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Use Case:

Citizen Science for Hyperlocal Data Collection – Clean Air Carolina and the AirKeepers

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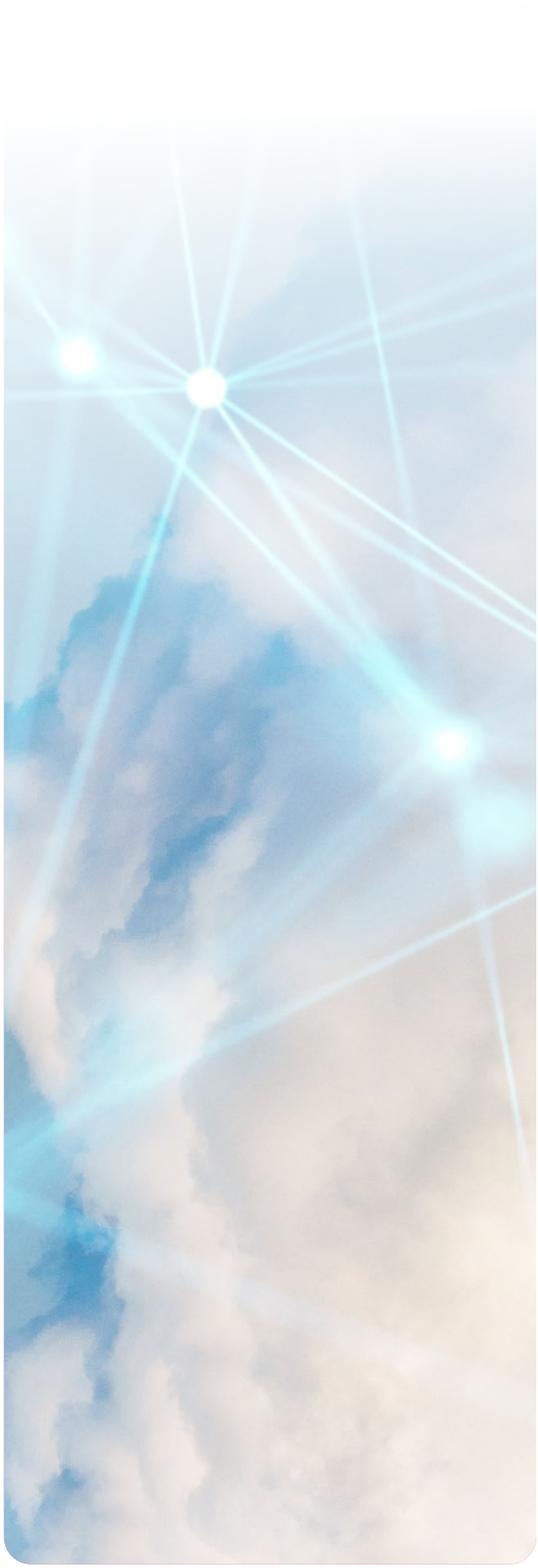

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Introduction

Decades of air quality and public health research has demonstrated the negative health effects of short- and long-term exposure to air pollutants. Respiratory diseases such as asthma and chronic obstructive pulmonary disease, heart disease, cancers, cognitive impairments, and birth defects are associated with poor air quality.[1,2] In 1970, enactment of the Clean Air Act expanded the U.S. Environmental Protection Agency's (EPA) authority to set air quality standards and enforce them through new regulatory programs. Over the subsequent decades, new regulations reduced air pollution and its harmful health effects, contributing to a measurable improvement in life expectancy in the United States.[3,4]

Monitoring air pollution allows the government to enforce air quality standards as well as collect data to inform subsequent research and policies to improve society. While there are many ways the EPA and state, local, and tribal governments collect data to understand air quality and take action to reduce harmful pollutants, there remains an opportunity to collect data on a more granular level. Building an evidence base to better understand how individual communities and neighborhoods experience variations in air quality can have an impact on disparities in health outcomes across the country. This use case describes one such example where local scientists partnered with a community to collect hyperlocal, real-time data to fill a gap in the evidence and inform future decisions.

Regulatory Landscape of Air Pollutants

The National Ambient Air Quality Standards (NAAQS) refer specifically to six pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide.[5] The Clean Air Act authorized the expansion of the EPA's federal regulatory responsibilities, state and tribal governments have the primary role for enforcing the Clean Air Act and controlling pollution within their borders. As part of this responsibility, each state must formulate an enforceable plan to comply with the NAAQS. These State Implementation Plans are approved by the EPA and vary widely, but typically consist of a mix of state and local monitoring and permitting schemes.[6]

Under this regulatory structure, tribal governments, states, and other local governments operate EPA-approved monitors and oversee compliance with NAAQS and other federal thresholds for air quality. Each of the six NAAQS pollutants has criteria for exposure limits based on the severity of their impacts on public health and vulnerable populations ("primary standards") and on visibility, crops, animals, and the environment ("secondary standards"). Standards for NAAQS pollutant concentrations range from hourly to yearly averages.

Exposure to particulate matter poses serious health risks, especially to children, older adults, and people with heart or lung conditions. Short-term exposure to elevated particulate matter—such as a day-long spike in concentration from a construction project—can spur asthma attacks, increase vulnerability to respiratory infections, and aggravate pre-existing heart and lung problems. Long-term exposure to particulate matter over multiple years is associated with chronic lung conditions such as bronchitis.[7]

Since the effects of short-term particulate matter ($PM_{2.5}$) exposure are not as drastic and immediate as those of carbon monoxide (CO) or lead (Pb) exposure, $PM_{2.5}$ concentrations are averaged over a longer period of time to determine NAAQS compliance. For example, carbon monoxide (CO) concentration is regulated by an hourly average which cannot be exceeded more than once per year, whereas exposure limits to $PM_{2.5}$ is based on a yearly average.[8] Since NAAQS enforcement is built on these averages, states and local authorities place monitors in "areas of relatively high population and/or areas believed to have relatively higher pollutant concentrations," according to the EPA.[9]

The EPA's guidelines for locating monitors vary by pollutant and purpose. For example, when monitoring to determine the *highest* concentration of a pollutant in a given area, a middle scale monitor with a range of 110 yards to 0.3 miles might be appropriate, whereas a neighborhood-scale monitor with a range of 0.25 to 2.5 miles would be more appropriate for determining baseline pollutant concentrations in densely populated areas.[10] This multifaceted approach is meant to capture trends in air quality and detect NAAQS violations which may harm the public.

However, since monitoring networks rely on broad trends and predictions of pollutant concentrations, it is possible for some areas to have less comprehensive air data than others. This makes it possible for local spikes in air pollution to go unnoticed, putting residents—and those with pre-existing conditions that are affected by air pollution, such as asthma, for example—at higher risk.

Filling a Gap: A Need for Hyperlocal Data Collection

Recognizing that current monitoring structures may overlook certain areas, some communities are working to collect more localized data. In Charlotte, North Carolina, residents identified a research need and worked with local scientists to fill a gap in the data to address the communities' questions and build an evidence base for future policy.

Historical Context of the Historic West End

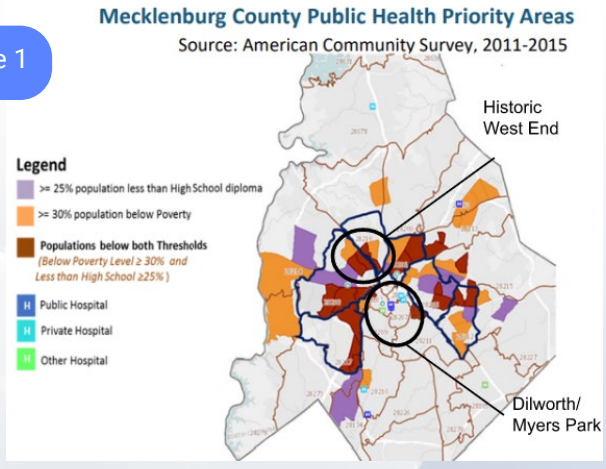
The Historic West End is a neighborhood in Charlotte that was established over 150 years ago. It is deemed a "Public Health Priority Area" by the county, meaning it is an area where residents of the neighborhood suffer from higher rates of chronic diseases such as high blood pressure, asthma, cardiovascular disease, and diabetes compared to the rest of the city.[11]

The West End was historically affected by housing and mortgage practices that led to inequities in valuation, opportunity, and economic circumstances. Due to lower home values and the subsequent decline in economic power, these neighborhoods were often more vulnerable to industrial development. For example, the Interstate 77 extension in the 1970s and 1980s removed more than 240 families, several schools, a park, and many businesses in the Historic West End's predominantly black neighborhoods.[12,13,14]

The neighborhood is often compared to the Dilworth/Myers Park neighborhood of Charlotte to demonstrate the implications of West End's history. Dilworth/Myers Park is a similarly sized area south of West End with a higher median income relative to Charlotte and fewer permitted sources of air pollution. This area received high ratings for home loans in the 1930s and 1940s, allowing more families to buy homes and build generational wealth.

Proximity to industrial developments, such as high traffic interstates, leads to increased air pollution and is correlated with adverse health outcomes. Higher rates of disease—as seen in the Historic West End's designation as a Public Health Priority Area—can indicate higher rates of air pollution. Research shows the health conditions seen in the West End can be linked to and exacerbated by exposure to air pollution over time, especially in vulnerable populations such as children, the elderly, and people with asthma or pre-existing heart and lung diseases.[15] The county's report sparked an interest in the community to better understand the connection between their proximity to I-77 and other development projects and their health.

Figure 1



Charlotte's "crescent" including the Historic West End. Source: 2017-2018 Mecklenburg County Community Health Assessment, Mecklenburg County Health Department.

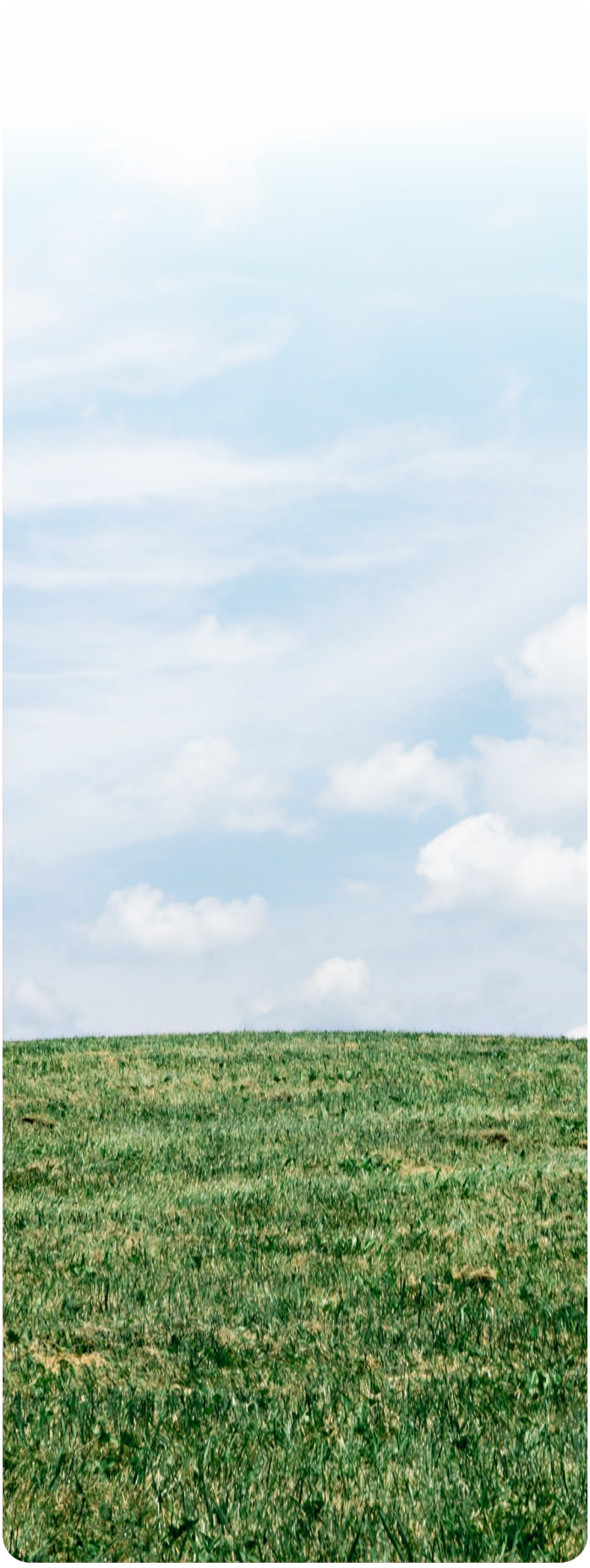
Clean Air Carolina

Clean Air Carolina—an advocacy group now called CleanAIRE NC—was founded in 2002 to improve air quality in Mecklenburg County. The organization's mission is reducing the impacts of air pollution in North Carolina, with a focus on at-risk locales and equity. Their work helps citizens understand the relationship between air quality, climate change, and public health, and teaches them strategies for building cleaner, healthier communities.

In addition to reducing overall air pollution, Clean Air Carolina is concerned with ensuring that pollution's consequences do not fall disproportionately on certain groups. The organization sought out a partnership with West End residents because of the high concentration of freeways, interstates, businesses, and industries with air quality permits in the area relative to the rest of Charlotte.

In collaboration with the residents of the Historic West End, Clean Air Carolina identified two primary research questions:

- How did the air they were breathing compare with other parts of the city?
- Is air pollution in the West End reaching unhealthy levels?



Evidence Assessment

West End residents and Clean Air Carolina believed the local air quality data was not detailed enough to answer their questions. Seeing this gap in the data, they set out to collect and verify their own data to complement existing data sources.

First, Clean Air Carolina performed an initial analysis of existing data sources to identify data needs and shared their results with residents and community leaders. Next, they set up low-cost air monitors that enabled hyperlocal air quality monitoring and trained community members to use the monitors and read their outputs. West End residents then performed the local data collection and continued to monitor air quality.

Technical Analysis of Existing Data Collection

As the first step, Clean Air Carolina performed a technical analysis using various data sets from federal, state, and local sources. Staff began their work by looking at data from EPA national air monitoring programs, as seen in Table 1.[16]

Table 1. EPA National Air Monitoring Data Sets

Source	Data	Purpose
AirNow.gov[17]	$PM_{2.5}$ concentration from all EPA monitors	Determine current air quality and forecast future conditions
EJScreen[18]	NAAQS pollutant concentrations, locations of permitted polluter sites, traffic proximity, demographic data from Census Bureau, life expectancy, asthma, and heart disease rates	Measure communities' exposure to pollutants and climate change impacts relative to their state and the rest of the country
Superfund National Priorities List[19]	List of sites known to, or have the potential to, release hazardous substances or pollutants	Determine which facilities the EPA should investigate and monitor closely
Toxics Release Inventory[20]	The date, estimated amount, and type of release of chemicals or pollutants known to cause cancer or other adverse health effects	Ensure compliance and inform policymakers about proper public health policies
Permit Compliance System / Integrated Compliance Information System[21]	Facility name, permit number, geographic location, facility industrial classification, and released chemicals	National Pollutant Discharge Elimination System (NPDES) permit compliance
AirData[22]	All active and inactive EPA Air Quality Monitors, and hourly, daily, and annual concentration data	Track and make public outdoor air quality data for citizens, researchers, and policymakers

Because monitoring and permitting responsibilities are shared by local, state, tribal, and national authorities, researchers must synthesize data from multiple sources to learn about air quality in specific communities. In North Carolina, seven regional offices manage implementation of air quality standards through permitting, inspections, and air monitoring.[23] The Eastern Band of Cherokee Indian Reservation and three counties—Mecklenburg, Buncombe, and Forsyth—operate their own air quality districts and enforce federal, state, and local regulations.[24] Some of the state's 100 counties do not have regulatory-grade monitors, and the state itself operates 22 particulate matter monitors.[25] Counties may choose to monitor above and beyond the state's requirements, but costs often prevent them from doing so. This means that disparities in air quality within each region, and especially between counties and individual neighborhoods, are difficult to track.

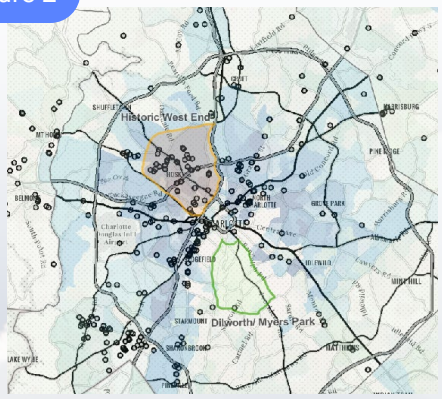
As one of the state's independent air quality districts, Mecklenburg County Air Quality (MCAQ) administers county air ordinances and state and federal air quality regulations. Five EPA-approved monitors in the county collect data, which are stored by the EPA and displayed on the county's Current Air Quality Index.[26] MCAQ also maps all businesses and facilities that are required to be registered and permitted with the county for air monitoring.[27] Aside from the county's Air Quality division, the North Carolina Department of Transportation's maps can be used to determine the proximity of residents to mobile sources of air toxins such as cars, trucks, and trains.

Existing Data Shows Alignment between High Air Pollution and Public Health Priority Assessment

Clean Air Carolina began to create the "story map" of air quality in the Historic West End by analyzing Charlotte's zoning and infrastructure. Using the city's original redlining map, the team demonstrated why property values were lower and why more highways, railroads, and industrial plants with air quality permits were built in the West End over decades. They then situated Census Bureau data over a map of highways and railroads from the North Carolina Department of Transportation and layered the EPA's "Traffic Proximity Index" on top—seen in Figure 2. The product showed the Historic West End was exposed to higher concentrations of vehicle exhaust—which can worsen asthma and heart conditions and damage crops—than the Dilworth/Myers Park neighborhood of the city.[28,29]

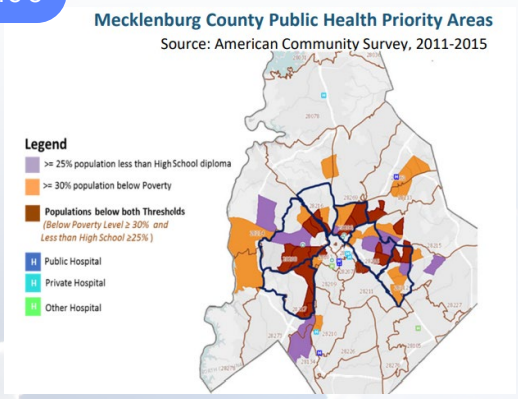
Drawing from Mecklenburg County Air Quality's list of permitted sites and the EPA's national databases, Clean Air Carolina then mapped stationary sources of air pollution in the City of Charlotte and added them to the traffic proximity map. The Historic West End is home to dozens of permitted facilities that release regulated substances, while the affluent Dilworth/Myers Park neighborhood is home to only a few. Finally, Clean Air Carolina compared their map to the county health department's Community Health Assessment, seen in Figure 3, and found the areas of Charlotte most exposed to air pollution closely matched the Public Health Priority Areas identified by the county as having higher rates of chronic disease and early death.

Figure 2



The blue represents air pollution from auto traffic, based on the EPA's "Traffic Proximity" index. The circles represent registered sites of air pollution.[30]

Figure 3



Mentioned above, Mecklenburg County's "crescent" of poor health outcomes and educational attainment.[31]

Using a Citizen Science Model: the Launch of Clear Air Carolina's AirKeepers

The review of existing data sources revealed that of Mecklenburg County's four air quality monitors, none were in the West End. Wanting to understand the variations in air quality on a more granular level, Clean Air Carolina and West End residents saw a need to collect more localized data.

To better understand the possible association between air pollutants and poor health outcomes at the neighborhood level and address this gap in the data, Clean Air Carolina launched the AirKeepers initiative. Based on a "citizen science" model which empowers residents to participate in and direct the research that affects them, AirKeepers are local residents who are trained by the Clean Air Carolina staff to measure their own exposure to air pollution. With the help of Clean Air Carolina's staff, the AirKeepers built a network of low-cost sensors at schools, businesses, and individual residents' homes to gather hyperlocal data. Community leaders hosted events with the Clean Air Carolina staff to raise awareness about air pollution and train their neighbors to use the low-cost monitors so residents could better understand the air quality in their own community.[32]

To validate the accuracy of the local monitoring data, the AirKeepers placed the low-cost sensors at the same locations as EPA regulatory monitors and compared measurements, a process known as collocation.[33] Clean Air Carolina staff, along with employees of Mecklenburg County Air Quality, were able to establish the efficacy of their sensors over time.

Once the low-cost real-time sensors were installed, the AirKeepers' citizen scientists monitored their neighborhoods and regularly shared their data with the community, enabling residents to track daily and even hourly changes in air quality. For example, one citizen scientist noticed a jump in particulate pollution from a street-paving crew in her neighborhood. In another instance, a resident saw an increase in air pollution due to highway construction and worked with Clean Air Carolina to request that construction traffic be redirected to avoid the heavily populated areas of his neighborhood.

Hyperlocal Data Offers More Granular Insight into Air Pollution

The hyperlocal data collection supplemented Clean Air Carolina's analysis of existing databases to reveal high levels of pollution exposure and association with ongoing development projects in the area. The AirKeepers' air monitors provided a level of granularity that allowed the residents and researchers to understand variation in air quality between neighborhoods in the city, indicating trends that may not have otherwise been identified in state and county level monitoring.

For example, pollution exposure measurements for the West End ranked "some of the highest in the county for things like hazardous waste proximity, diesel particulate matter (PM), and $PM_{2.5}$ (microscopic particulate matter)" compared to the EPA's census block measurements of those exposure categories. Although the measurements did not indicate pollution levels beyond what the EPA deems safe, the county's public health assessment results show the area experiences higher rates of health problems. This may indicate the need for additional research into what the EPA deems harmful for public health.

To understand the historical impact on the West End's air quality when compared to Dilworth/Myers Park, Clean Air Carolina installed low-cost sensors in Myers Park and alongside a federal monitor in eastern Charlotte—two more affluent neighborhoods—and three sensors in the West End. Comparing a year's worth of readings between the five sensors, the team found that the Historic West End experienced far more days of particulate pollution above the normal range than Dilworth/Myers Park across the city.[34] Clean Air Carolina explained that while the frequent elevated particulate matter in the West End may not constitute unnoticed violations of NAAQS, the disparities in air quality between neighborhoods in Charlotte is worrisome from an equity perspective.[35] More data are needed to determine the severity of the differences and their possible health consequences on residents of the West End. Continued monitoring will help answer that question.

In addition to these comparisons, the AirKeepers' low-cost real-time monitoring network allowed residents to better understand variations in air quality on a daily basis and take action. For example, residents used this access to real-time air quality data to inform the community when particulate matter levels spiked, and used training and education opportunities to help their community understand what they could do to be cautious of the potential health hazards related to air pollution through a variety of methods, including:

- Encouraging at-risk people to stay inside during pollution surges;
- rerouting diesel trucks to less-populated roads; and
- asking the city to warn residents before construction or paving began.

AirKeepers' Data Collection Informs Policy Action

The AirKeepers' work did not stop with data collection. In partnership with Clean Air Carolina, West End residents worked to engage more community members through education efforts and identified policy solutions. In May 2019, the AirKeepers and other West Enders presented their data to the Mecklenburg County Board of Commissioners, showing the variation in pollution levels and highlighting the potential health impacts that could exacerbate the county's distinction of the neighborhood as a Priority Health Area.

As a result, the Board verbally agreed to establish an EPA air quality monitor at Friendship Park in the Historic West End to replace a monitor that had been shut down in South Charlotte that same year.[36] This regulatory monitor is included as part of the EPA's national monitoring network for NAAQS compliance and enables regulators and residents to see a clearer picture of the air quality in the Historic West End.

In addition to increased monitoring capabilities, this project spurred several other measures to fight air pollution. Residents established a West End Green District to educate and mobilize citizens and organizations to reduce air pollution. They have also taken a more active role in zoning and permitting activities, advocating to their local representatives for greener projects and reduced emission permits, and asking developers in the city to invest in newer, cleaner engines during construction. [37]

Ongoing Effort to Promote Citizen Science in North Carolina

Since the founding of AirKeepers in 2016, Clean Air Carolina has worked to extend the program across North Carolina, establishing the "first statewide network of hyperlocal air pollution monitors in the country."[38] These data fill local gaps between the state's 22 particulate matter monitors and give a real-time snapshot of local air quality online for free. The cache of locally-collected air quality data allows citizens across the state to track their air quality over time and be aware of potential health hazards.

The EPA took note of Clean Air Carolina's citizen science model and asked the organization to build a citizen science toolkit which other organizations can use to launch similar projects in their own locales.[39] In 2021, the agency announced a grant competition "to improve air quality monitoring in and near underserved communities across the United States, support community efforts to monitor their own air quality, and promote air quality monitoring partnerships between communities and tribal, state, and local governments." Through this competition, CleanAIRE NC and the Environmental Justice Community Action Network were awarded $500,000 to build a low-cost monitoring network in Sampson County, North Carolina.[40]

Lessons

The residents of the Historic West End, in coordination with local scientists, recognized a need for more specific local data collection to understand a potential link between their designated priority health status and the air they breathe. Using data collected and analyzed in collaboration with Clean Air Carolina, West End residents were able to advocate for further investment into air pollution monitors to continue building an evidence base to compare health outcomes in the future. This case study demonstrates the value of establishing sustainable data collection methods while engaging the impacted community throughout the process. Though more data are required to indicate a definitive link between the particulate matter in the West End and the community's health outcomes, Clean Air Carolina and West End residents' data collection efforts laid the foundation for future studies and policies. We can draw three lessons from their story.

Engaging local stakeholders is important for sustainable, dedicated data collection.

The residents of the Historic West End had questions about their air and mobilized to answer them. Having an interest in the health of their own community, West End residents showed consistent dedication to protecting the quality of their air through advocacy, education, and air quality monitoring. Treating residents as stakeholders rather than research subjects makes public health initiatives more collaborative, fosters more trusting relationships, and enables residents to contribute their local knowledge as an important resource in the research process. West End residents had a say in how their data were collected and used, which is a crucial component of addressing equity concerns and has proved to be key to the success of the community's ongoing air monitoring efforts.

Hyperlocal data are a valuable low-cost source of information communities can use to inform local decisions.

Hyperlocal data such as the air quality data collected in the West End are not used by the EPA for regulatory decisions, but state and federal policymakers are not the only decision makers of interest for achieving air quality improvements. The granularity of data that low-cost sensor technology can generate provides communities with detailed, low-cost, localized information that residents can use to learn about their air. This information can inform advocacy efforts and local policy decisions that go beyond state and federal regulations, as well as inform personal risk tolerance decisions. The residents of the West End used low-cost sensor data to demonstrate the existence of neighborhood-level differences in air quality and leveraged that evidence to encourage the Charlotte City Council to establish a Green District in the West End, reform permitting and zoning practices, and implement other local air quality rules that extend beyond EPA standards. Individual residents also used data from the air monitors to make personal decisions, such as staying indoors during pollution surges. Hyperlocal data can be collected and used in other contexts to provide specific information that can inform decisions that reflect the needs of residents down to the individual level.

Local air quality monitoring builds a baseline infrastructure for long-term public health studies.

Poor public health outcomes are influenced by many factors outside of individual health decisions. The built environment of Charlotte—a result of its zoning, infrastructure, and housing laws over decades—subjected some residents to much higher levels of air pollution, which can both cause and worsen chronic diseases such as asthma and heart disease. The residents of the Historic West End were able to use environmental and public health data to tell the story of their community's health. In fact, some of the residents' most vocal advocates were not environmentalists but doctors who understood the health consequences of exposure to air pollution. The model used by Clean Air Carolina and the residents of the West End can be replicated to lay a foundation of local data collection that can continue to inform long-term public health studies. By establishing consistent collection and analysis processes of hyperlocal data, future longitudinal studies will be possible and the West End will have the infrastructure in place to understand the impact of policy interventions on the interaction between air quality and public health in their area.

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