Measuring Neighborhood Air Pollution: The Case of Seattle's International District

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Abstract:

Current regulatory air quality monitoring networks measure ambient levels of pollutants and cannot capture the effects of mobile sources on the micro scale. Despite the fact that air quality has been getting better, more sensitive populations suffer from traffic-related air pollution. As development intensifies in urban areas, more people will be exposed to road-related air pollution. However, the only consideration given to air quality, if any, is based on ambient measures. In this paper, we use an inexpensive, portable Particle Soot Absorption Photometer (PSAP) to measure Black Carbon (BC) emissions, a surrogate for diesel fuels, in Seattle's International District. With the aid of a GPS receiver, we geocoded street-level BC data. We found that pollution levels differ substantially from street to street. The results show the need for street-level air pollution monitoring and for revisions in current land use and transportation policies and in air quality planning practice.

The Need for Micro-Scale Air Quality Monitoring:

American urban planning is rooted in public health and land-use zoning laws based on the notion that people should not live next to polluting sources. Common sense would then suggest that mobile sources deserve the same treatment as point sources, with established regulation, not only from the perspective of the guidelines governing auto manufacturers and tailpipe emissions but also from a land use perspective. While epidemiological studies demonstrate causality between mobile-source pollutants and various diseases, current monitoring practices are not implemented at the spatial scale appropriate for determining the magnitude of exposure or risk to neighborhood-level populations. As such, micro-scale monitoring is not only necessary, it is feasible and simple to implement as was the case for this pilot study.

Recently, the California Air Resources Board (CARB) issued a set of recommendations that included avoiding the siting of sensitive land uses within 500 feet of major freeways (CARB, 2005) and alignment with California Senate Bill 352 (2003) that places a prohibition on siting schools near an urban freeway without an environmental impact assessment. These new regulations are largely based on health effects of mobile-source diesel pollution, such as the aggravation of asthma, depressed lung function, aggravation of acute respiratory symptoms, and an increased risk of bronchitis in infants, all of which have been well documented (Bae et al., 2006; Samet et al., 2000), and on an association between higher rates of respiratory illness and living near freeways (Henderson & Brauer, 2005). Nevertheless, in Los Angeles there are more than 70 schools that are close to highways, most built before 1977 but five are currently under construction and two under consideration. More than 60,000 children in the Los

Angeles Unified School District attend schools within 500 ft.of a freeway (*Los Angeles Times*, September 24, 2007). In California as a whole 23 percent of public schools are located within 500 ft. of high-traffic roads (defined as having more than 50,000 vehicles per day).

In order to measure the individual exposure of residents to airborne pollutants, the regional air quality monitoring network is insufficient, because it measures air quality regionally rather than at the micro level. In this study, we use a simple, portable monitoring device to collect Black Carbon pollution data, (a proxy for diesel emissions) along every street in Seattle's International District (ID) and examine pollutant levels relative to sensitive land uses. The ID was chosen as a suitable study area because of its diversity of mobile source pollutants and a predominantly elderly and low-income population who are at an increased risk from pollutants. We map the entire boundary so that individual exposure can be measured and property locations assessed for potential risk.

STUDY AREA

Seattle's International District (ID) faces respiratory disease rates that are 2.54 times higher than in other Seattle neighborhoods (SKCPH, 2005) and a large elderly population that is more severely impacted by air pollution than other local populations. The International District Housing Alliance (IDHA) held a series of workshops through the winter and spring of 2006 in order to address residents' concerns. Even though the community elders in attendance raised issues relating to additional buses on the surface streets because of the bus tunnel closure associated with rail construction and the fumes from idling trucks, one comment that was unanimously agreed upon suggested that focus should be given to indoor air quality because there was nothing the community could do to change exogenous outdoor factors.

Mobile Source Pollutants

Seattle's International District (ID) is situated at the intersection of two major freeways, Interstate Highways 5 and 90 (see Figure 1).

<Insert Figure 1: Context map about here>

While I-90 terminates near the neighborhood and has traffic volumes of about 18,000 vehicles per day at the on and off ramps (UW ITS, 2006). I-5, the major North-South corridor for the region, carries an average annual daily traffic volume of about 300,000 vehicles per day. Of these vehicles, roughly eight percent (25,000) are heavy-duty trucks (WSDOT, 2005). Directly to the west of the neighborhood is State Route 99, which includes the Alaskan Way Viaduct. This highway carries an annual daily traffic volume of 103,000 vehicles per day, one fourth of the city's North-South traffic (WSDOT, 2006). All three of these thoroughfares are used for freight movement to and from the Port of Seattle along the waterfront, which handles roughly 1.3 million containers annually, with slightly over 5,000 heavy-duty trucks visiting the Port each weekday (Port of Seattle, 2003).

While traffic on the surrounding freeways bypasses the neighborhood, the arterial and collector streets have heavy city traffic volumes. Along all of the major corridors in the neighborhood (4th Ave. S, 5th Ave. S, S. Jackson St., S. Dearborn St., Boren Ave. S, and Yesler Ave. S), average weekday traffic exceeds 10,000 vehicles per day (SDOT, 2006). Bordered by the Duwamish Industrial Area on its south, and near to the Port of

Seattle activity, which produces 500 daily truck trips on local streets (Heffron, 2003), the International District has several designated truck routes bordering and intersecting the neighborhood. While only S Airport Way and S Dearborn St. carry the official truck route designation, many trucks have been observed on other main arterials such as S Jackson St. and on the smaller streets of the neighborhood. According to Seattle's Transportation Strategic Plan, all arterials are places where trucks are allowed to travel, and, indeed, they are encouraged to do so (SDOT, 2005). Both large, heavy-duty, double-trailer trucks and smaller delivery vehicles travel through the neighborhood. In the absence of any "no idling" legislation, smaller delivery vehicles are frequently observed idling at their delivery stops. This is particularly troubling as idling trucks emit an hourly average of 10.2 grams of NOx, 2.59 grams of PM and 738 grams of CO (EPA, 1998).

Data on truck volumes are difficult to gather. Private trucking firms do not readily volunteer information on routes and travel volume. In addition, due to the method through which traffic volumes are reported, all vehicle classes are lumped into a single number per time period. Both the Seattle Department of Transportation (SDOT) and the Washington State Department of Transportation (WSDOT) collect traffic volume information for this area. While WSDOT reports the percentage of trucks, they only collect data on limited locations on the freeway and not on city streets. SDOT collects data on city arterials, which would be sufficient in addressing truck volumes in this area but do not report the number or percent of trucks, only total vehicle volumes. This makes it difficult, if not impossible to separate truck traffic from cars and buses. Nevertheless, field observations along S. Jackson St. yielded an hourly afternoon average of 45 trucks, on S. Dearborn St. traffic was close to 70 trucks per hour.

King County Metro houses one of its bus terminals, the Ryerson Bus Base, just outside of the International District at 1220 4th Ave. S, which accounts for a large part of bus traffic within the neighborhood. On weekdays, 111 different routes, with 3,034 bus trips, pass through the neighborhood (KC Metro, 2006). As shown in Table 1, the area nearest to the bus terminal has the highest volumes of buses with the intersection of 5th Ave. S and S. Jackson St., carrying 1,488 stops daily.

<Insert Table 1: Bus volumes, about here>

During an afternoon with a Mariner's baseball game at the nearby Safeco Field, 350 buses were observed at three major intersections in a half hour period, which (depending on fuel type) could produce as much as 50 grams of PM (Kado et al., 2005). During game events, additional bus service is provided from the ballpark and park-and-ride lots, increasing the number of buses that travel through the neighborhood. It should be noted that not all of the buses that travel through this area operate on polluting diesel fuel. Many of Metro's buses run on electricity or use hybrid technology. Because bus coaches do not necessarily serve the same route every day and are in rotation, it is difficult to estimate the number of buses traveling on each route that rely solely on diesel or bio-diesel fuels.

In addition to car, bus, and truck traffic, train locomotives are also a source of diesel exhaust. On the neighborhood's western border, along 4th Ave. S, there are rail lines that service the Sounder commuter trains, Amtrak, and the freight haulers Burlington Northern-Santa Fe and Union Pacific. The freight haulers, working in conjunction with port activity, generate an average of fifty trains that pass through the area daily (Siler, 2006). The passenger rail lines, Amtrak (Amtrak, 2006) and Sounder

(Sound Transit, 2006) have thirteen and twelve trains, respectively, that use the tracks daily. Sound Transit plans to expand Sounder service in the coming years, thus adding train volumes to these tracks.

Demographics

The ID was chosen as a study area because of its proximity to major roadways and because it is one of the few areas in Seattle that both abuts freeways and consists of predominantly low-income, minority, and elderly residents (Bae, 2006). With a population of nearly 5,000, minorities account for about 80 percent of the area's residents, as compared with 30 percent in the City of Seattle as a whole. In addition, average household income for the neighborhood is $13,000, high school graduates comprise only 60 percent of the population, and the elderly population stands at 26 percent,compared with the city's figures of $46,000, 90 percent, and 12 percent, respectively (U.S. Census, 2000).

However, the official Census data may not accurately reflect the demographic composition of the ID. For instance, a large proportion of ID residents (around 70 percent) speak languages other than English (City of Seattle, 2006a). If census takers do not speak the language of the residents, this may make residents hesitant to accept questions or offer information to a stranger. Furthermore, the only option of permanent, affordable housing for many residents is in a single-room occupancy hotel. These residents may not be included in the population count, or they may not be classified as households. It is estimated that the actual population of the ID is, therefore, much higher than the Census indicates.

Land Uses

According to current land uses in the ID places all residential parcels average 598 feet (182 meters) from a major freeway.

<Insert Figure 2: Potentially sensitive land uses about here>

The ID is a destination for visitors and workers, as well as a place to live and for community gatherings. The area includes a diversity of land uses including several mixed-use structures. The two most predominant land uses in this community are parking and retail. Other uses (including industrial, mixed uses, multi-family housing, offices, terminals and warehouses) have a relatively even distribution in terms of absolute numbers (see Figure 3).

<Insert Figure 3, mix of ID land uses about here>

Also included among these land uses are places such as elderly residences, schools, and gathering spaces, where children and the elderly spend significant amounts of time. Both children and the elderly are more sensitive to the negative health affects of poor air quality than healthy adults. "Sensitive land uses" are places near heavily polluting roads and freeways where vulnerable populations live, work and play.. Two examples of sensitive land uses in the ID include the Nikkei Manor, a retirement facility located at S. Dearborn St. and 6th Ave. S, and the Leschi House, another low-income retirement facility, located at 1011 S. Weller St., operated by the Seattle Housing Authority and that also offers daycare service for children..

All residences, schools, and hospital facilities are "potentially sensitive land uses", but they become designated as sensitive land uses only if they are near pollution sources. The entire housing stock of the ID includes potentially sensitive land uses and is uniquely distinct from other Seattle neighborhoods because it is composed almost entirely of multi-family housing, with very few single-family homes. Housing in the core of the ID includes multi-family apartments, single-room occupancy hotels, and some condos, including units in mixed-use buildings. The few remaining single-family homes are located in Little Saigon, towards the eastern boundary of the ID, and these are slated for demolition. An important source of affordable housing is the single-room occupancy hotels in the ID. Many of the parcels zoned for retail or services are actually historic hotels in which elderly residents continue to rent single rooms (InterIm, 2006).

There are relatively few public open spaces serving the community. Hing Hey Park, located on S. King St. and Maynard Ave S, is a paved park in the heart of the ID. This park is easily accessible and is protected from major transportation corridors. The Danny Woo Community Garden at 620 S. Main St. is the main green space available to residents and visitors. This P-Patch garden is used by the low-income elderly living in the neighborhood. The garden is located on the edge of the ID, elevated on an incline above the rest of the neighborhood, which makes it less accessible than Hing Hey Park. In addition, the Danny Woo Community Garden is located directly adjacent to the I-5 freeway, which puts its visitors close to this major air pollution source.

The Chong Wa Educational Society, whose building is owned by the Seattle public schools and is located on S. Weller St. and 7th Ave. S. serves as one of many neighborhood gathering places. Churches and markets also serve as community spaces where people spend time, and these also could be vulnerable to air pollution. There are several churches that own property in the ID, including the Nichirin Buddhist Church, the Southern Baptist Church, and the non-profit Seattle Goodwill Industries.

Uwajimaya Village at S. Lane St. and 6th Ave. S, is the largest supermarket in the neighborhood and attracts shoppers from around the region seeking Asian groceries and specialty goods. In addition, several smaller markets selling Asian groceries are scattered throughout the ID, many located along busy streets. For example, there is a market located on S. Jackson St., almost directly under I-5. A shopper spending time outside browsing through the produce is quite likely susceptible to breathing polluted freeway air.

Parking is very abundant in the ID, possibly as a result of its proximity to two major sports stadiums in south downtown: Qwest and Safeco Fields. During sporting events, parking lots fill up and traffic volumes throughout the area increase. At other times, many of these parking lots sit empty or are only partially full. In the area to the east of I-5, there is more industrial land use and more warehouses than in the area to the west. Trucks traveling to and from these industrial sites are one of the mobile pollution sources examined in this study.

Future Land Uses

In recent years, Seattle has seen a push, through Mayor Nickels' Center City Seattle program, for increased residential densities to facilitate more walkable and livable neighborhoods. The aim of this program is to increase family housing, employment opportunities, and entertainment venues while at the same time minimizing the creation of new roads by providing alternative transportation solutions such as light rail and a trolley.

Future development slated for the ID, under the recently approved downtown zoning changes and a south downtown plan, is intended to encourage new housing developments and to provide street improvements for pedestrian activities by increasing building density and relaxing height limits. In the core of the ID, the new height limits can be further increased if the development provides residential units (City of Seattle, 2006b).

<Insert Figure 4: ID zoning about here>

While a great deal of attention is being shown to improving street conditions for pedestrians, little consideration if any is being given to the surrounding environment. If walking promotes healthier lives through the benefits of increased physical activity, it should not come in the form of a tradeoff via participating in activities in places where air may result in more harm, especially for people who are more susceptible to respiratory disease while they exercise.

AIR QUALITY MONITORING

Background

Adverse health effects of mobile-source pollutants are well documented in the epidemiological literature. Particulate matter (including ultrafines) can aggravate asthma, depress children's lung function, result in acute respiratory symptoms, increase infants' risk of bronchitis, and can lead to cancer (van Vliet et al., 1997; Gehring et al., 2002; English et al., 1999; Wjst et al., 1993). Nitrogen dioxide can increase respiratory morbidity, aggravate asthma, and reduce lung function (Nitta et al., 1993; Delfino et al., 2003; Nicholas et al., 2005). Volatile organic compounds increase response to allergens, raise the risk of lung cancer, and increase the risk of childhood leukemia (Janssen et al., 2003; Crosignani et al., 2004).

The EPA sets the National Ambient Air Quality Standards (NAAQS) for six criteria pollutants (carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur oxides). Siting criteria are established for air quality monitors, which are generally located away from major roads because they are meant "to ensure a consistent and representative picture of air quality in the overall area" (PSCAA, 2006). In the Seattle area, air quality monitors are operated by the Puget Sound Clean Air Agency (PSCAA) and the Washington State Department of Ecology (DOE), with several monitors located within several miles of the International District (See Figure 1).

The Puget Sound region is currently considered to be "in attainment" for the measured criteria pollutants. This is a critical designation in that non-attainment could cause delays in transportation projects while they are upgraded to meet additional requirements based on the Clean Air Act (PSCAA, 2006). However, while ambient air quality for the region is considered to be in attainment, the data collected by the regulatory monitors do not express conditions at the micro scale other than those within the immediate vicinity of the monitor.

The sizeable costs of operating and analyzing the data from an air quality monitor preclude the ability to monitor at every location where there might be a concern. It is nevertheless crucial to monitor air quality in some way, as land use decisions promoting high-density simultaneously with walkable neighborhoods may unduly place people at risk. Although some mitigation measures, such as the appropriate location of building air intakes, may reduce these risks, *a priori* knowledge through monitoring would aid in designing healthy cities. A low-cost, simple monitoring method such as the one used in this research could assist planners in their land use decisions.

Mobile Air Quality Monitoring Methodology

Utilizing a filter-based particle/soot absorption photometer (PSAP) (from Radiance Research, Seattle, WA), we identified locations of relatively high mobile source air quality burdens by taking real-time mobile measurements of black carbon (BC), a surrogate for mobile source emissions, especially diesel exhaust. The PSAP and a vacuum pump were mounted in a car with the air intake tube protruding from a rear window. Measurements were then carried out during the P.M. peak period between May and August 2006. Spring and summer months were used to avoid capturing wood smoke, a very different pollutant commonly present during cold weather, especially in the Seattle region. We chose the P.M. peak period because air is more stable in the afternoon than the in the morning, allowing for diminished temporal sensitivity over the several hours during which measurements were taken.

To measure location, we used a Trimble (Sunnyvale, CA) ProXRS mapping-grade GPS receiver. We measured a location coordinate once per second, to coincide with PSAP measurements, and location data were differentially corrected in post-processing to achieve an overall horizontal precision of 0.63 m (sd = 0.15 m).

For calibration purposes, the driving route began at the Olive Street monitoring site, where the PSCAA collects black carbon data adjacent to Interstate 5.

<Insert Figure 5: Study area driving route about here>

The route then continued through downtown Seattle and along I-5 into the ID. A cloverleaf pattern was driven around each possible block in the study area, with major intersections covered multiple times on each run. The total drive time lasted roughly two hours for each outing, and driving speed was usually kept between 10 and 15 mph. Every attempt was made to maintain slow driving speeds through traffic because data were collected every second and a faster speed could result in road segments without data collected. Field notes were kept to account for data outliers resulting from unusually long wait times behind buses or trucks at traffic lights, stops, or for other reasons. On all but one of the monitoring sessions, which featured mild rain, the weather was sunny and warm.

A total of 11,921 unique GPS observation points were collected. In order to standardize and manage the data, new points were created along the street network at an interval of 50 ft, (15.24 meters).

The individual observation points were then "snapped" to the new points on the street network, which resulted in 467 snapped points. Each of the snapped points contains the data from all of the raw data locations that are closest to it. This resulted in many observations surrounding major intersections and fewer in the outlying areas. The snapping methodology both adds statistical power and provides ease for interpretation in that points no longer appear as a straight line and do not overlap.

Analysis

Halfway through the data collection period, we examined the data for geographical patterns. Using the ArcGIS Kriging statistical tool, a surface model was created (see Figure 7) that showed areas with consistently high readings relative to the mean for all days.

<Insert Figure 7: Kriging surface model about here>

Field note observations were then matched to collected data points, and outlier points with exorbitant readings were expunged from the database. While these observations illustrate true values, they do not explain aggregate pollution levels. Instead, they suggest that black carbon levels near a stopped bus or truck are extremely high and potentially dangerous to nearby bicyclists and pedestrians. Because pollutants decay very close (100 m.) to roads (Zhu et al., 2002), any high readings distant from mobile sources are not an immediate threat to the people working or living in an area, and are beyond the scope of this work

Once the outliers were removed, the surface model predictably showed high levels of pollution along heavily trafficked roads and bus ways. However, in the north-eastern part of the study area, levels of pollution were found to be substantially higher than those adjacent to the freeways or other roads with heavy traffic volumes. Several explanations for this discrepancy were considered, including the facts that the roads in that area are being used for port traffic by heavy-duty trucks and that delivery trucks for a large number of businesses are allowed to idle (including during the monitoring hours).Further monitoring sessions devoted extra time to this area, and as additional data were collected the mean carbon concentration values decreased, falling closer to the expected dissipation pattern away from major roads.

At the conclusion of data collection, all data were standardized to the readings at the Olive Street monitoring station on a day-by-day basis. Data from each monitored day were then plotted relative to these values to illustrate the location of pollutant concentrations higher than those found at the PSCAA's monitor. While some of the monitored days showed a general pattern of high-pollutant-concentration areas, overall there was a great deal of variability in pollution levels by location. Daily black carbon concentrations may differ dramatically over a one-week sampling period (See Figure 8).

In order to aggregate the data, each sample point was coded for being either above or below the median BC concentration observed at the Olive Street monitor for that observation's sample day. Each snapped point was then given a percentage value for the number of observations above or below the observed median. The results shown in Figure 9clearly illustrate higher concentrations of pollution near roads with heavy traffic volumes.

<Insert Figure 9: Results about here>

DISCUSSION

The methods introduced in this paper can be used to measure the localized effects of mobile-source air pollution in the ID and elsewhere. For existing sensitive land uses in the ID, several simple mitigation measures could be adopted. Windows facing highways, main bus-ways, or arterials should remain closed whenever possible, especially during peak traffic periods. Further, tall vegetation should be planted in residential areas to reduce airborne pollutants. This idea might be expanded to include a greening policy by which streets not essential to commerce and freight movements are made pedestrian streets. The core of the neighborhood presents a unique opportunity for this type of design because traffic volumes are low, there is already an existing park around which development could be implemented, and pollution levels are consistently below the ones found at the monitoring site.

Future development efforts sparked by the new South Downtown plan should not allow new residential uses, especially senior housing, within 100 meters of high-pollution roads, highways, and intersections. Instead, new residential structures should be built facing away from high-pollution roads or in the core of the ID along lower-traffic roads. Truck loading zones should not be located on the street side of a building but preferably within a covered area in or beneath the structure. As most new structures include fresh air intake vents that supply the building with outside air, these vents should not be located at the street level, which would allow polluted air to flow into the buildings, but should be placed facing away from arterial streets, on the roofs of buildings, or on the side of the building near the top. Developers should also be required to add green space and landscaping to their projects because the ID is underserved by park space compared with many other Seattle neighborhoods.

The same type of mitigation measures suggested for the ID could be used elsewhere in situations where there is high-density residential and/or sensitive uses next to high-volume roads. The PSAP is a relatively inexpensive, simple tool to use, and because the air quality in the ID has been shown to be significantly different from that at the monitor station a mile away, it is advisable that some form of monitoring be performed prior to changes in land use codes that might place more people at risk of exposure to pollutants.

Table 1: Daily Bus Volumes at ID Intersections

Intersection	Number of Buses
5th Ave S & S Jackson St	1,488
4th Ave S & S Jackson St	1,349
S Washington St & 4th Ave S	824
Maynard Ave S & S Jackson St	445
8th Ave S & S Jackson St	408
12th Ave S & S Jackson St	352
Yesler Way & Boren Ave S	284
S Dearborn St & 5th Ave S	215
Rainier Ave S & S Jackson St	172
S Dearborn St & 6th Ave S	167
S Lane St & Rainier Ave S	162
S Dearborn St & Rainier Ave S	162
S Weller St & 12th Ave S	135
S King St & Rainier Ave S	117
S Weller St & Rainier Ave S	117
S Dearborn St & 7th Ave S	94
Yesler Way & 6th Ave S	51
Yesler Way & 8th Ave S	51
S King St & 8th Ave S	37

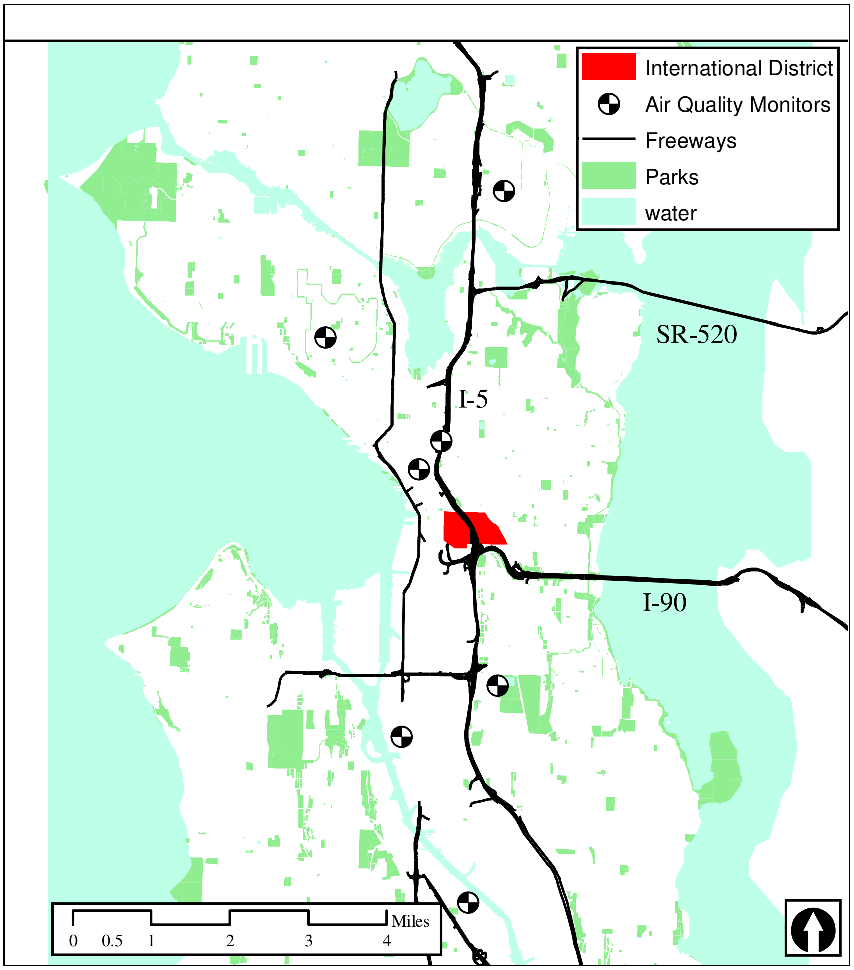

Figure 1: Puget Sound Monitoring Network.

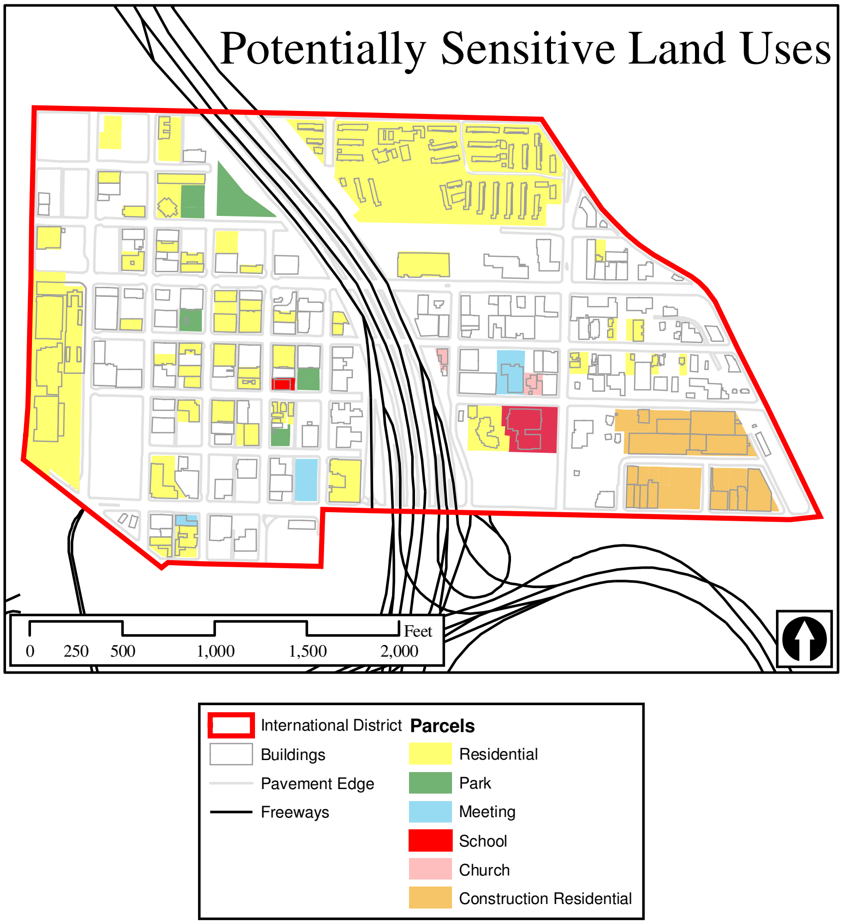

Figure 2: Potentially sensitive land uses.

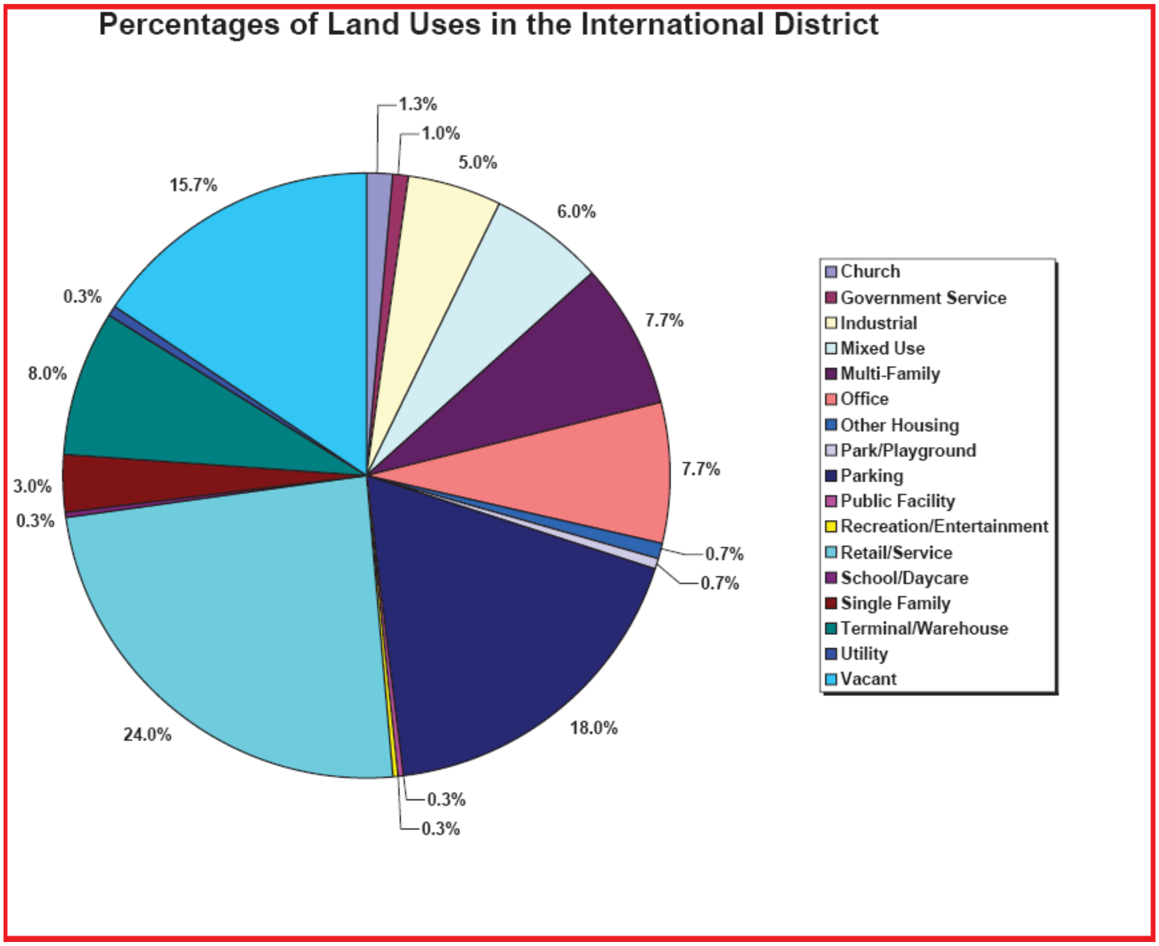

Figure 3: Percentages of land uses in the ID.

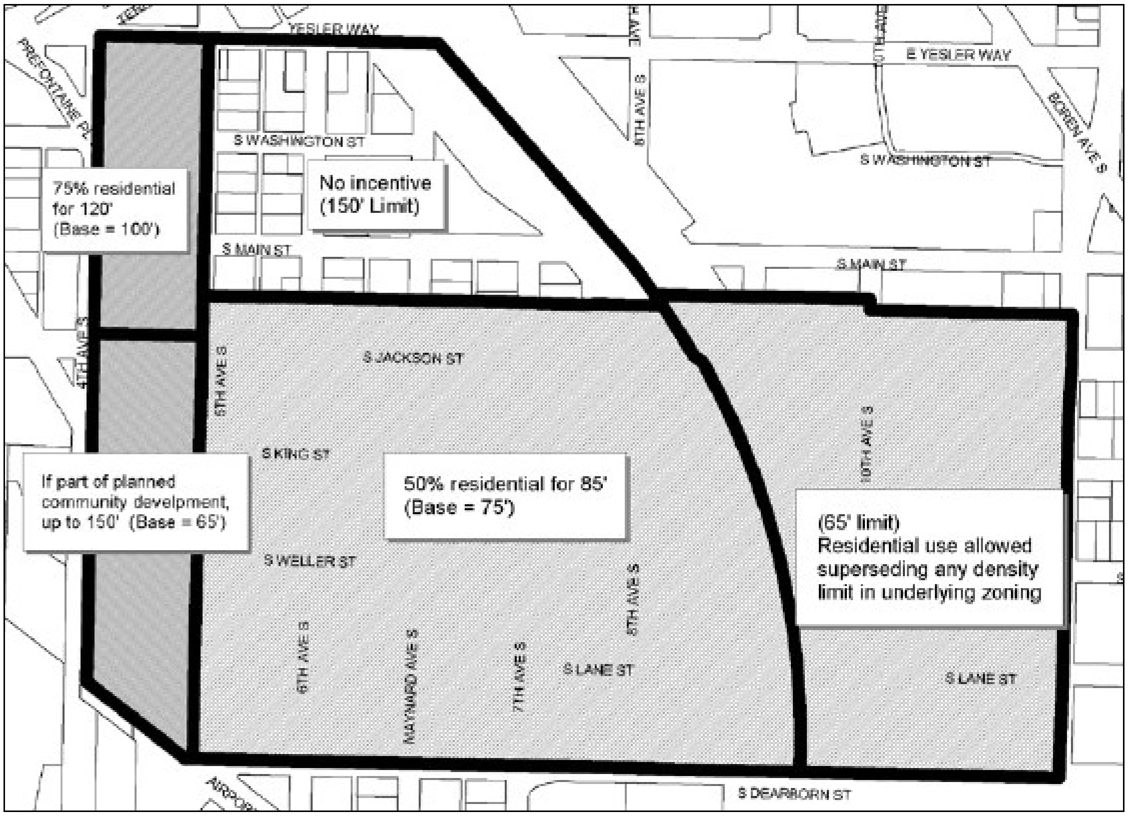

Figure 4: ID zoning.

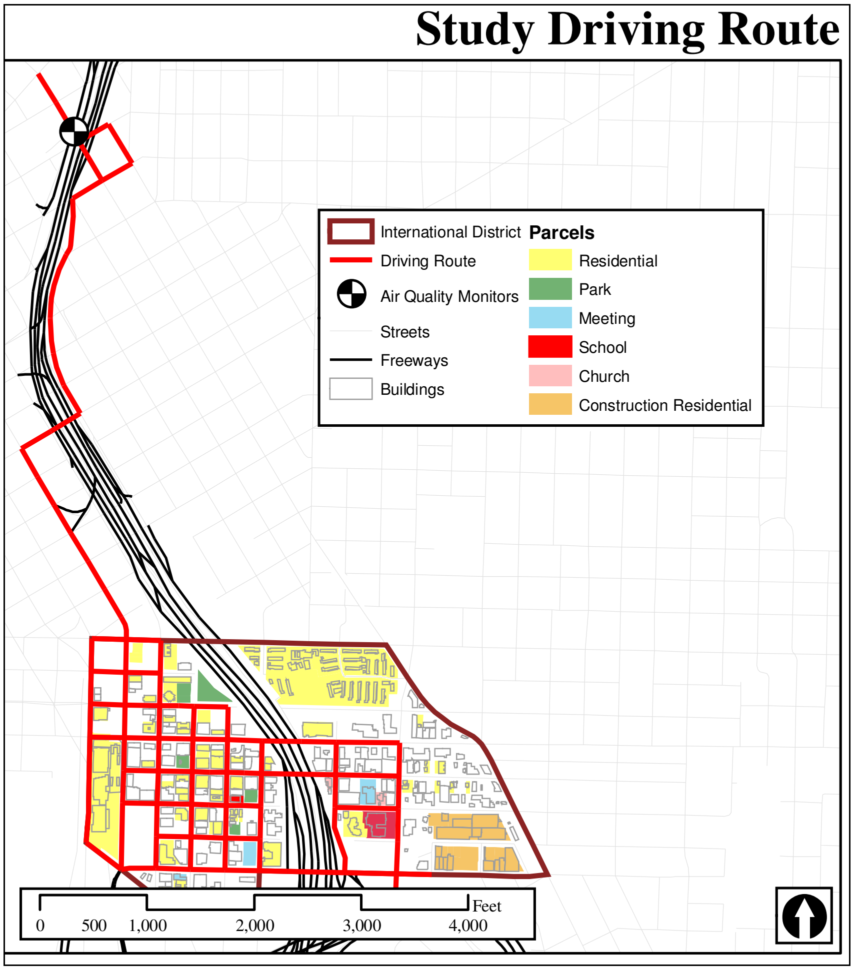

Figure 5: Study driving route.

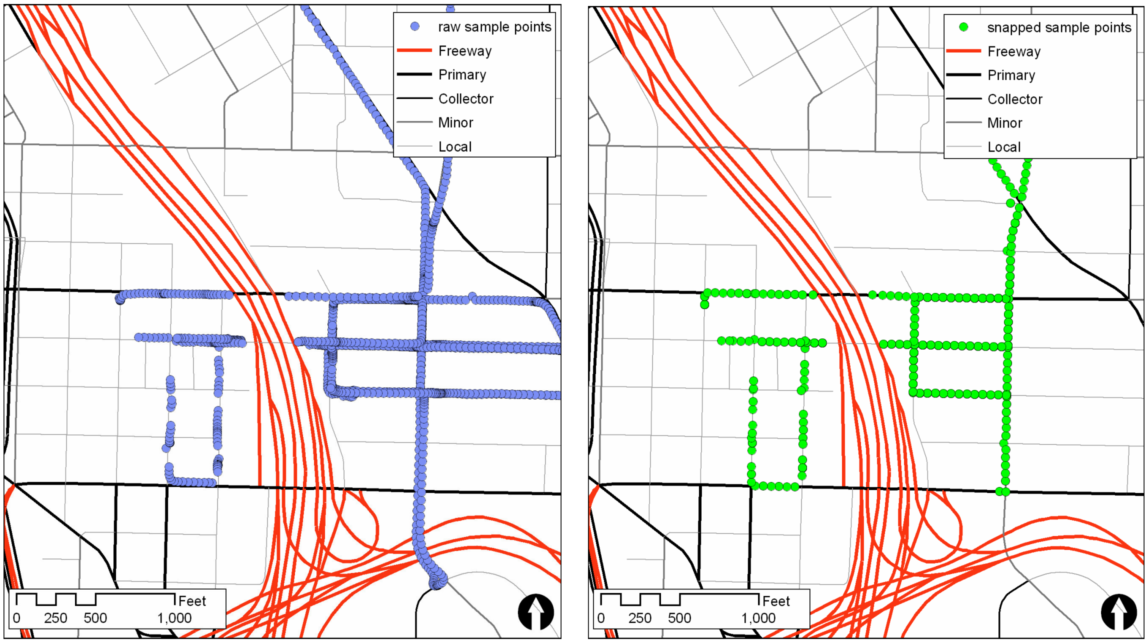

Figure 6: Snapped data points on street network.

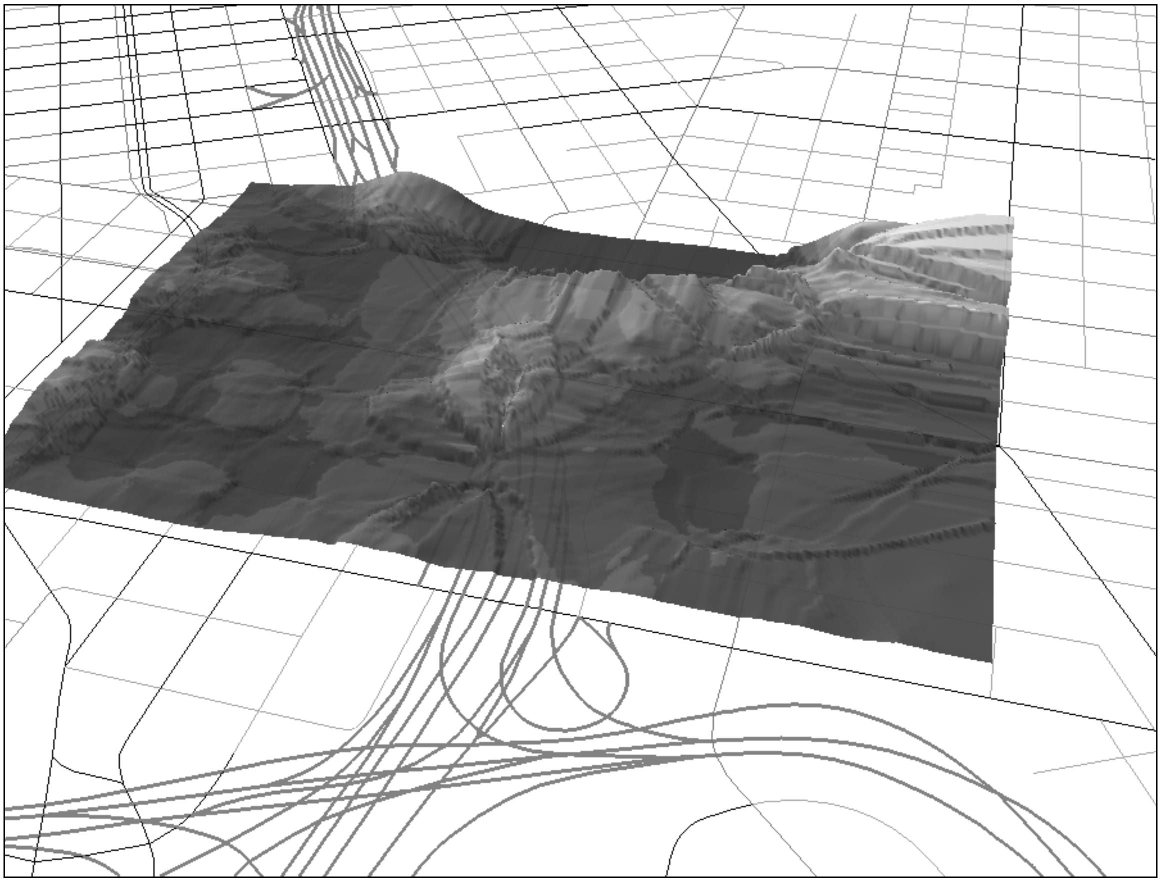
Figure 7: Kriging surface model of initial results.

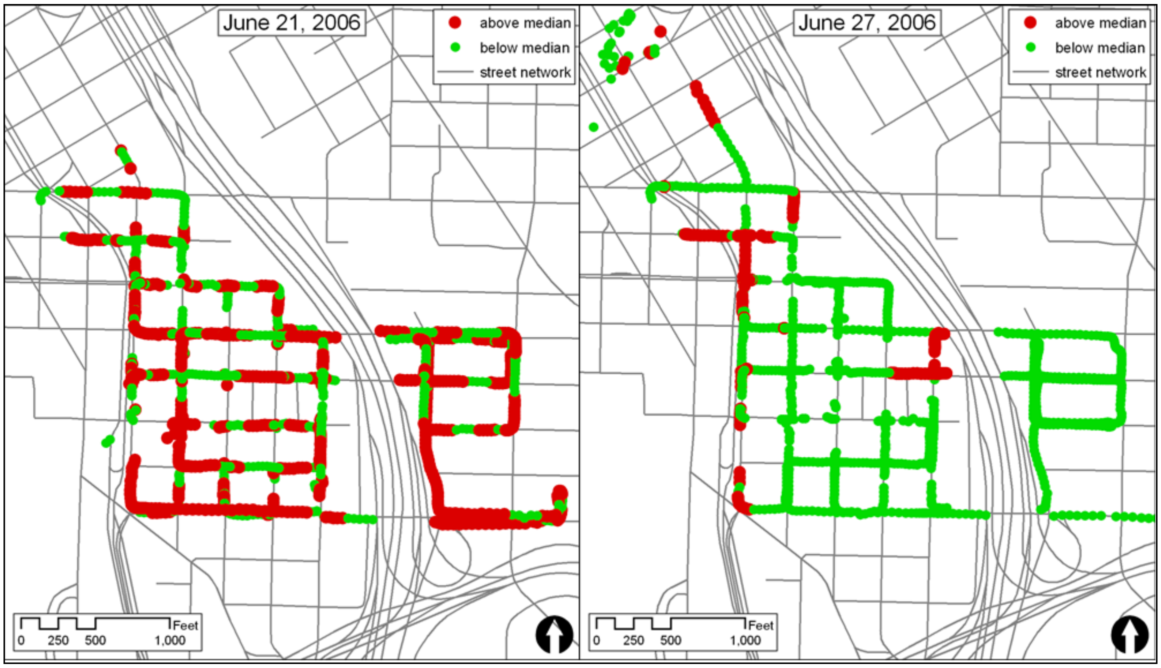

Figure 8: Variation in daily monitoring.

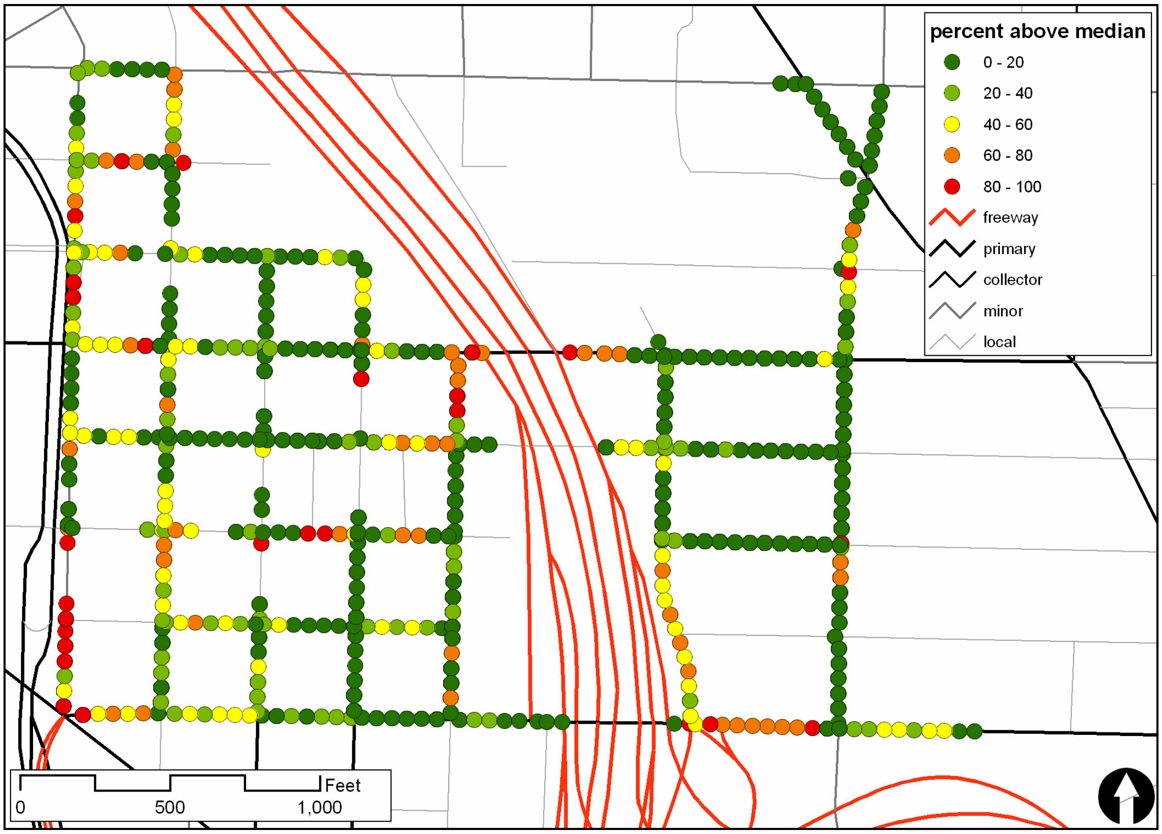

Figure 9: Results, percentages above median pollutant levels.

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