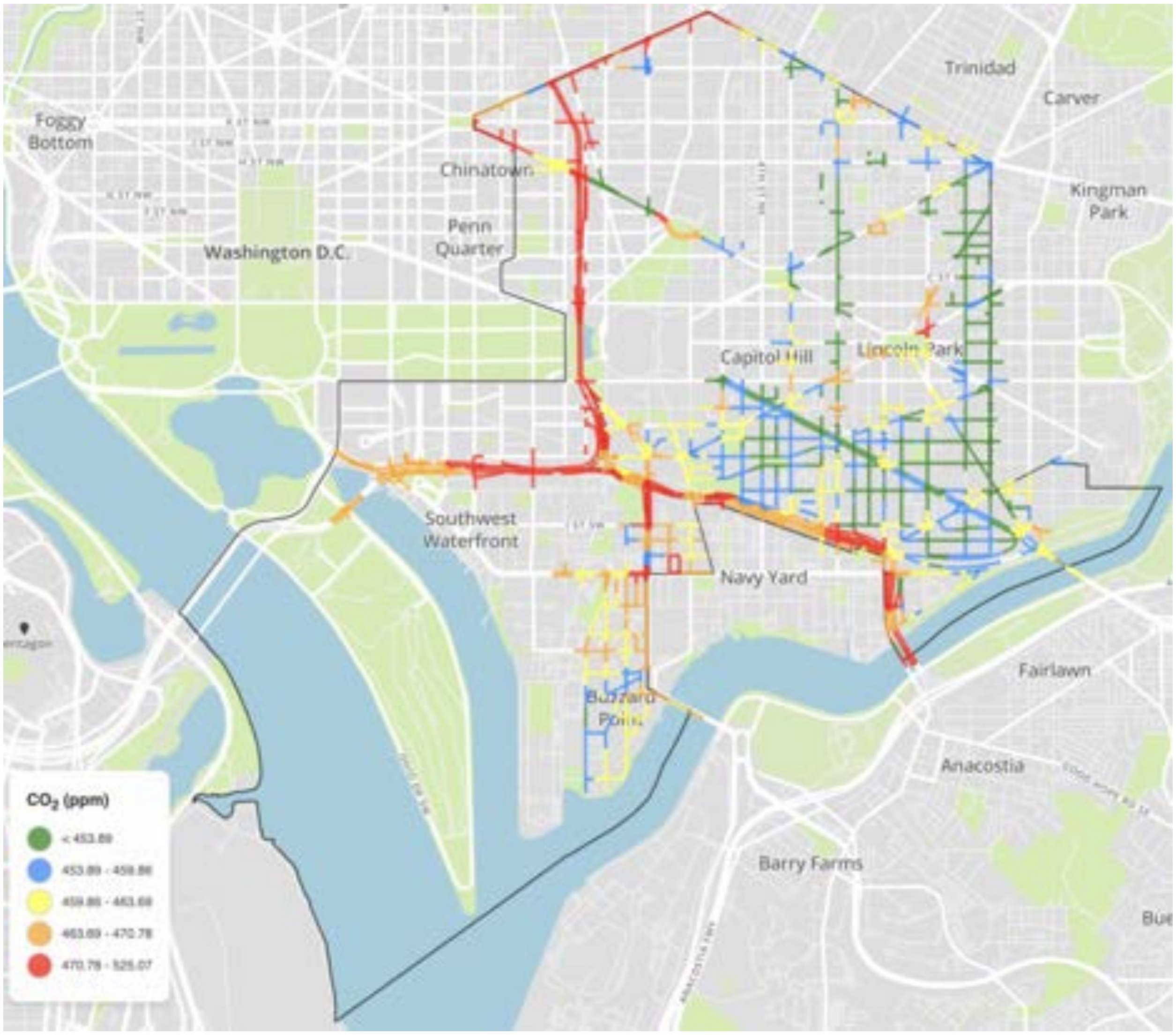


Figure A38: Carbon Dioxide line medians for Ward 6

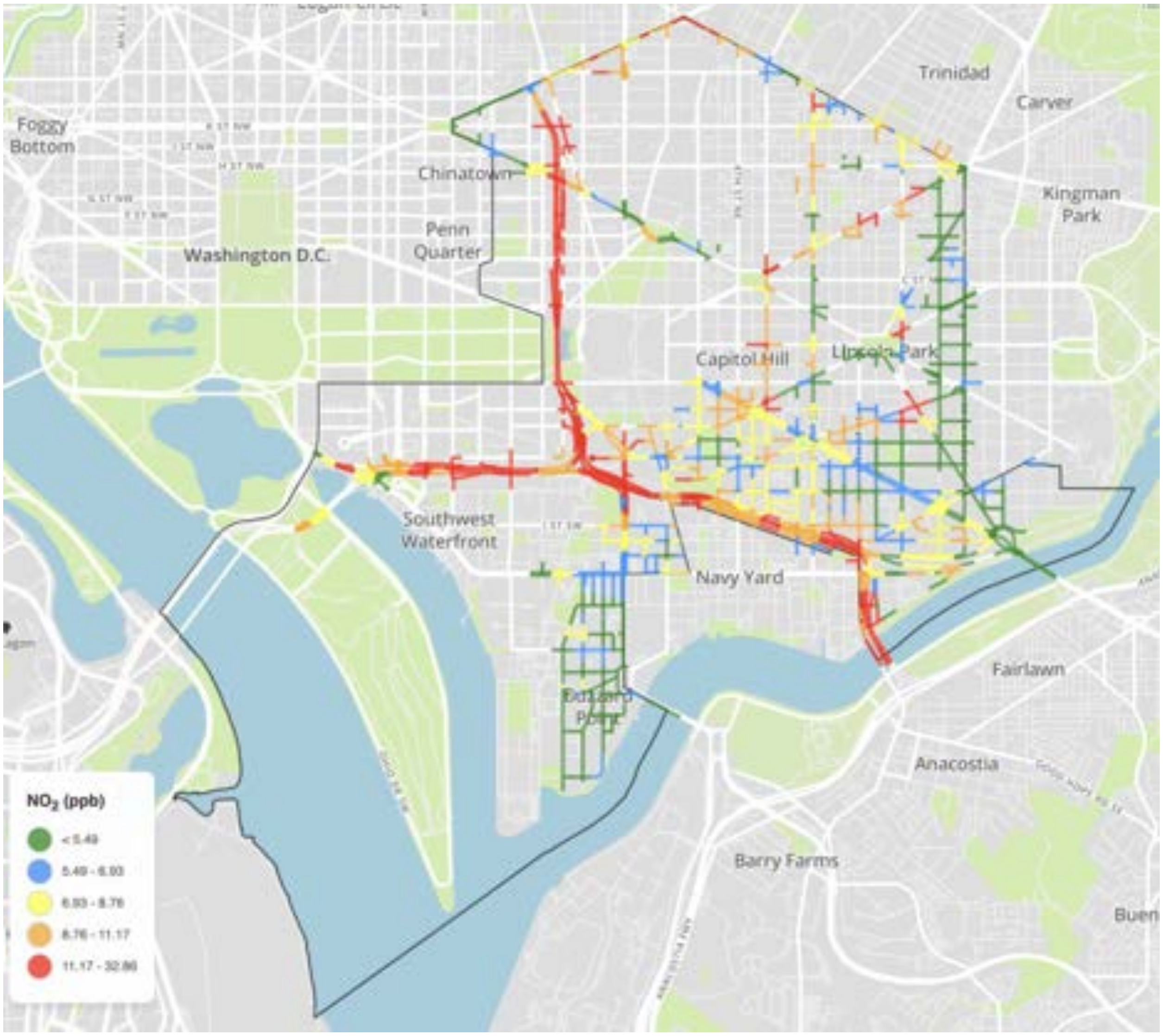


Figure A39: Nitrogen Dioxide line medians for Ward 6

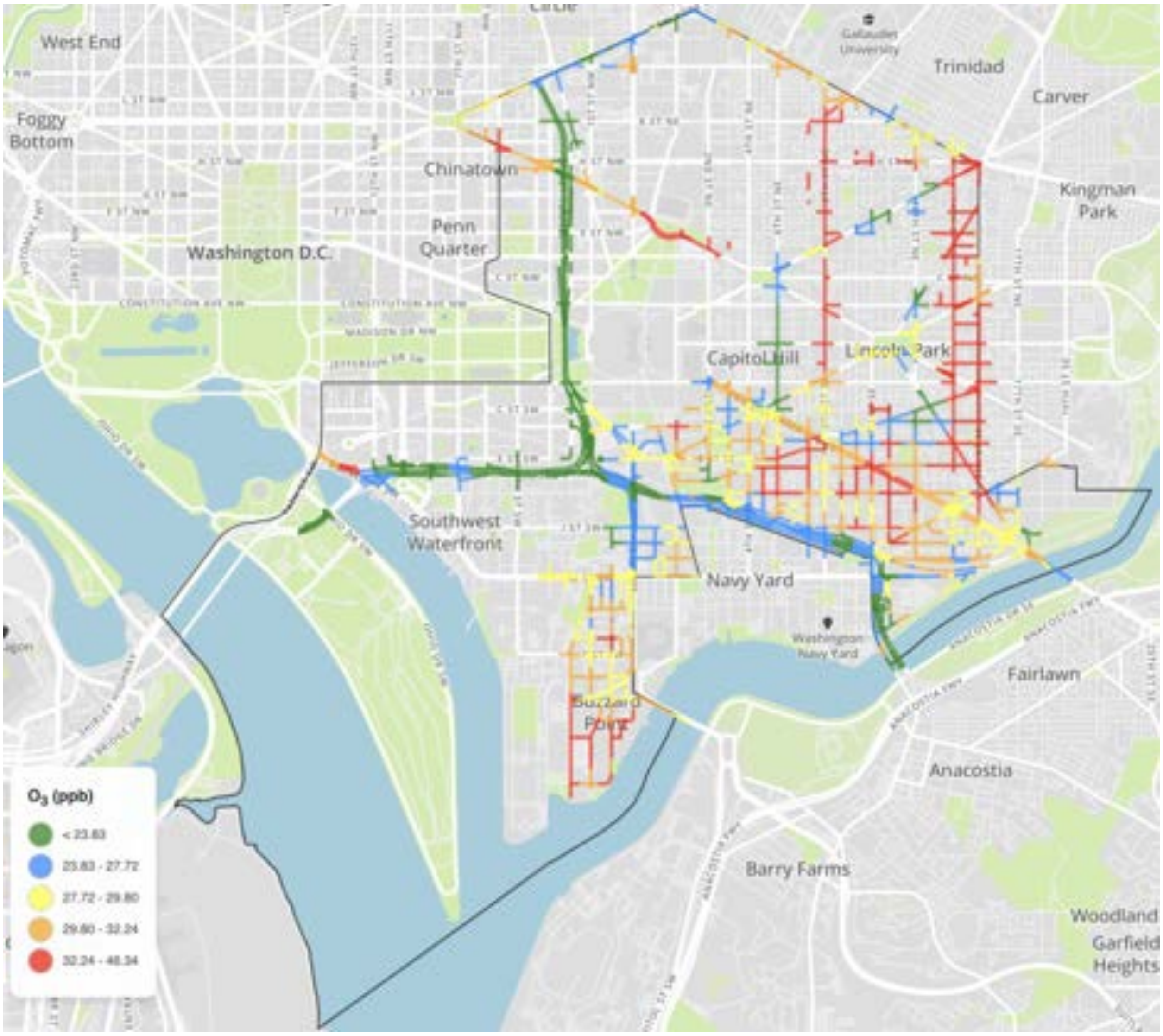


Figure A40: Ozone line medians for Ward 6

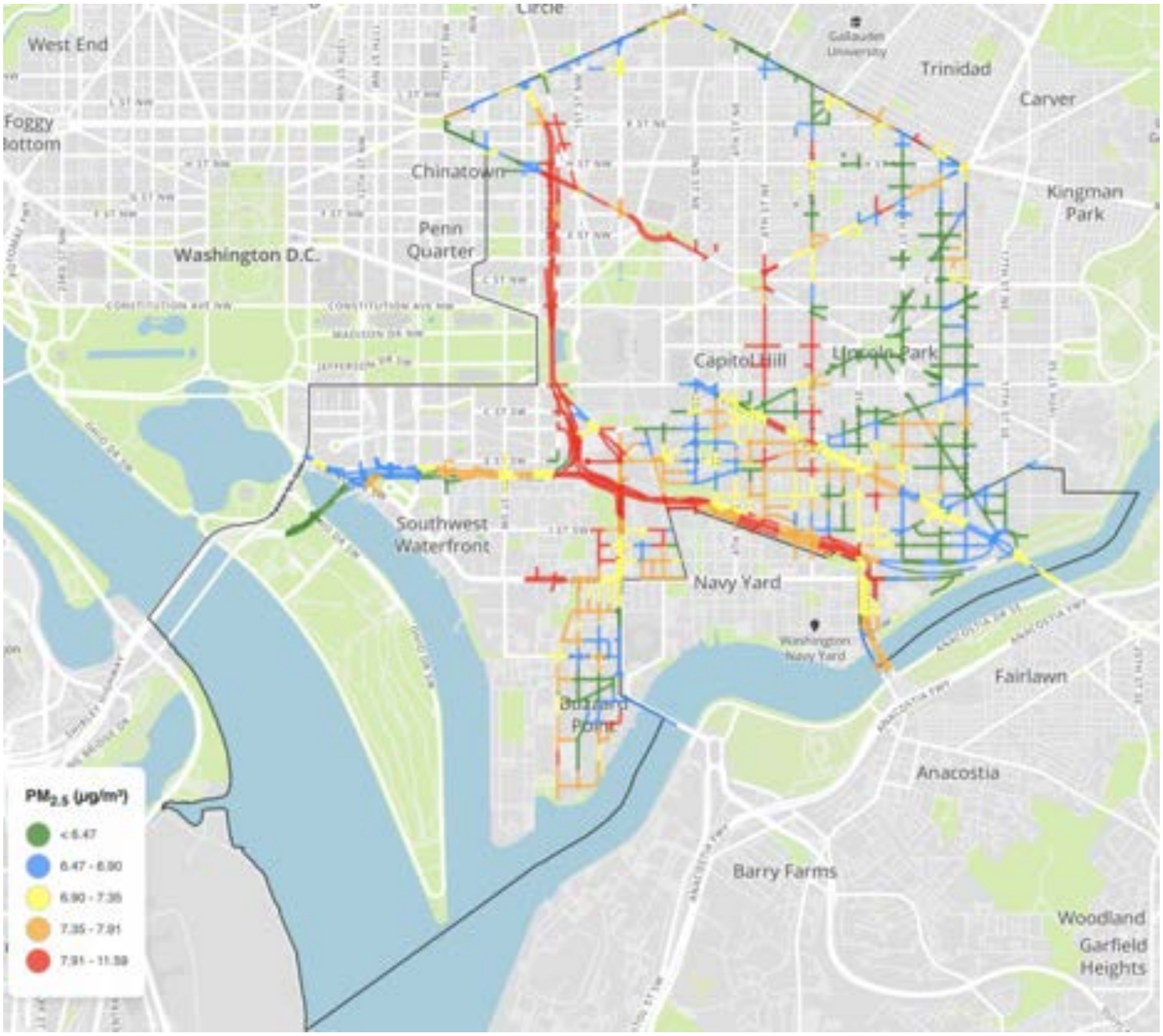


Figure A41: Particulate $Matter_{2.5}$ line medians for Ward 6

A.4.6 Ward 7

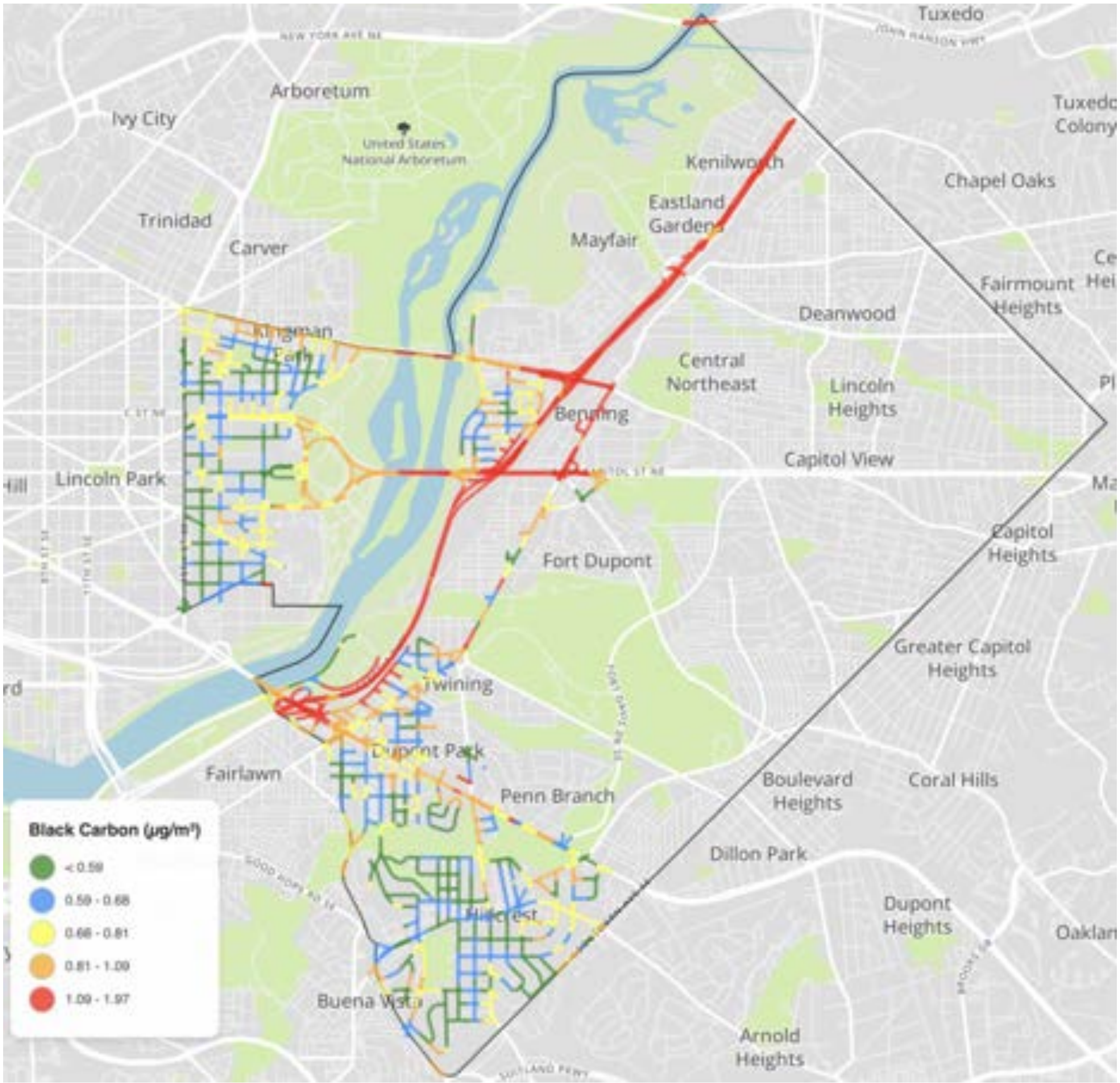


Figure A42: Black Carbon line medians for Ward 7

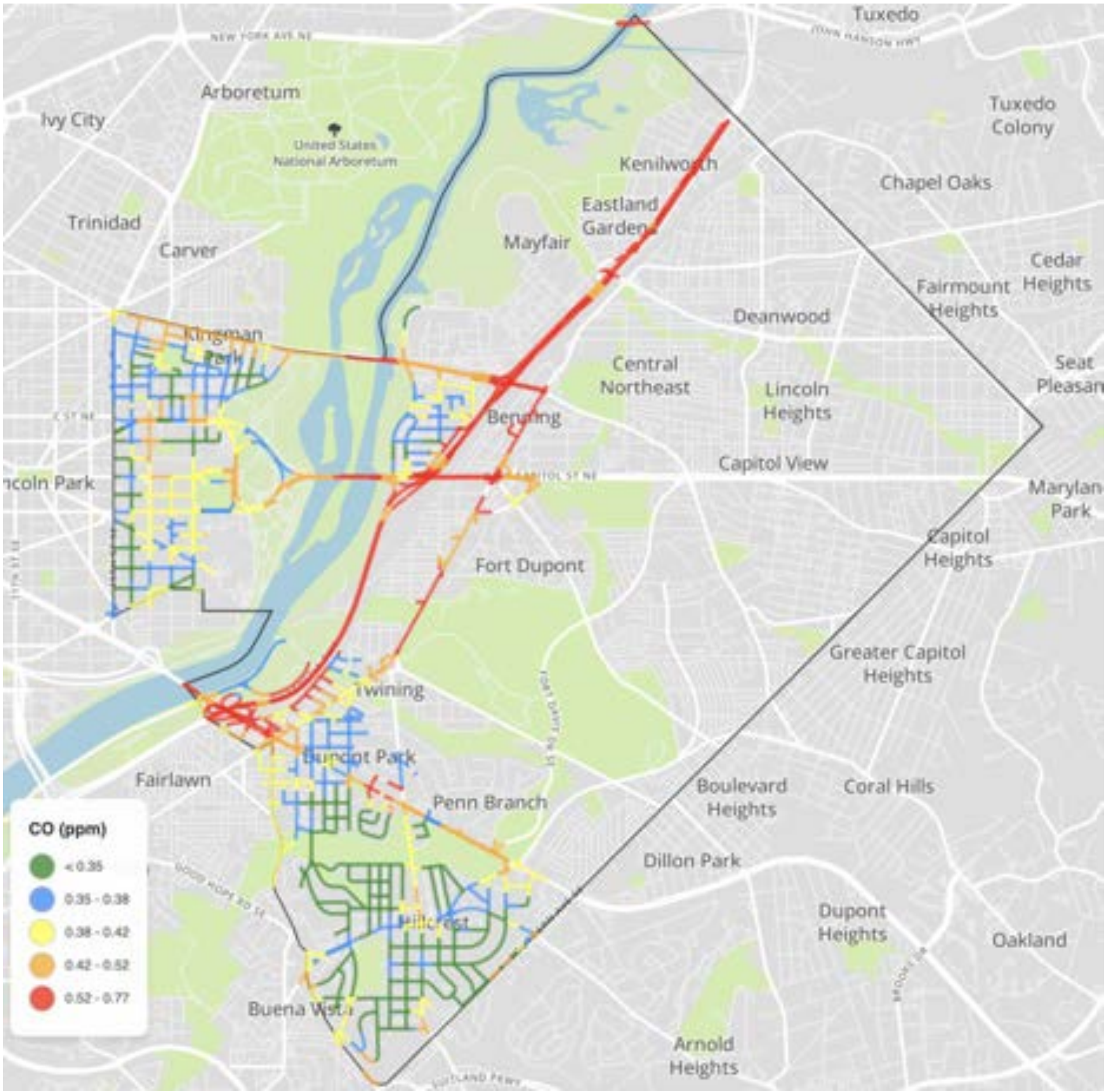


Figure A43: Carbon Monoxide line medians for Ward 7

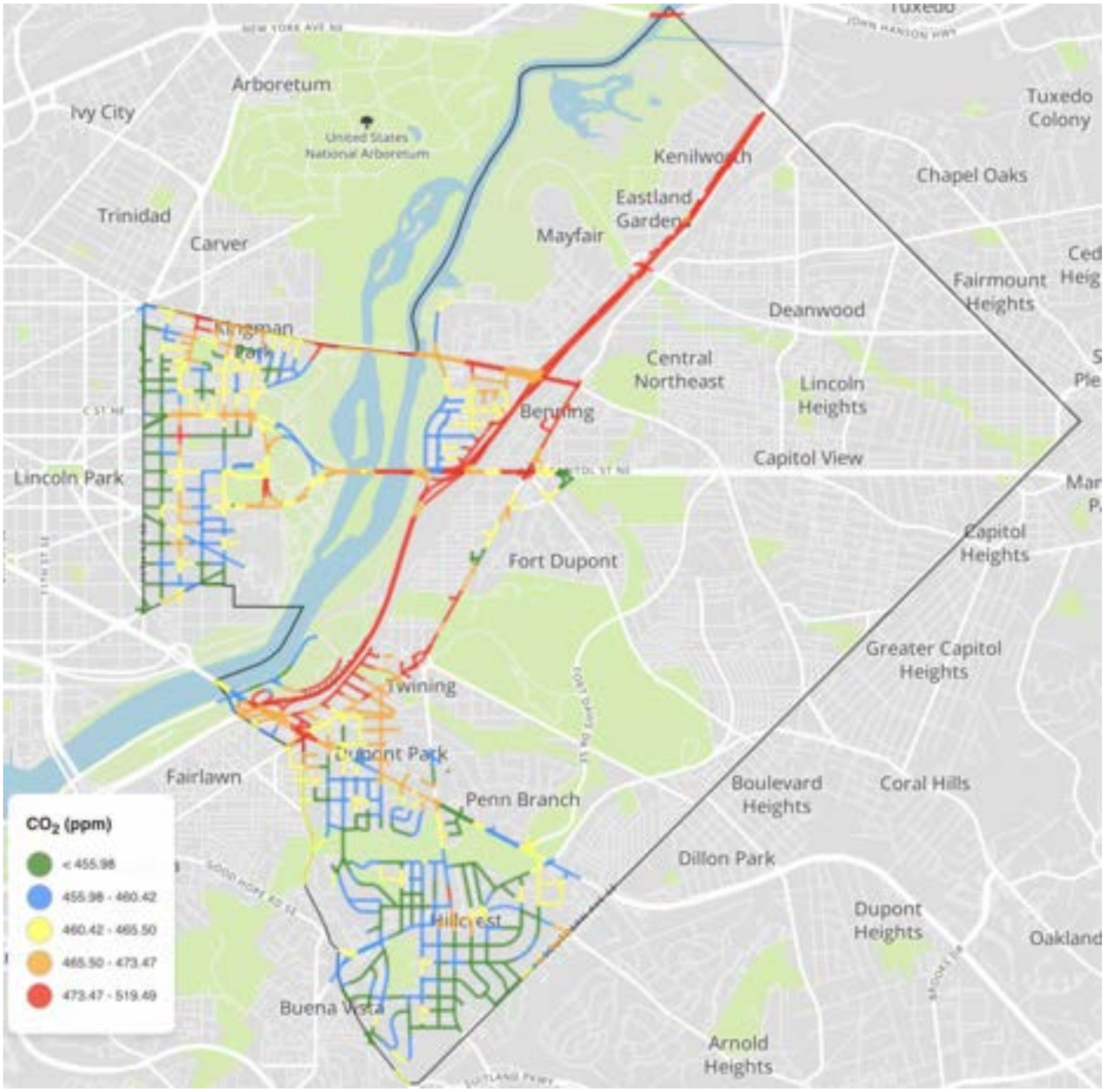


Figure A44: Carbon Dioxide line medians for Ward 7

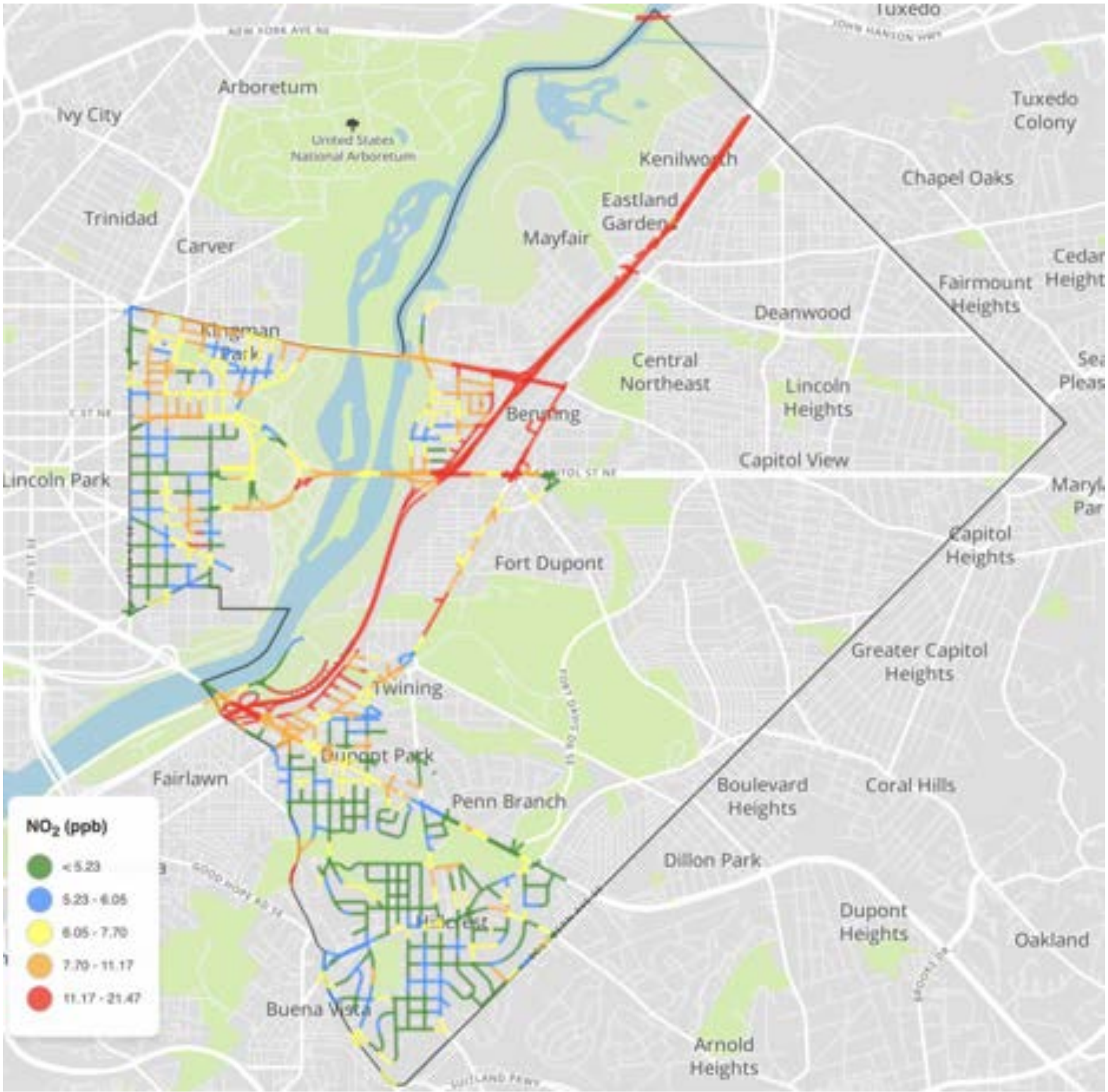


Figure A45: Nitrogen Dioxide line medians for Ward 7

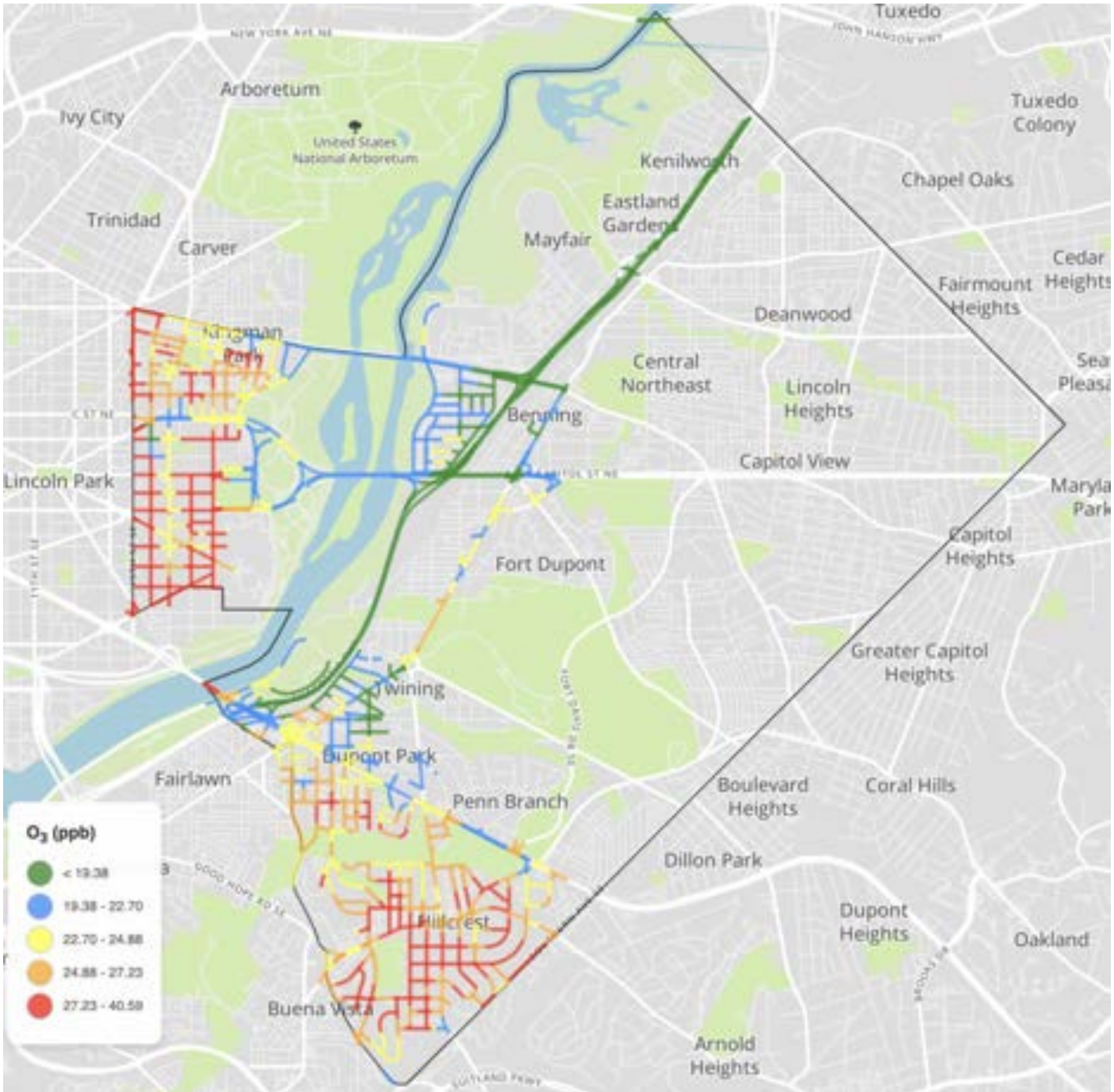


Figure A46: Ozone line medians for Ward 7

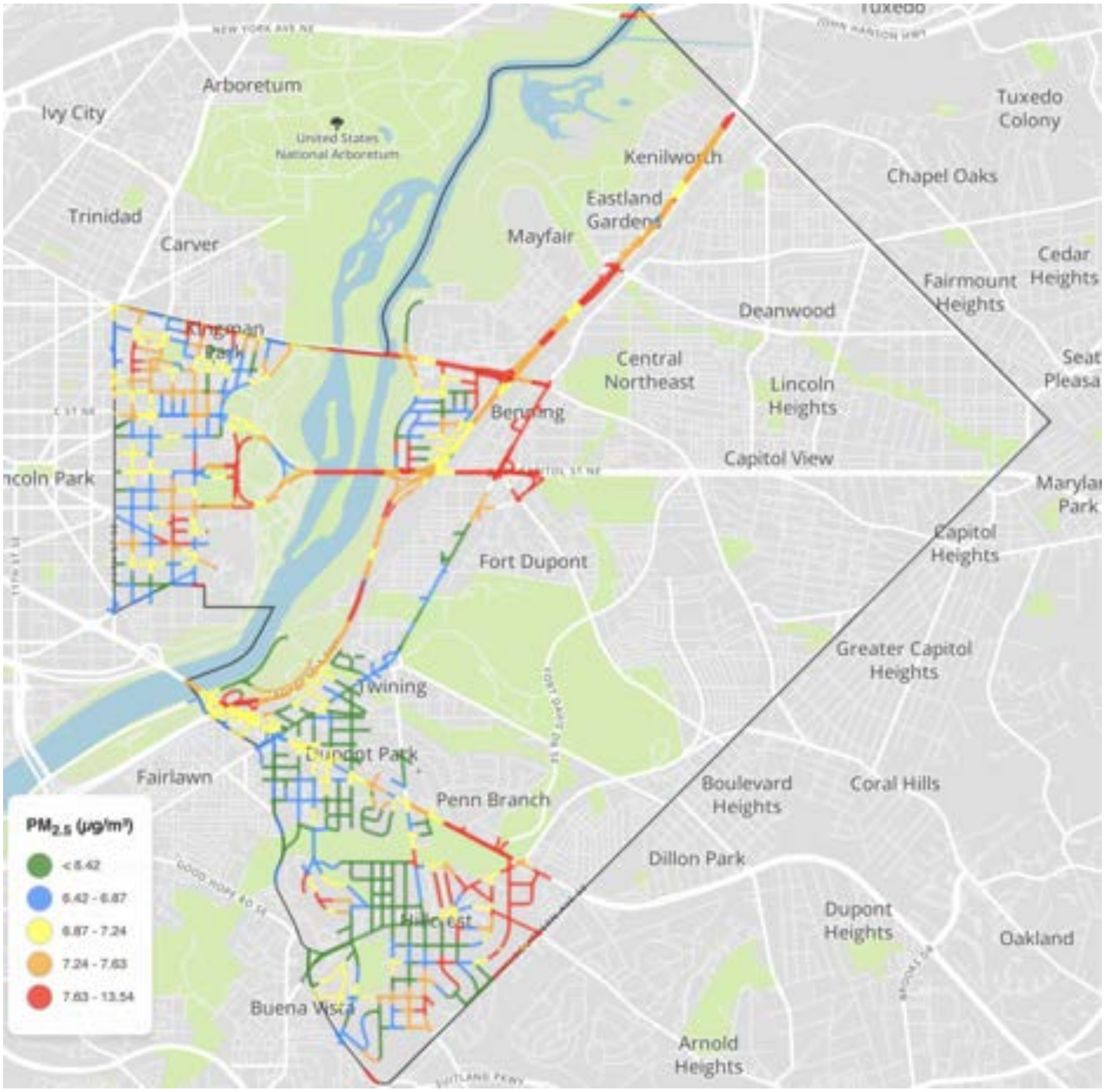


Figure A47: Particulate $Matter_{2.5}$ line medians for Ward 7

A.4.7 Ward 8

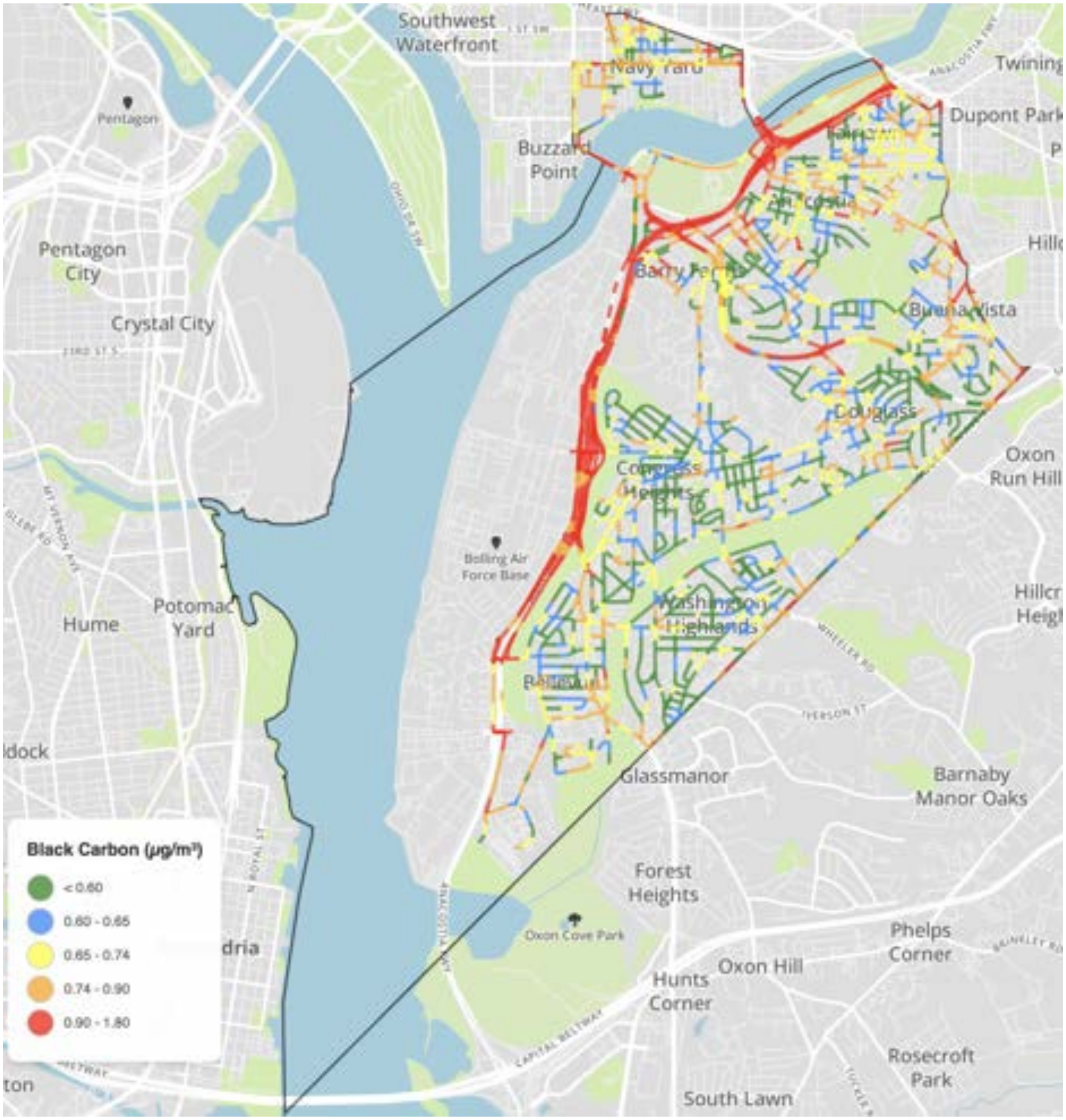


Figure A48: Black Carbon line medians for Ward 8

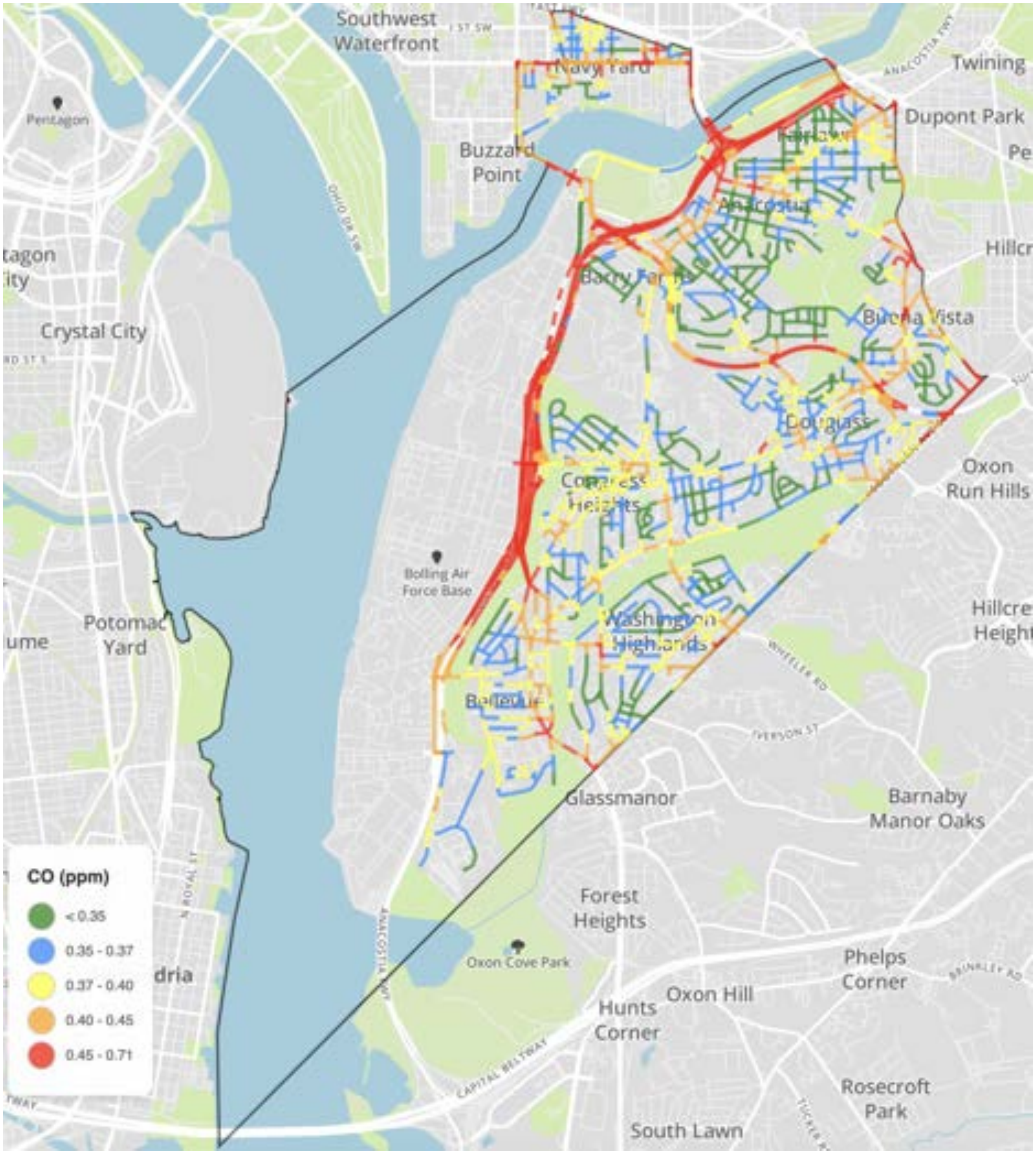


Figure A49: Carbon Monoxide line medians for Ward 8

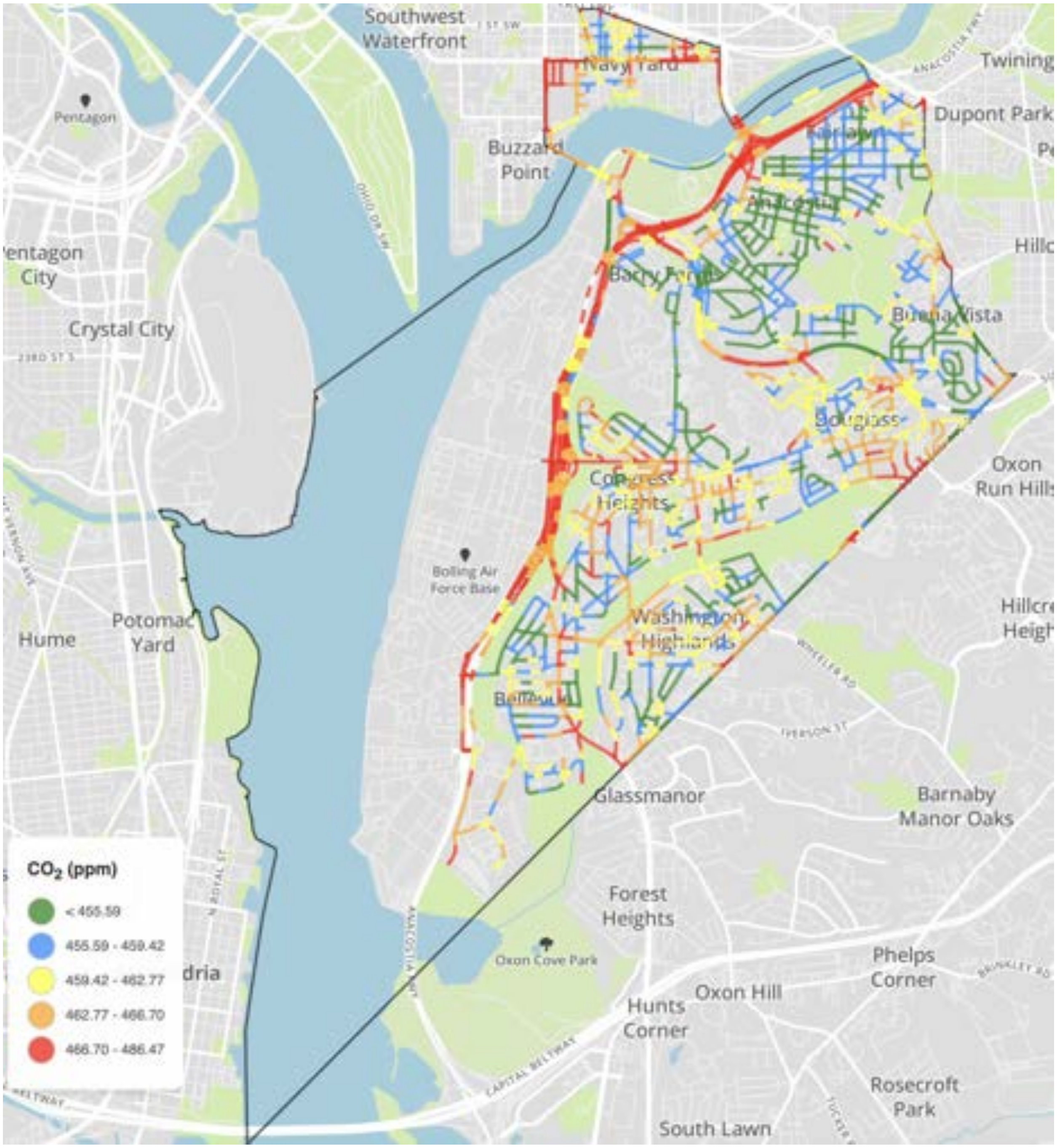


Figure A50: Carbon Dioxide line medians for Ward 8

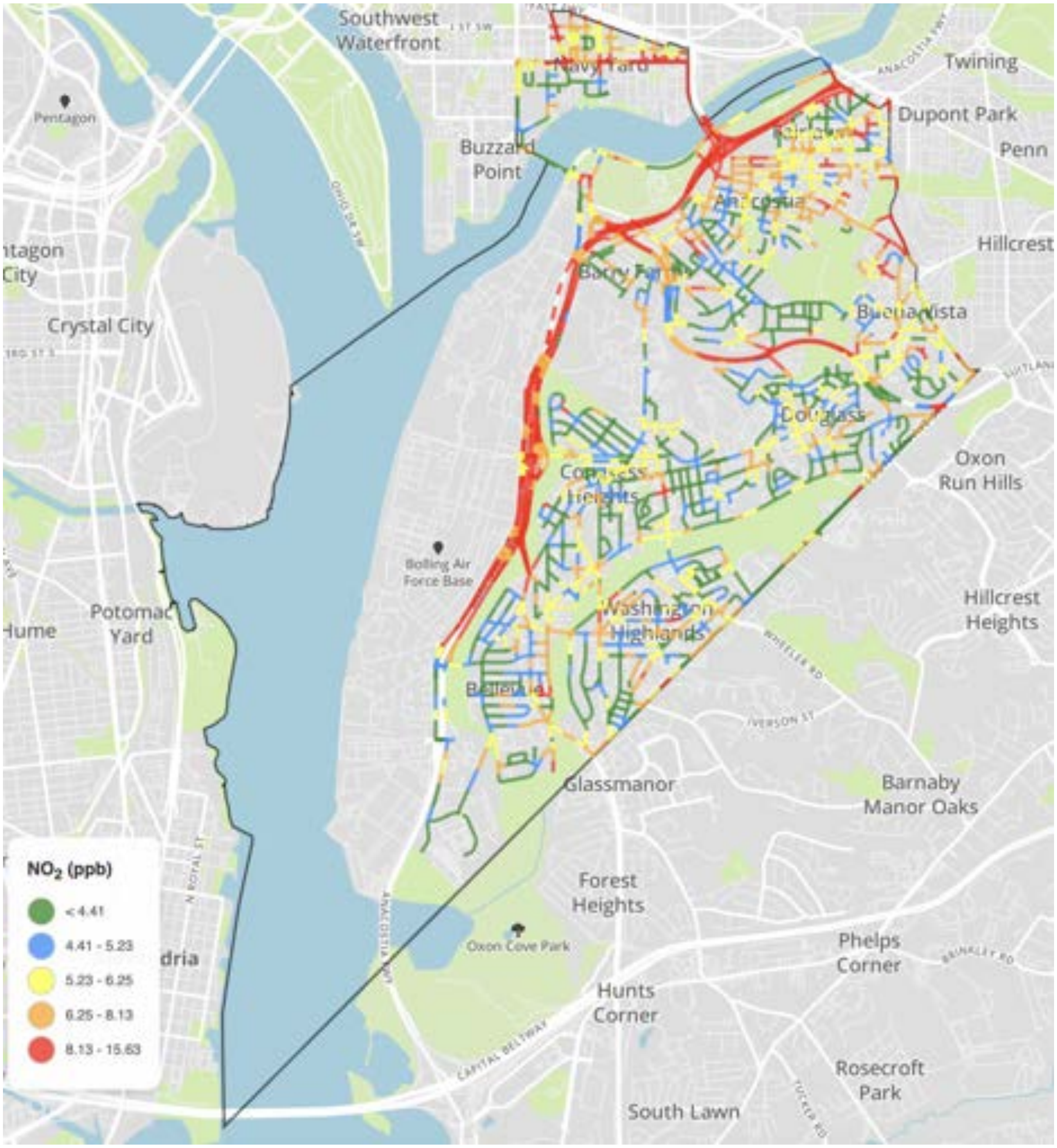


Figure A51: Nitrogen Dioxide line medians for Ward 8

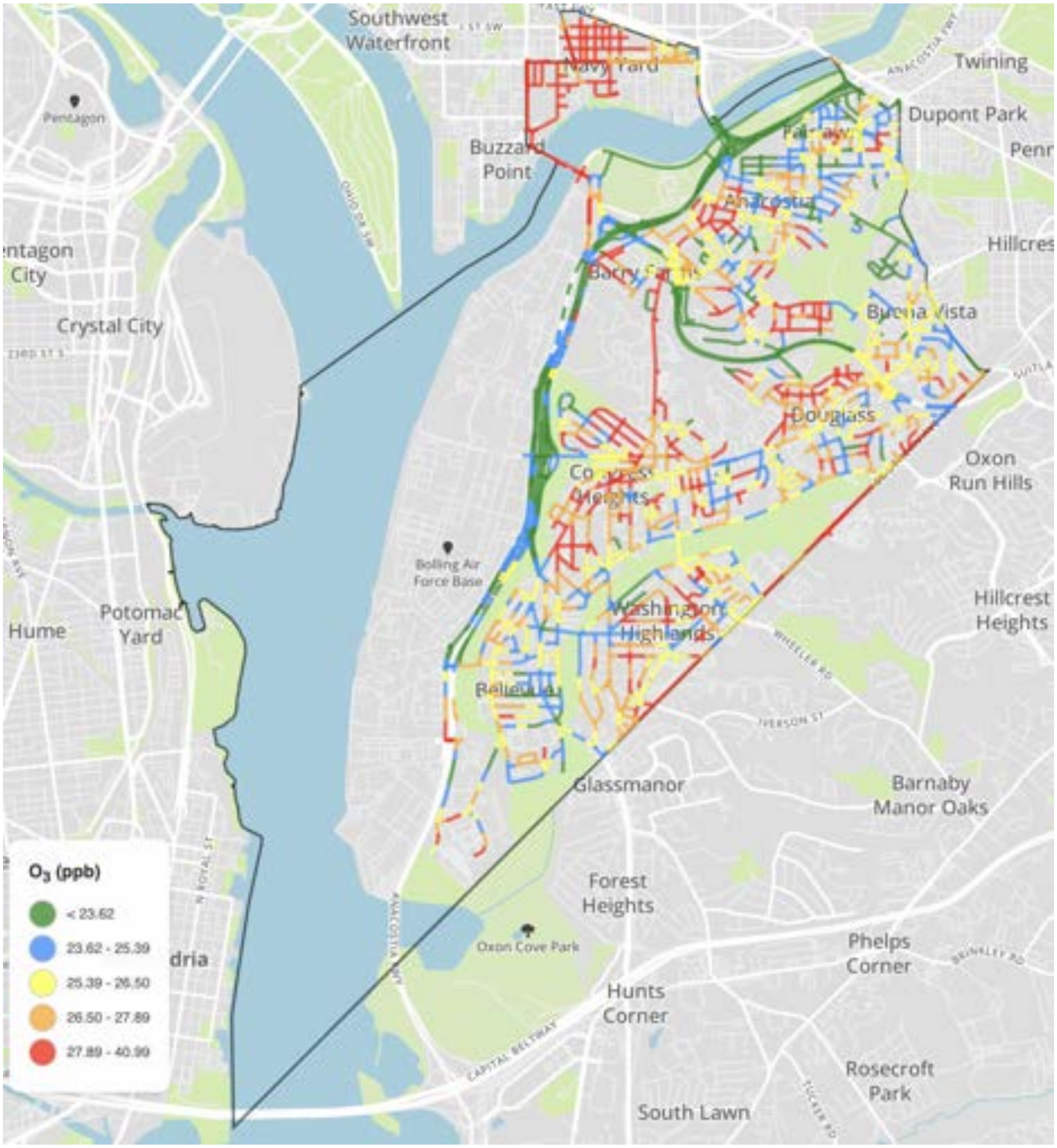


Figure A52: Ozone line medians for Ward 8

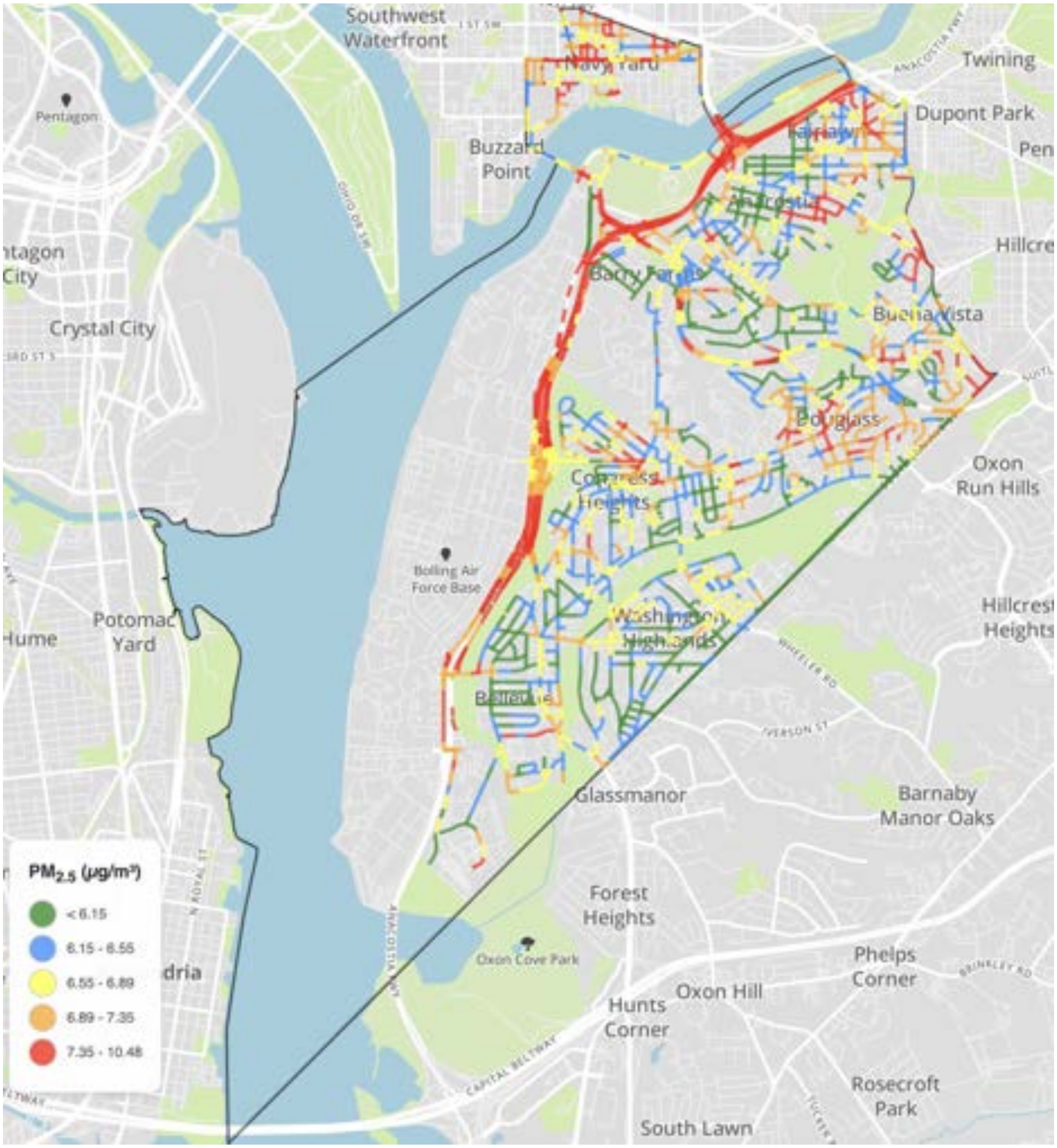


Figure A53: Particulate Matter$_{2.5}$ line medians for Ward 8