CNH: The ecology of highways in Baltimore and Los Angeles: Pollution hotspots or opportunities for redevelopment?

Introduction

As cities in the United States confront the economic, environmental, and social issues of urban sustainability, there is increasing interest in re-developing the urban core. Urban redevelopment has been proposed as a means of economic revitalization, increasing urban density, and providing affordable housing and amenities such as parks and green space (Slocombe 1993, Schilling and Logan 2008, Seto et al 2010, Schweitzer 2010). However, in many large cities, redevelopment may target areas that are polluted or located near pollution sources, raising questions about environmental justice, public health, and the potential for pollutant mitigation and reduction. Highway corridors, for example, contain rights-of-way that are appealing options for integration into redevelopment plans where available land is scarce yet there are important concerns about the influence of highway pollution on adjacent land use. Prior studies have examined human health near highways, while other studies examined the effects of road pollution on plants and ecosystem processes, our understanding of the role of highway corridors in the urban ecosystem as a whole is limited. Transportation infrastructure is integral to urban form, and there are consequences of transportation design for air, water, and soil pollution as well as for vehicle miles, traffic congestion, and energy use. The road network plays many other important roles in urban ecosystems (Foreman and Alexander, 1998; Coffin, 2007). Highways may alter hydrology (Jones et al, 2000) act as dispersal corridors for non-native plant species (Barney et al, 2008) and bisect human communities and neighborhoods with important, often unintended, consequences for local socioeconomic conditions. Vegetation and built structures along roads may adsorb pollutants or alter their dispersion, with potential implications for highway design, adjacent vegetation, and adjacent land use. There are also uncertain impacts on human health, as the composition of roadway pollution varies greatly with land cover, dispersion patterns, and season. The complex interactions among these components of the urban system and its road network highlight the need for an ecosystem approach that links road design and performance with pollutant emissions, dispersion, economic redevelopment, human health, and ecosystem metabolism, along with an understanding of redevelopment incentives, local decision-making and urban planning and policy.

This study will compare and contrast two major U.S. cities considering redevelopment near major highways located in formerly natural riparian zones. Urban redevelopment projects provide a fertile test bed in which to study the unintended consequences of parallel and disconnected paths of revalorization of urban land. The historic juxtaposition of road corridors and riparian ecosystems is closely tied to redevelopment in many cities, such as Chattanooga, Austin, Portland, and Dallas, which have invested in river redevelopment projects. In Los Angeles and Baltimore, river revitalization may have an inconvenient cost of increasing human exposure to hazardous air emissions, since the rivers closely parallel major highways. While natural riparian systems have relatively well studied, their transformation into modern transportation corridors is poorly understood from a coupled human-environment perspective. Like riparian ecology, "**highway ecology**" includes a unique assemblage of components that are not found elsewhere in the urban ecosystem, including transportation elements, pollution gradients, and many specific aspects of urban design. Riparian ecosystems are "hotspots" of biodiversity and biogeochemical processes resulting from the collection and concentration of surface water, nutrients, and sediments. Similarly, highway ecosystems are strongly shaped by transport processes, but unlike riparian corridors, which tend to collect inputs from adjacent landscapes, highways tend to be sources of particulates and gases that disperse into the larger ecosystem. We lack a systematic body of knowledge of the complex and interacting components of this ecosystem that can inform decisions about land use and management to sustain urban communities without causing deleterious health effects.

These knowledge gaps prompt us to ask the following questions:

- Does river revitalization in highway corridors enhance ecosystem services, or do pollution hazards outweigh the potential benefits?

- What new ideas of nature in cities motivate the current valorization of riparian corridors that were previously considered hazardous, mundane, or unimportant?

- What are the spatial footprints of different highway pollutants and how do they change along a rural-urban gradient?
- What are the interactions between roadway pollutants and adjacent vegetation?
- What do biomarkers tell us about potential human exposure to highway pollutants?
- Can land use, zoning and right-of-way management along highway corridors benefit urban communities while mitigating potential health risks?
- Does appraisal of health impacts affect redevelopment planning in highway corridors?

Specific Aims

We propose to study major highway corridors in Baltimore, MD and Los Angeles, CA. Both cities are currently the focus of major urban ecological projects, so this study of highway ecology can be integrated into larger, place-based frameworks of coupled human-environment interactions. In addition, the comparative approach provides an opportunity for understanding more general patterns across disparate cities and regions. The Baltimore Ecosystem Study is one of two current urban LTERs, and is bisected on a north-south axis by the I-83 corridor, also known as the Jones Falls Expressway, which parallels the Jones Falls (i.e. river). Land use patterns along this corridor are likely to shift as Baltimore revises its zoning ordinance for the first time in 40 years. We propose to conduct a comparative study with the I-5/710 corridor in Los Angeles, which follows a north-south axis that parallels the Los Angeles River, and is targeted for a major redevelopment effort outlined in the Los Angeles River Revitalization Master Plan. Both highways service major ports and play central roles in the transport and transformation of materials through the urban ecosystem while transforming the ecology of the historic riparian corridors.

To fully understand pollutant removal as an ecosystem service, it is important to understand likely outcomes for human health in addition to quantities and spatial distribution of particulates and reactive gases. However, air pollution dispersion studies rarely address these linkages with direct measurements. Both epidemiological and clinical studies show that air pollution plays a key role in cardiopulmonary disease development and incidence. A recent study showed that PM2.5 has declined in the past 30 years due to emissions restrictions mandated by the Clean Air Act and that life expectancy has increased in tandem (Pope et al, 2009). Despite this population wide trend, the incidence of asthma has increased, especially among minority children in low-income urban neighborhoods that are disproportionately affected by transportation corridors, and where environmental amenities such as parks and green space and often lacking.

We seek to improve our understanding of the linkages among vehicular traffic, air pollution, vegetation, redevelopment and human health. But we further wish to integrate this understanding into the broader emerging framework of urban ecology. There has been a great deal of progress in developing the "ecology of cities", which requires an understanding of many aspects of human-environment interactions (Grimm et al. 2000, Pickett et al. 2001). This integration has both scientific merit and is greatly needed for urban planning and policy. As described by Pincetl (2010), there is currently an urgent need to better understand and integrate ecosystem services into urban designs that move beyond the "sanitary cities" of the early 20th century, which were engineered to provide sanitized water and transport sewage and pathogens away from cities, and create new infrastructure to avoid and mitigate the concentrations of pollutants that have resulted from the sanitary city design. This involves consideration of many aspects and implications of "green infrastructure," from the basic science that determines their physical impacts on the environment, to the governmental and institutional structures that determine whether and how they will be implemented and managed in practice, to complex factors that determine their impacts on communities and well being. Currently, we are very far from having the same level of understanding of road-transformed riparian ecosystems that we have for their natural counterparts.

To advance this understanding, we have developed a set of hypotheses that focus on central uncertainties in the relationships among land use policy, vegetation, pollution, and health outcomes:

H1: *The greatest impact of vegetation on air pollutant concentrations will be through dispersion, rather than removal by direct deposition* - Vegetation affects near-road pollutant concentrations either via uptake and surface deposition or by turbulent mixing and dispersion. Uptake and deposition reduce ambient concentrations by direct removal to storage pools in or on leaves. With the exception of CO_2, uptake and deposition are passive processes: there are no active mechanisms in trees that maintain concentration gradients from the atmosphere to the leaf to drive diffusive transport of gases and particulates. The residence time in or on leaves varies, but dry re-suspension is minimal: for all practical purposes, pollutants remain in the leaf storage pool before being deposited onto the soil by rain or litter fall. It is commonly believed that trees enhance deposition of particulates because of their comparatively large surface area. However, it has long been known that the deposition velocity of airborne particulates to environmental is a parabolic function of particle size. Deposition velocity reaches a minimum around 0.2 μm, the region containing the majority of the PM2.5 size range. It is precisely this range that penetrates the lower respiratory tract and therefore affects health (Sehmel, 1980). Given this property of PM2.5, the effectiveness of leaves in improving air quality should be treated as a testable hypothesis, not an established fact. Furthermore, we propose that the influence of dispersion is greater than the influence of deposition, which we will test with a combination of models and measurements.

H2: *The isotopic composition of plants and soils will provide biomarkers of pollutant loading* - Stable nitrogen isotopes, stable carbon isotopes, and the radiocarbon content of organic matter tend to change in predictable ways in transects away from roadways (Ammann et al. 1999, Alessio et al. 2002). Nitrogen isotopes are generally enriched in gaseous N pollution, which is reflected in the nitrogen isotope ratio ($d^{15}N$) of plant and soil organic matter (Ammann et al. 1999, Pataki et al. 2005). Conversely, fossil fuel-derived CO_2 is depleted in both stable carbon isotopes ($d^{15}C$) and radiocarbon ($D^{14}C$) (Pataki et al. 2003, 2005). Wang and Pataki (2010) showed that the isotopic composition of plants in the Los Angeles region was closely correlated with the distribution of gaseous pollutants such as NOx and CO. We propose to compare plant and soils biomarkers with high-resolution measurements of airborne particulates and NOx, and directly compare atmospheric and plant/soil isotope measurements. Furthermore, we will conduct a new comparison of the relationship between different classes of particulates collected in the field with health markers, specifically cytokine induction in epithelial cells and monocytes, which is a measure of the inflammatory response associated with asthma (described below). This will allow us to explore novel correlations between stable isotope tracers and more direct markers of human health outcomes.

H3: *Particulates collected from poorly mixed locations beneath tree canopies have greater intrinsic inflammatory capacity than open locations*. Objects that impede vertical and horizontal movement of air impede flushing and mixing of particulates, resulting in localized increases in particulate concentration. Additionally, vegetation contributes to the load of spores, hyphal fragments and insect parts, all of which are composed of chitin, a protein that stimulates the human immune system. Preliminary studies by Whitlow show higher particulate concentrations downwind of rows of trees in an urban park and that PM collected in parks had greater inflammatory ability than curbside samples.

H4 – *Unexpected alliances of environmentalists, business interests, and local government are galvanized by a mutual interest in equitable distribution of open space and the need for housing. This drives a perception that new redevelopment opportunities lie in lands along highways..* In densely developed urban areas such as Baltimore and Los Angeles, opportunities to create new park and housing infrastructure on affordable land are relatively few. We hypothesize that the possible economic benefits of redevelopment adjacent to highways– which is attractive in part because of its association with historic rivers – has overshadowed the potential health risks posed by placing people in close proximity to pollution sources, and obscured the role of government in facilitating the advancement of economic interests. Underutilized except for flood control, these previously undervalued urban spaces are now rising to the level of opportunities for redevelopment. Urban theory holds that real estate and urban interests are closely aligned in the U.S. (Elkin 1987) as local governments depend on real estate investment and development for revenue. In this situation, redevelopment is further propelled by ecological revitalization and framed as the evolution of "sustainable cities". While justified as providing open space and housing for underserved communities, ironically these projects do not consider heath impacts. It is noteworthy that such consideration is not required under federal, state or local regulation. We propose that the policy mechanisms of environmental review, leveraging of funds, and plans for redevelopment combine in complex and previously unexamined ways along highways. For example, Interstate-5 that stretches from the Mexican to the Canadian border and is considered an intermodal corridor of economic significance, has traffic counts of 304,000 cars per day by the Los Angeles River bicycle path. This area is already heavily used for recreation and is slated for further revitalization. How ecology, atmospheric processes, politics, and economics are woven into projects that drive urban transformation and embody social values must be further studied to more fully understand both the current planning process and how it can be improved (Evans 2007).

Background Studies

Vegetation and air pollution removal – Vegetation may impact air pollution through stomatal uptake, surface deposition, alterations to dispersion, and also by acting as a source of both gases and particulate matter. While uptake and deposition reduce pollutant concentrations, mixing and dispersion either dilute or redirect pollution plumes without changing the total amount of pollution in the atmospheric pool. The complex and porous structure of tree canopies affects local turbulence while at the same time concentrating pollution in entrained downwind eddies. Variables including vegetation type, height, porosity and thickness will influence the extent of mixing and deposition, although specific relationships for these factors have not been well quantified (Bowker et al, 2007; Beckett et al, 2000; Heath et al, 1999; Munch, 1993). Additionally, the presence of trees is far from universally positive from a pollution abatement standpoint. Two recent studies (Gromke and Ruck, 2007, 2008) have shown that avenue-like tree planting increases pollution concentrations on the leeward side of tree crowns in comparison with a tree-free street canyon. This is caused by a reduction in the vortex normally found at the top of a treeless canyon. A comparison of ultrafine particle dispersal downwind of highway noise barriers (with and without downwind trees) found that PM concentrations declined faster without any barriers (Bowker et al, 2007). Further, downwind concentrations equaled those next to the highway where the deflected air stream returned to ground level. Clearly, there can be unexpected consequences of placement of any barriers, including "green" ones, along roadways. Before any meaningful advances can be made in our ability to use trees to reduce particulate air pollution, much less affect human health, we need quantitative answers to the following questions:

1) What is the relative importance of turbulence and deposition in near-road air pollution concentrations?
2) What are the roles of leaf area, canopy structure, and species in affecting the capacity of green space to reduce the pollutant concentrations?

P.I. Whitlow has developed methods for quantifying fine scale variation in PM2.5 using portable particle counters at different locations in the landscape during brief monitoring campaigns. Using multiple counters it is possible to characterize variation in concentration gradients in real time. In contrast to standard monitors that integrate over 30-60 minutes, this method integrates over 6-sec intervals to approximate the human inhalation rate. Plotting PM2.5 concentration as a function of time yields a "koniograph" (Gr. *konia*, for dust or soot) that is directly analogous to hydrographs depicting stream discharge over time. Notably, both the hydrological and atmospheric systems fluctuate stochastically, are unstable and easily deflected from their ground state) *and* are resilient, decaying rapidly back to the ground state (FIG 1A,B).

Extreme event analysis (Gumbel, 1941) can resolve stochastic fluctuations into meaningful information about exposure risk. This is directly analogous to the return period of storm and flood events, e.g. the 100-year flood, only at intervals of minutes instead of years (FIG 1C,D). The concentrations of particulate events at ground level and rooftop diverge for return periods exceeding 2 minutes, and the 20-minute event is 1.5 times greater on the ground than beside a rooftop monitoring station (FIG 1D). The likelihood of being exposed to high particulate concentrations is clearly greater at street level that on the roof. In a parallel study monitoring PM2.5 count concentrations along a transect traversing an urban park, we found that concentrations downwind of a heavily traveled street were highest behind 2 rows of trees (FIG 2). In this proposal we will use extreme event analysis to evaluate the spatial and temporal distribution of pollutants along distance gradients away from highways. This approach is novel in that it associates exposure risk with locations in a landscape. This approach has great power to explain both epidemiological patterns as well as informing individuals about personal exposure risk. This information could readily translate into decisions about personal behavior.

Modeling of pollution dispersion - Zhang's research group has developed a novel modeling framework to describe near-road air pollution that integrates Computational Fluid Dynamics (CFD), Vehicle Induced Turbulence (VIT) and Road Induced Turbulence (RIT). This integration simulates both transport and transformation of multiple air pollutants near roadways (FIG 3). On the transport side, it captures the major turbulent mixing processes in the roadway environments and can accommodate variation in roadway configuration (e.g., elevated vs., depressed highways) and road surface properties. On the transformation side, the model incorporates NOx chemistry and aerosol processes such as nucleation, condensation/evaporation, and coagulation. Additional chemical mechanisms such as detailed photochemical reactions of hydrocarbon can be added on. All of the existing components in CFD-VIT-RIT have been validated against field measurements. Compared to a both a Gaussian plume dispersion model (CALINE4) and a standard CFD model, the CFD-VIT-RIT model more accurately simulates the vertical CO profile near an elevated portion of highway I-405 in Los Angeles (FIG 4a) and costs less from a computational standpoint. CFD-VIT-RIT simulations also more accurately predict actual measurements of NO_2 than CALINE4 simulations and are capable of including detailed chemical reactions (FIG 4b).

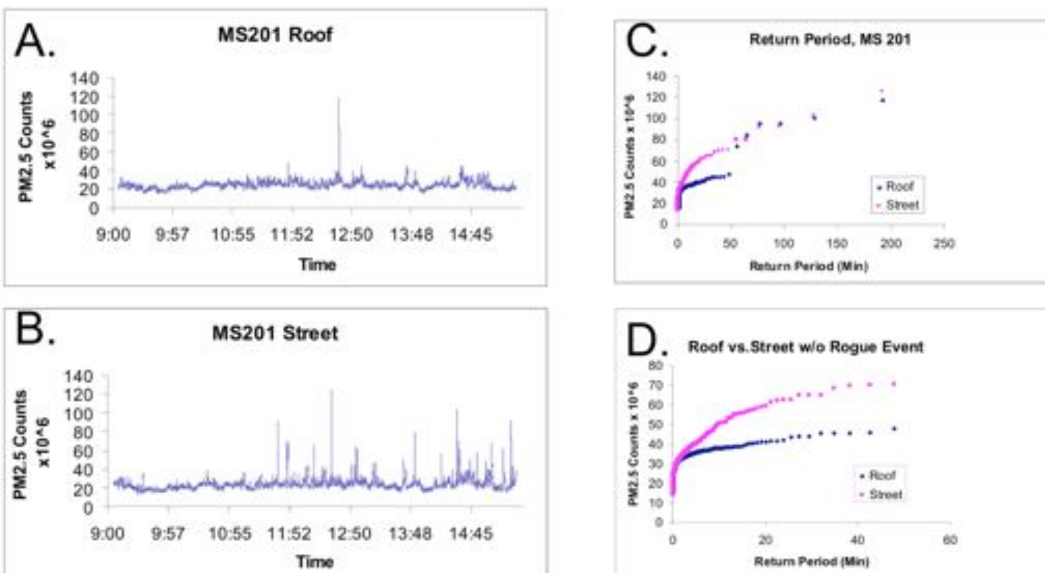


Figure 1. A comparison of PM2.5 count concentrations on a school roof next to an NYDEC monitoring station and those at ground level on the playground. Koniographs show variation in PM2.5 concentration over the day on the school roof, A and on the playground, B. C shows the return period of events including the very large event around 12:30. D shows the data with this point removed for clarity.

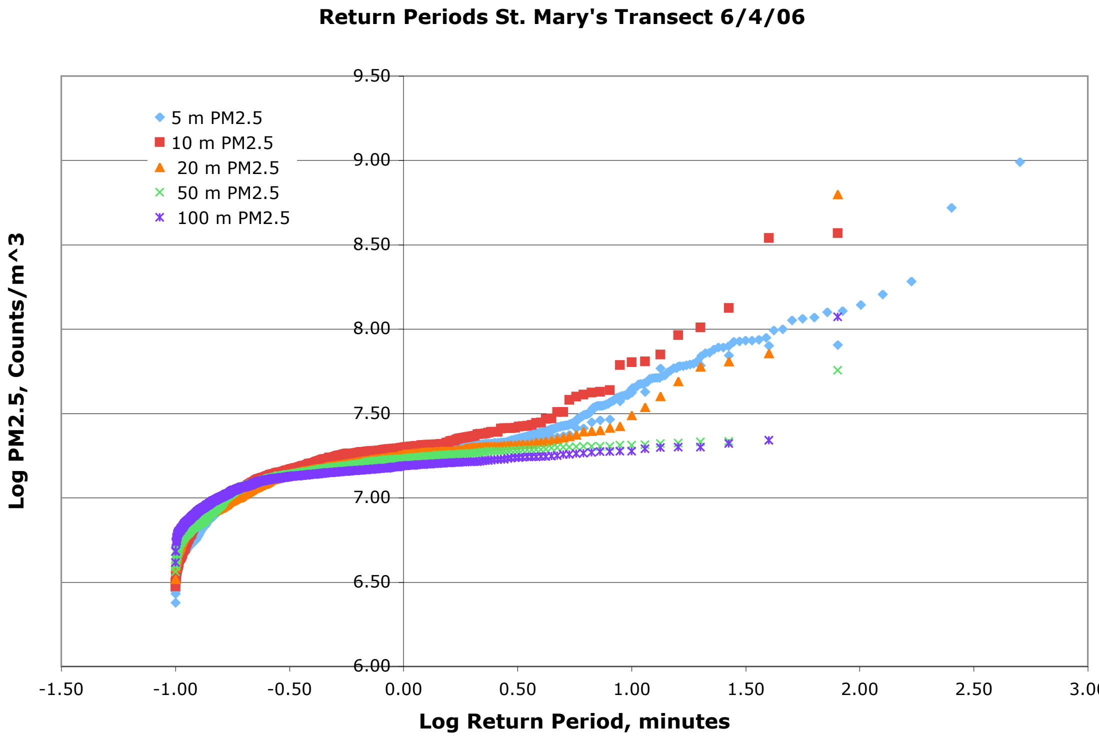


Figure 2. Return period plots of PM2.5 events along a 100m transect across St. Mary's Park, The Bronx. Samples collected at the curb and 5 meters across the sidewalk are indistinguishable (blue diamonds) while samples taken 10m from curbside behind both street trees and a row of park trees (red squares) had consistently higher concentrations than at curbside for events with return periods exceeding 1.8 min. This finding suggests that mixing was impeded at this location, possibly by tree canopies, allowing particulates to accumulate.

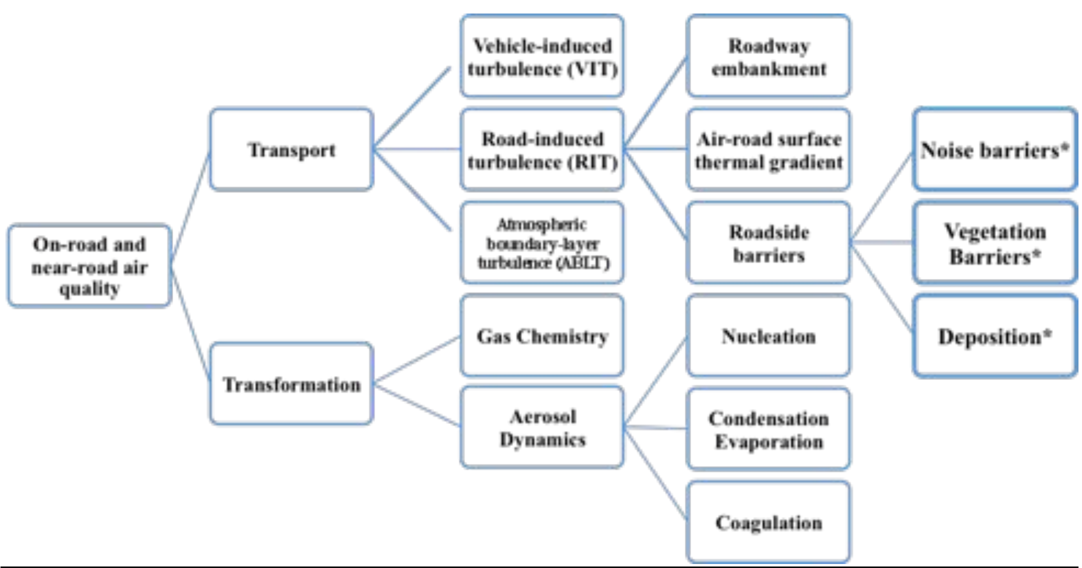
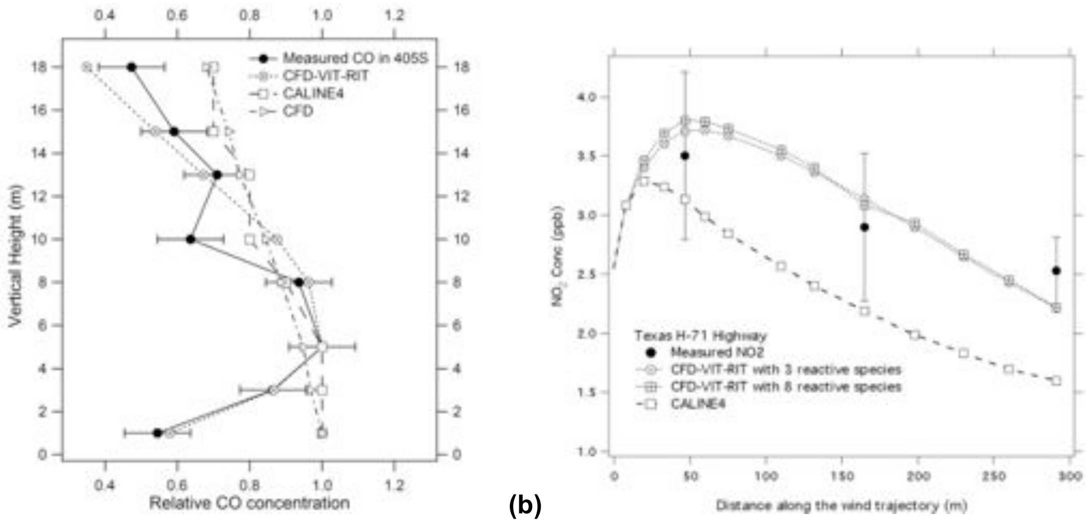


Figure 3. The integrated CFD-VIT-RIT model.



(a) **(b)**

Figure 4. A comparison of measured values with CFD-VIT-RIT, CFD and CALINE4 predictions of (a) CO adjacent to I-405 in CA (a) and (b) for highway H-71 in Austin, TX.

Pollution and biomarkers for human health – Epidemiological studies consistently link air pollution and negative health outcomes, especially asthma, across a wide range of spatio-temporal scales. However, the epidemiological method suffers from an unavoidable “ecologic fallacy”: it cannot translate group exposure and disease incidence into the risk experienced by an individual (Soskolne et al, 2000.) The etiology of asthma is complex and not completely understood, but ultimately, the persistence of an allergen and its interaction with lung cells are responsible for the chronic nature of the disease. The cellular infiltrate in the asthmatic lung involves from macrophages, eosinophils and lymphocytes, as well as resident epithelial cells (Siddiqui and Martin, 2008). These cells respond to allergens by producing cytokines and other factors that directly promote inflammation and tissue remodeling (histamine, mucus, amphiregulin) (Paveglio et al, 2007) or have the capacity to modulate the overall cellular response (such as chemokines and cytokines that support the recruitment of inflammatory cells or the maintenance of Th2 and Th17 CD4+ T cells) (Huang et al, 2008). Coarse PM is comprised of crustal material, endotoxins, beta glucans, spores, allergens and pollen, while fine and ultrafine PM are composed of various metals, polycyclic aromatic hydrocarbons (PAH), black carbon and other exhaust compounds from traffic (Schwarze et al, 2006). This variety poses great challenges in assessing the health effects of PM, and likely explains the seemingly conflicting findings linking air quality to human health. Evaluating the inflammatory capacity of field-collected particulate samples is a first step toward solving this puzzle. Cytokine induction is a necessary precursor of inflammation and the cascade of immune responses.. While identifying the specific composition of PM undeniably aids in identifying emission sources, we submit that focusing on chemical composition distracts from the central task of predicting health outcomes. Using cytokine induction as an environmental biomarker refocuses the discussion on health, avoids the inevitable confounding variables associated with human populations, shifts the emphasis to the spatial distribution of risk factors and avoids the time lag required to detect disease occurrence in populations. Ultimately, this focus turns the ecologic fallacy into an asset with the ability to predict patterns that would otherwise escape detection. The biomarker approach has unexplored value as a tool for inferring causality and informing decisions about redevelopment in highway corridors.

Over the past 3 years, Anguita and Whitlow have developed a method for using biomarkers to evaluate the capacity of field-collected airborne particulates to induce proinflammatory responses associated with asthma. They have performed cytokine induction assays with filtered air particulates (FAPs) collected during brief monitoring campaigns in the South Bronx, Baltimore, and Manhattan. An example from a campaign comparing curbside PM2.5 concentrations with school playgrounds with rooftops and park margins with interiors shows the power of the biomarker approach (FIG 5).

Particulates collected from locations in small scale urban landscapes were used to stimulate the murine macrophage cell line, RAW 264.7. The cells were stimulated for 12-16 h with soluble extracts (1/20th to 1/100th vol/vol) of filters containing particulates. The cytokines TNF, IL-6 and IL-10 were used as stimulation markers and measured by ELISA or cytometric bead arrays (CBA, BD Biosciences). The responses were separated by particulate size: 1) coarse, PM>2.5 μm; 2) 1-2.5 μm; 3) 0.501.0 μm; 0.2500.5μm; and 5)ultrafine, PM< 0.25 μm. Overall, coarse particles collected in parks near busy roads were more inducing than samples from other urban sites, suggesting that tree canopy does not afford protection against airborne allergens. Furthermore, rooftop samples were no less inducing than those collected beside busy streets despite the fact that concentrations were lower on rooftops. These results contradict both the expectations of the study and conventional wisdom. To understand the mechanisms underlying these results, it is necessary to couple high resolution sampling along environmental gradients with laboratory induction assays.

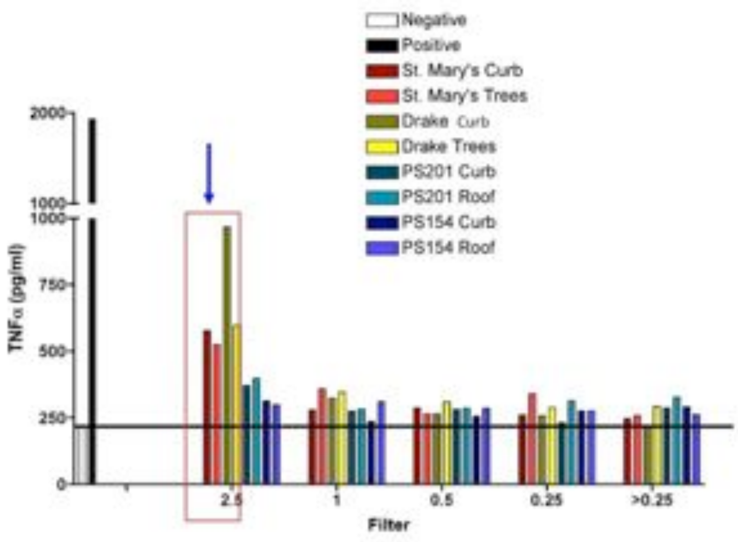


Figure 5. A comparison of induction of the proinflammatory cytokine, Tumor Necrosis Factor alpha (TNFa), by particles in 5 size classes ranging from <0.25 μm to >2.5 μm in diameter. Negative and positive refer to control standards. St. Mary's and Drake refer to public parks, and PS201 and PS154 refer to two public schools, all in South Bronx. Curb samples were collected at curbs beside busy streets; roof samples were collected adjacent to NYDEC air quality monitors atop the schools; tree samples were collected in copses in the interiors of the two parks. Arrow denotes coarse particles collected in around parks.

<u>*Biomarkers in plants and soils*</u> - Pataki developed the application of the stable isotope composition of leaves and soil organic matter as pollution tracers in a previous NSF-funded study that mapped isotope biomarkers throughout the LA Basin (see results from prior support). As a result, Wang and Pataki (2010) reported that the spatial distribution of leaf δ^{15}N showed a pattern of isotopic enrichment near downtown Los Angeles (Figure 6a). A multivariate analysis showed that leaf δ^{15}N was significantly correlated with atmospheric NO_2 and ozone concentrations, point sources of NOx, population density, and distance to the coast. These results point to plant uptake of anthropogenic N. In addition, population density was likely related to δ^{15}N because of its relationship with traffic, though traffic statistics were not directly available in that study. In a follow-up study, Wang and Pataki (2010) combined measurements of leaf d^{15}N in urban plants with both soil isotope measurements and laboratory assays of soil N cycling. The incorporation of soil variables into the analysis explained much more of the spatial variability in δ^{15}N. One

very useful parameter was the difference between plant and soil isotope composition, or the plant enrichment factor (EF), which was strongly correlated with atmospheric NO_2 concentrations.
For carbon isotopes, radiocarbon was a powerful measurement of the exposure of plants to fuel combustion. Leaf samples collected in downtown Los Angeles were depleted in $\Delta^{14}C$ by more than 100 ‰ relative to CO_2 in clean, background air (Figure 6b). Plant $\Delta^{14}C$ can be used to calculate the concentration of atmospheric CO_2 in polluted air by determining the proportion of plant matter derived from fossil fuel CO_2. The values we measured in downtown Los Angeles correspond to a photosynthate-weighted, average CO_2 concentration of 437 ppm, relative to about 380 ppm in clean air. When the spatial distribution of plant $\Delta^{14}C$ was evaluated in relation to population density, elevation, meteorological variables, and criteria air pollutants in a multiple regression model, $\Delta^{14}C$ was found to be significantly related to atmospheric ozone and carbon monoxide concentrations, population density, and distance to roads. These variables explained more than half of the spatial variability in leaf $\Delta^{14}C$, supporting the use of $\Delta^{14}C$ as an integrator of atmospheric pollution to complement and enhance traditional air quality monitoring metrics. Stable carbon isotopes provide measures of both atmospheric conditions

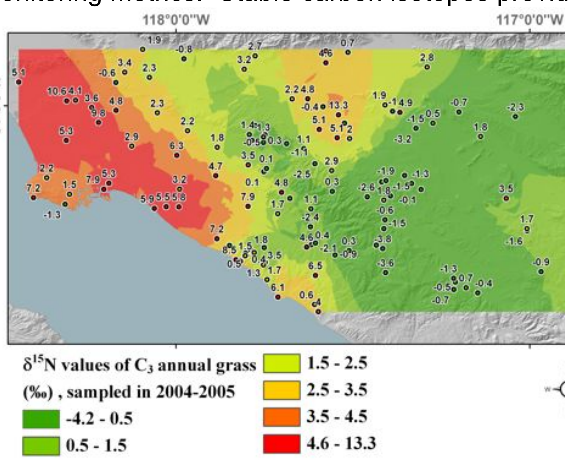


Figure 6a – Plant nitrogen isotope ratio ($d^{15}N$) in the Los Angeles Basin reported by Wang and Pataki (2010).

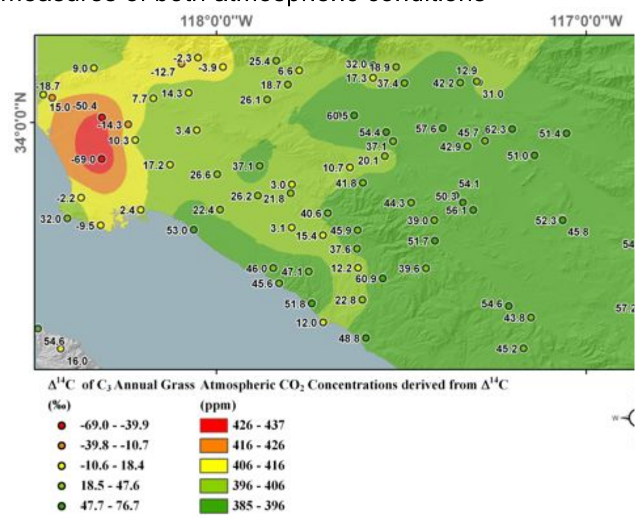


Figure 6b – Plant radiocarbon content ($D^{14}C$) in the Los Angeles Basin reported by Wang and Pataki (2010).

as well as the impacts of pollution and other environmental variables on plant physiology. Fossil fuel CO_2 is depleted in ^{13}C, which is reflected in the isotopic composition of plant biomass (Lichtfouse et al. 2003, Pataki et al 2005). However, the balance between photosynthesis and stomatal conductance also greatly affects plant $\delta^{13}C$, at least in plants that use the C_3 photosynthetic pathway (the majority of plants). Wang and Pataki (2010) reported that $\delta^{13}C$ of annual grasses in the Los Angeles basin was correlated both pollutant concentrations and with environmental variables such as soil moisture. The passive influence of pollution on plant $\delta^{13}C$ (uptake of depleted CO_2) can be distinguished from physiological effects (changes in photosynthesis and stomatal conductance that are reflected in ci/ca) by examining additional tracers such as radiocarbon and oxygen isotopes ($\delta^{18}O$), which reflect changes in plant transpiration and stomatal conductance.

<u>*Urban redevelopment, riparian areas, and roads*</u> - Redevelopment in the United States has historically been associated with the destruction of low-income communities to the benefit of new uses and gentrification, with a concomitant increase in local revenues (Sugrue, 2009). At the same time, the environmental justice movement has identified inequalities in the distribution of urban hazards such as highways, and also in amenities such as parks and green space (Boone et al 2009, Heynan et al 2006, Wolch 2005, Iverson and Cook 2000). This has led to a paradox in the treatment of highway rights-of-way: some groups highlight emissions from highways as an example of inequitable distribution of pollution, while others call for development of public parks, greenways, recreational trails, and even housing in the underdeveloped zones left in the wake of major highway construction. Further complicating our understanding of the highway ecosystem is the historical legacy of locating

transportation corridors on or adjacent to riparian ecosystems. This pattern is central to both the ecology and the development of communities and cities.

Many current issues involving the application of the ecosystem services concept are manifest in the well-known Los Angeles River restoration project. Much of the river is completely armored and channelized for flood control, but there is a strong desire from many different groups and jurisdictions to return some natural function to the river, and also to utilize river restoration for redevelopment. The Los Angeles River Revitalization Master Plan focuses on the 32 miles of the river that flow through the city of Los Angeles, and involves building parks along the river, finishing a 30 mile bicycle path, incentivizing the construction of housing and businesses, and making the river corridor a vibrant, attractive and accessible asset (ttp://www.lariverrmp.org/). Given the importance of rivers and riparian ecosystems to communities throughout human history, it not surprising that this plan has received strong support; indeed, politicians have lined up to support it, and park bond funding has been successfully applied to planning efforts and the creation of several new parks along the river. Yet, all of this will take place along one of Los Angeles' most heavily used freeways. To date, we are not aware of any studies of the potential pollutant hazards in the proposed development. Further, given the complex nature of the redevelopment, it is not clear how this information can and would be used in the continued development and implementation of the plan.

Experimental design

We have developed parallel experimental designs in both cities that involve:

- *Short-term measurements* of ultrafine PM, PM 2.5, PM 10, NO, NO_2, NH_3, BC, CO
- Markers of *human exposure to atmospheric pollutants* using *in vitro* induction of proinflammatory cytokines
- Measurements of *long-term ecosystem integrators* of pollution and its effects in stable carbon and nitrogen isotopes, radiocarbon, and black carbon
- *Modeling studies* of the dispersion of atmospheric pollutants
- Comparative studies of the *planning and design processes* in redevelopment zones in the two cities, and the use of new information resulting from this study, in ongoing planning efforts

Study regions – Los Angeles, a relatively new city with strong environmental nonprofit organizations, has long been organized around the automobile, and is now trying to shift this approach and take advantage of missed opportunities to increase access to open space, especially for underserved communities. Baltimore has a much more robust open space infrastructure, and with the BES LTER has also developed strong relationships between tree planting organizations, open space management entities, and researchers. In Los Angeles, researchers have begun to develop these relationships through 2 smaller projects – an NSF HSD grant that assessed the benefits of the Mayor's Million Tree Planting initiative, and a current ULTRA Ex project focused on determining outdoor water use in the City through a "socio-ecohydrological" approach. Although the highway systems that we have chosen have similarities as major transportation and riparian corridors, the development patterns of the two cities and the importance of the highway systems in the larger ecosystems are quite distinct. This provides excellent opportunities to compare and contrast the two systems.

The Los Angeles River stretches 52 miles and crosses 13 cities, flowing through diverse communities from Canoga Park in the San Fernando Valley through downtown Los Angeles to the ocean in Long Beach. The Los Angeles freeways are major NAFTA shipping routes that connect the Port of Los Angeles to major distribution centers and the rest of the country. A portion of Interstate 5 through Glendale and Burbank stands out as one of the region's most congested stretches of freeway, according to a draft report by the Los Angeles County Metropolitan Transportation Authority. This portion of the freeway has 8 lanes carrying 304,000 cars a day. Los Angeles is also notoriously deficient in parks, with public parks providing less than 1.3 acres of public open space per 1,000 - well below the 6.25-10.5 acres per 1,000 recommended by the National Recreation and Park Association (Wolch et al, 2001). There is an ongoing debate about the future of the 710 corridor (which connects Interstate 5 to the port) and its role in truck traffic in the region. There are plans for a new truck-only lanes, and truck diesel pollution is an increasing topic of concern, linked to plans to expand the port. Freight trains also run along this portion of the Los Angeles River Corridor.

Jones Falls drains a 53 square mile watershed and is the largest of 3 watersheds emptying into Baltimore harbor. Since early settlement, it has been exploited for waterpower, transportation and as a public water supply and it reflects these legacies. Today, an interstate highway, a railroad and a light rail line dominate the former riparian corridor. A portion of the river flows through a tunnel and essentially all of its tributaries within the City limits flow in storm sewers. The Jones Falls Expressway, which is the southernmost portion of I-83, was constructed between the late 1950s and mid-1970s and defines a major N-S axis through the City. Plans to connect with I-95 to the south were abandoned in the 1980s, leaving an abrupt terminus with traffic lights and an unused overpass to nowhere in downtown Baltimore. Just beyond the City line to the north, I-83 joins I-695 (the Baltimore Beltway) for a short distance before continuing through rural northern Maryland, crossing the Pennsylvania state line and finally terminating north of Harrisburg, PA at I-81. It is the major commuter and commercial route between Baltimore and York, PA 35 miles to the north. Significantly, most of the highway inside the City is elevated, a configuration especially conducive to dispersing pollutants originating from traffic. A plan to replace the elevated portion with an at-grade road is being discussed in conjunction with the current re-zoning initiative, the first in 40 years. Redevelopment of the urban portion of the I-83 corridor in the 2020 time frame is highly likely.

While there are structural similarities between the two highway corridors that we propose to study, there are also significant differences in both the human and natural dimensions. These include the history of urban development and infrastructure, types of local governance, regional climate, and vegetation types. A conceptual framework for "highway ecology" built around a contrast of an east and west coast city will be far more versatile than one developed in a single location. In addition to this advance in the theory of urban systems, our project will inform the questions underlying the larger BES LTER and ULTRA-Ex LA projects, which focus on heterogeneity, scaling, fluxes of both ecological and human currencies, sustainability, and ecosystem services.

Sampling – Along each highway corridor, we have chosen three locations (Table 1) representing different levels of urbanization, traffic and vegetation complexity where we will conduct intensive sampling of air quality, vegetation, and soil. Sampling campaigns in both Baltimore and Los Angeles will be conducted quarterly in March, June, September, and November. Each on-site campaign will consist of a 10-12 hour period during which spatial gradients will be sampled in relation to canopy cover and structure and roadway sources. The number of points along the gradients will vary depending on the position of roads, trees, downwind fetch and other features of the specific landscapes. We anticipate 6-10 sampling points at each location situated along transects from the highway to distances of up to 100m, depending on local physical conditions.

Table 1 – Sampling locations in each city.

Sampling location	Baltimore	Los Angeles/Long beach
Urban core	I-83 terminus, downtown	I-710 terminus, Port of Long Beach
Residential	I-83 at Cold Spring Rd/ Baltimore Polytechnic Institute	I-710 at Somerset Blvd/Compton Golf Course and Dominguez High School
Ex-urban/natural vegetation	I-83 and 137 near Hereford	I-5 at Griffith Park

Our measurements will consist of:

Real time measurements: Particle counts, black carbon, CO and NOx. Measurements will be made along transects crossing roadside vegetation using instruments deployed at either static locations or moved systematically among points. Particle count concentrations for sizes <0.5 μm will be monitored using 2 FMPS particle counters (TSI Model 3091, Shoreview, MN,); count concentrations for particles between 0.35-20 μm in diameter will be monitored using 3 optical particle counters (Grimm Model 1.108, Carrollton, GA); NO and NO_2 concentrations with real-time analyzers (2B technology Model 410 and 401, Boulder, CO: one in each city), black carbon will be monitored using micro aethalometers (E51, Magee

Scientific, Berkeley, CA) that will be moved along transects for spatial sampling. Where multiple instruments are used, they will be periodically co-located and against each other to permit post hoc correction for variation between instruments. The units can be mounted on either wheeled dollies or pack frames. Particle counters are equipped with isokinetic probes to compensate for variation in wind speed. If more than 3 points are necessary to characterize a gradient, one of the systems will circulate among sampling points at 15-min. intervals.

Samples for chemical composition, stable isotope analysis and immunoassays. Particles ranging from ultrafine to coarse will be collected onto humidity conditioned and pre-weighed filters PTFE filters using Sioutas cascade impactors (Model 255-370, SKC Inc., Eighty-four, PA) and battery powered pumps (Leland Legacy, SKC Inc., Eighty-four, PA) operating at 9 l /min. We propose to use 8 samplers (4/city) that will be positioned at static locations 2 m above the ground at strategic points along local gradients at each site where particle counts are made. Filtered Air Particulates (FAP) are size fractionated by the impactor into fractions corresponding to >2.5 μm, 1.0-2.5 μm, 0.5-0.1 μm,0.25-0.5 μm and < 0.25 μm diameter classes. The time integral for particle collection will be 5-6 hour, corresponding to morning and afternoon periods, in order to collect sufficient particle mass. After collection, filters will be returned to the lab, conditioned in a desiccator to a constant weight and re-weighed on a microbalance to determine the mass of particles in each fraction. Filters will then be cut in half and distributed between Anguita for immunoassays and to Pataki for nitrogen content and isotopic composition. We will collect small leaf and soil samples onsite along the transects for chemical and isotopic analysis using standard ICP and mass spectrometry methods.

Vegetation inventories, structure, and leaf area. We will inventory all vegetation using point sampling along the transects to record species, growth form, and height of all plants including shrubs and herbaceous species. In addition, we will need to characterize canopy structure and leaf area. This is difficult in urban areas with traditional methods based on closed, uniform, or homogenous canopies. Light extinction methods, for example, which are commonly used to estimate leaf area in natural forests, result in large uncertainties in open grown trees and shrubs. We have contended with these issues in previous urban forestry projects, and have used a combination of high resolution remote sensing (Quickbird), non-destructive measurements of leaf and branch geometry and dimensions, optical methods such as hemispherical photos, a Li-Cor canopy analyzer, litter traps, and destructive sampling to obtain allometric equations, all of which will be applied to this study. We will use an array of 4, 3-D sonic anemometers (CSAT3, Campbell Scientific) to relate canopy porosity and structure to local turbulence. These will be used in a 3-D mesh analysis (see below).

Traffic counts and *wind* . During each monitoring period, we will position anemometers (either Gill WindSonic or MetOne) and a video camera on site to monitor wind speed and direction and traffic conditions during each monitoring period. We will also utilize traffic data collected by the MD Dept. of Transportation and CalTrans. Traffic counts and vehicle type will be determined post hoc from the videos. These data will be used in the dispersion models described below.

Immunoassays – Particulates collected in the field will be brought to the laboratory to assess their ability to induce a proinflammatory response in epithelial cells and monocytes, which both have the capacity to profoundly influence the inflammatory response in the lung. The human lung epithelial cell line BEAS-2B, originated from a non-diseased individual, will be seeded into 48 well plates at a concentration of 10^6 cells/ml. The cells will be stimulated with 1% (vol/vol) of concentrated FAP extracted as follows: Filters collected from each sample point at every site in both cities will be separated according to size (PM>2.5 μm –coarse-; 2.5>PM>0.25 –fine-; PM<0.25 –ultrafine-). The area of deposition on the filter will be placed aseptically in eppendorf tubes containing 0.5 ml of DMSO and PBS, respectively. Extraction will be performed by vortexing 5 times for 10 min each, with resting periods of at least 1 h. As controls, we will use the same volumes of DMSO and PBS, as well as prototypical TLR ligands, PAM3CSK4 and LPS. The stimulation supernatants will be collected at 16 h and analyzed by ELISA for the presence of the following: IL-6, TGFβ, TNF and IL-8. The cells will be recovered and used to extract total RNA by standard methodology. The RNA will be then reversed transcribed and used to perform real-time PCR for the same genes plus the gene encoding the lung tissue remodeling factor, amphiregulin (Rumelhard et al, 2007).

The stimulation as described above will be also performed using the same conditions with the human monocytic cell line THP-1. The stimulation supernatants will be analyzed for IL-6, IL-12, IL-1β, TNF and IL-23. RNA will be also extracted and used to perform real-time RT-PCR for the genes encoding the cytokines. The results will be presented relative to volume of air aspirated through the filters as well as the weight of the dry particles. The first expression will reflect the stimulatory effect of the total dose, while the second will reflect the toxicity on a unit mass basis according to exposed surfaces (Schwarze, 2006).

Modeling - We will use our measurements combined with the CFD-VIT-RIT model developed by Zhang to quantify the effects of tree canopies on air pollution dispersion and mixing [86]. We will construct the 3-D computational mesh of the tree canopies, measurement sites and the surrounding areas using ANSYS workbench (version 12, Canonsburg, PA). The tree-canopy-modified turbulent kinetic energy and velocities predicted by the CFD-VIT-RIT will be validated against the turbulence measurements by the sonic anemometer array. Then we will validate the predictions of particle counts, black carbon and NO_2 concentrations against the measured values at our field measurements sites. The performance of the model will be evaluated using normalized mean bias (NMB), normalized mean error (NME), normalized mean square error (NMSE), the fractional bias (FB) and the correlation coefficient (R). After the validation processes, spatial variations of PM and gaseous pollutants predicted by CFD-VIT-RIT will be combined with the results of the immunoassays to translate predictions of canopy affects on PM to the subsequent impacts on biomarkers related to asthma.

Analysis of the planning and redevelopment process. City decision-making affects the distribution of benefits and burdens and how well the collective problems of city residents face are addressed (Elkin,1987). This is a matter of social problem solving. Cities' actions are shaped by the activities of interest groups, business organizations, economic performance (leading to a healthy local economy), the relative autonomy of bureaucracies, state and federal government rules and financing, and race. Our study has the added component of environmental special interests that span a broad spectrum – environmental justice organizations as well more traditional environmental groups that advocate for water quality, open space, and habitat restoration – and their participation in economic development projects. The social science research will map these interests and their potential intersection around what is widely perceived as a win-win project for river revitalization, accompanied by economic development that will offset the monetary costs. Flows of funding, applied for by various sectors, will be analyzed as well as whether the ecology and river restoration discourse is used to conceal other interests in urban development for revenue. We will also evaluate the restoration plans for these rivers from an ecological perspective to determine if the ecosystem services desired by stakeholders are likely to be achieved by the current redevelopment plans. For example, the Los Angeles River was formerly a seasonal river, capable of very high intermittent flow volumes as well as unpredictable shifts in flow paths. Today it is encased in a concrete flood control channel with continuous flow supplied by the local sewage treatment plant. Its "restoration" appears to be represented largely as a recreational amenity, yet it carries significant symbolic value as a natural amenity. To date, the potential impacts of highway pollution appear to be overshadowed by the perception of ecological revitalization. We will develop an analysis of the interplay among ecology (both actual and perceived), politics, pollution hazards, nature and city discourses, and how they are constructed in the plans for revitalization. This research will help reveal the forces and processes behind economic development that is now increasingly framed in terms or urban sustainability. In examining the Los Angeles River and Jones Falls examples, the impacts on human health and the role of revegetation will provide important theoretical additions to more conventional analyses of the forces around economic redevelopment in American cities and the distribution of benefits and burdens.

Integration and synthesis. We will correlate traffic flow with particle counts, black carbon and concentrations of NO and NO_2 based on the real time field observations. We will perform an extreme event analysis on these data to provide estimates of exposure risk to potential triggering events of varying magnitudes (Gumbel, 1941) at specific locations in the landscape. This method is identical to that used for computing statistics like the 100 year flood except that instead of years as the time interval, we use minutes, which is a more appropriate scale for daily human activity. A 6-sec. averaging interval for PM2.5 and a 10-hour sampling period will provide 6000 observations/day, which is more than adequate for deriving the event return period for any given day. The beauty of this approach is that if return period curves for different locations along local dispersion gradients coincide, then relative differences in exposure risk will be the same at each location regardless of the magnitude of the events. A relatively small number of campaigns will allow us to characterize the differential exposure risks at various locations within a site. We will compare our measurements and model results with the local criteria air pollution monitoring conducted by the Maryland Dept. of Environmental Protection and the California Air Resources Board, to determine how widely local ground measurements deviate from regional background.

Our results will ultimately be mapped onto the economic and park development plans for the highway corridors. This will allow us to infer potential health impacts of different scenarios of park and housing development. An important component of this work will be to: 1) compare and contrast the economic redevelopment strategies of Los Angeles and Baltimore; 2) the extent to which these leverage ecosystem revitalization as the basis for organizing new projects; and 3) the role that pollution and highway health hazards play in the planning process. By examining the potential health effects of air pollution and the exposure levels in two different cities, we will determine the extent to which highways pose similar hazards in regions that differ in meteorology, vegetation structure, and development history. Our final products will be to:

- Compare and contrast the history, important institutions and organizations, political and economic factors, and the role of perceived and actual ecological factors that produced current plans for highway/river redevelopment in city
- Produce pollution and exposure risk maps for the highway corridor redevelopment zones
- Develop scenarios for mitigation including vegetation and other barriers to pollution dispersal
- Utilize these results to evaluate the effectiveness of proposed plans for redevelopment and the potential health hazards to residents and users of new environmental amenities.

We will present our results to stakeholders in both cities, both as part of our broader impacts activities but also as a part of our research, which will evaluate the ways in which new scientific information influences the planning process. We have a successful track record of doing so in previous projects (see broader impacts and results from prior support sections).

Education, Outreach & Engagement

Baltimore. The project will recruit one Research Experience for Teacher (RET) fellow each year to join fellows that are part of the Baltimore Partnership for Environmental Science Literacy project being spearheaded by BES. The bulk of the RET fellowship would occur during the summer months. The RET fellow will assist project scientists during periodic field monitoring campaigns, will participate in data reduction and will develop an independent project within this framework. The fellow will develop a classroom application of their research project to use in their teaching working closely with the BES Education Team (Alan Berkowitz, Bess Caplan, others). The lessons developed by the Fellows will become part of a series of RET-generated units available to teachers and other educators not only in Baltimore but globally through the BES website. Fellows acquire strong research skills and a deeper understanding of cutting edge ecology, while contributing to the development of environmental science literacy frameworks and teaching resources for teachers and students in grades 6-12.
Informational meetings will be conducted with local stakeholders in coordination with other outreach and engagement activities of BES. Meetings may be held at the Parks & People Foundation office, or at other locations depending upon the nature of the meeting. Community outreach will be achieved through collaborative partnerships with local schools including Baltimore Polytechnic High School whose property borders the Jones Falls/I-83 corridor. Scientists will partner with science classrooms to expose students to the research components of this project and to facilitate the use of data collected by this project in classroom applications of established and new science lessons.

Los Angeles. The Institute of the Environment and Sustainability has a yearlong problem-solving practicum program for its senior undergraduate students. We will develop a set of research problems associated with this project that will engage 10-15 students who will be involved in coupled research, both assisting in sampling in the field and conducting research on the LA River revitalization projects themselves. Further, the co-PIs have long-standing working relationships with the major environmental and environmental justice organizations in the city who have been concerned with both the lack of public open space in low income communities of color, and the impacts of air pollution due to the major traffic corridors. We anticipate using the umbrella environmental organization Green Los Angeles, to present our research and to solicit feedback. Finally, the Director of the LA Revitalization project is a former student of Dr. Pincetl thus we will be able to interact with the official planning entities for the project.

Bridging. UCLA will employ one postdoctoral social science researcher who will conduct comparative research on redevelopment strategies in Baltimore and Los Angeles, including river revitalization plans and the institutional context creating the possibilities for these approaches. This researcher will assist in organizing the yearlong problem solving practicum programs for the Institute of the Environment and Sustainability. The goal will be to create a blend of strong content preparation and research experiences to provide students with environments of discovery and inquiry-based learning.

Expected Project Significance

Anticipated Intellectual Merit. Highway corridors are integral to the form and function of cities yet we lack an integrated science of highway ecology. Because they are entirely human artifacts and require multiple approaches in order to be understood, they are daunting as foci for ecological study. This is unfortunate because they also possess many attributes often desired model ecosystems. They are linear, mediate fluxes of mass and energy, have input/output nodes arranged as archipelagoes, are distinct from the surrounding matrix, and span recognized environmental gradients. Highway ecosystems also have a profound impact on the human populations occurring within nested zones of influence whose dimensions vary depending on the factor being measured. These ecosystems are thus simple enough to be tractable, complex enough to be interesting and directly relevant to humans. Identifying the links between re-development and human health in these ecosystems raises fundamental issues of causality. For example, emissions from fuel combustion that are proximately deterministic become stochastic when we try to model their dispersion into the atmosphere. This proposal melds deterministic models with empirical observations to predict the effect of vegetated buffers on near highway pollutants. Extending this argument, we will translate model predictions into reliable metrics of human immune response and use these to infer probable health outcomes in relation to various landscape configurations. The final step will be to determine how this understanding affects decisions about the location and forms of re-development interventions. Answering questions like these is central to understanding urban sustainability and applying the emerging practice of translational ecology (*sensu* Schlesinger, 2010).

Anticipated Broader Impacts. This project has strong theoretical and applied components, as we propose to directly assess the effectiveness of current redevelopment plans and the human health hazards of highway and development design. We will be directly disseminating this information to local governments and non-profit agencies, with one public forum in each city as the conclusion of our project. In addition, we have developed specific educational and outreach plans in each city as described above. This project builds on ongoing research efforts supported by NSF: the BES LTER in Baltimore and an ULTRA-Ex in Los Angeles. Additionally, it complements a new multi-city pilot project by the EPA to study roadside NO_2 prior to implementing a recent EPA rulemaking that mandates roadside monitoring. It introduces to BES a novel theme of highway ecology while at the same time complementing long-standing themes of the urban nitrogen processing and the new theme of sustainability included in BES III. The study's links to this broad range of projects will make direct contributions to education and outreach programs in socio-ecological literacy through both formal and informal channels that reach schools, community groups, regulatory practitioners and decision makers. Finally, by sustaining a vital collaboration among ecologists, sociologists, atmospheric scientists and immunologists, it will enrich and enliven discussions both within and among these disciplines.

Management Plan

The multiple aspects of this study will involve sharing of samples and data among the PIs. Specifically, Zhang's preliminary spatial models of pollution dispersion will inform site-specific location of sample points chosen by Whitlow in Baltimore and Pataki in Los Angeles. To close this loop, monitoring data from both cities will need to be sent to Zhang for refined modeling. Data from periodic field campaigns will be sent to Whitlow for return period analysis and the interpretation will be the responsibility of both Whitlow and Pataki. Particulate samples from both Baltimore and LA will be sent to Anguita for human biomarker analysis and Pataki for isotope analysis. Plant samples collected by Whitlow in Baltimore will be sent to Pataki for isotope analysis. The combined results will need to be interpreted and understood by the entire team. Similarly, the socio-political dimensions explored by Pincetl in both cities will have implications relevant to all team members. Education and outreach on both coasts will require close integration of the science with the messages. All of this depends on open reciprocity among team members. This may pose some logistical hurdles, but we believe that a novel interdisciplinary synthesis of highway ecosystems will be catalyzed by these interactions. This will be best supported by shared ownership and joint authorship of all publications that result from this study.

Dr. Thomas Whitlow (Cornell) is a physiological plant ecologist who has worked extensively with plants in human dominated urban landscapes. His background includes studies of intra-specific variation in drought and flood tolerance in trees, adaptive traits of trees and shrubs growing in the coastal strand, and invasion biology. He has adapted gas exchange methods to design and fabricate a wind tunnel capable of quantifying real time deposition of fine and ultrafine particulates to leaf surfaces. He initiated a collaboration with Zhang and Anguita in 2006 to develop rapid deployment field methods to determine the impact of traffic and vegetation on local particle dispersion and the use of cytokines as biomarkers for particulate air pollution. He is one of many co-PIs in the most recent renewal of the Baltimore Ecosystem Study LTER, BES III. Whitlow will oversee the overall project execution, convene quarterly teleconferences among the co-PIs, organize annual team meetings of the PIs in conjunction with NSF sponsored CNH workshops, act as liaison with the West Coast team, coordinate and compile progress reports and act as liaison with collaborators in federal agencies, including the EPA and Federal Highway Administration. In addition, he will lead field campaigns in Baltimore, cooperate with BES co-PIs on Baltimore based activities, and co-direct a PhD student at Cornell in conjunction with Zhang.

Dr. Diane Pataki (UCI) is an ecologist with a background in physiological plant ecology and land-atmosphere interactions. She previously led an NSF-Biocomplexity study of coupled human-natural interactions influencing CO_2 sources and sinks in the Salt Lake City metropolitan region. She has collaborated with Pincetl to study urban tree water use, water relations, forest-climate interactions, and urban ecosystem services in a now completed NSF-HSD and an ongoing NSF-DEB and ULTRA project. She also has extensive experience in stable isotope ecology and the radiocarbon content of urban plants (see Results from Prior). Pataki will be responsible for all of the isotope measurements in this project, which will be conducted at the UC Irvine Isotope Ratio Mass Spectrometry Facility. She will serve as the Los Angeles project liaison, will collaborate with Whitlow to design and interpret the vegetation surveys and estimates of canopy structure and leaf area (Baltimore and LA), and will oversee the team that will measure air pollutants in Los Angeles using Whitlow's methods.

Dr. Stephanie Pincetl (UCLA) studies the politics and institutions of urban planning and natural resource management. She has worked extensively on land use history and impacts on resource management in California (Pincetl 1999). Her Urban Center on People and the Environment has conducted a number of studies on policy implementation in the city of Los Angeles, southern California and the state. She currently leads the NSF-ULTRA study on urban socio-ecohydrology in Los Angeles, and led the NSF-HSD study of the LA Million Tree Initiative. She will conduct the social science research component analyzing the redevelopment process and planning in Los Angeles and Baltimore, and will work with the other PI's to integrate their results into comparing and contrasting the planning process with the perceptions of redevelopment by stakeholders.

Dr. Juan Anguita (UMass) is an immunologist focused on the mammalian host immune defense against infection by the spirochete causing Lyme disease, *Borrelia burgdorferi* and immune responses to atmospheric particulates. His group has extensive experience in murine macrophage biology particularly in response to Bb. He has collaborated with Whitlow to test the proinflammatory capacity of fine and ultrafine particulates collected in urban locations. In this project he will be responsible for conducting immunoassays using particulates collected in Baltimore and Los Angeles.

Dr. K. Max Zhang (Cornell) is an environmental and energy systems engineer who measures and models spatial and temporal variations of air pollutants in urban areas. In particular, he aims to develop a mechanistic understanding on near-road air pollution and potential mitigation strategies. He has been conducting air quality projects in Los Angeles, New York City, Rochester, NY and Beijing, China. In this study, he will work with Whitlow on field campaigns and model dispersion and transformation of pollutants to quantify the effects of vegetation on near-road air quality.

<u>The Cary Institute of Ecosystem Studies</u> has four scientists participating in this project. *Dr. Peter Groffman* is Deputy Director of the Baltimore Ecosystem Study urban Long Term Ecological Research Project and oversees long-term watershed and terrestrial plot studies. He has expertise in soil microbial ecology with a focus on carbon and nitrogen transformations. *Dr. Alan R. Berkowitz* is Head of Education at the Cary Institute of Ecosystem Studies. He develops curricula for K-12 classrooms, leads workshops and research experiences for teachers, does research into how students learn ecology and directs the Institute's program in independent research for undergraduate students. He has extensive networks and expertise for integrating environmental research into Baltimore City and County school curricula and professional development programs. *Ms. Bess Caplan* is the Ecology Education Program Leader for the Baltimore Ecosystem Study. She coordinates opportunities for Baltimore youth to learn about urban ecology, helps teachers integrate ecological inquiries into their curriculum and provides opportunities for teachers to conduct scientific research with BES scientists. *Dr. Neil Bettez* is a postdoctoral fellow at the Cary Institute of Ecosystem Studies. He has expertise in terrestrial ecology with a focus on nitrogen deposition and nutrient cycling.

<u>Results from Prior NSF Support</u>

Pataki was the PI on BCS 0620176, "The spatial distribution of isotopic tracers in urban organic matter: Understanding multiple and confounding effects of human activities on urban vegetation," 8/1/06 – 1/31/10, $299,914. The goal of this project was to map multiple isotope and chemical tracers in urban plant and soil samples and relate their spatial distribution to environmental factors. A common problem in studies of urban ecology and ecosystem services is understanding the effects of many interacting and confounding environmental disturbances such as different types of pollution, management strategies, and altered climate. This project involved landscape-scale sampling of urban organic matter as well as smaller-scale, process-level studies that greatly informed our understanding of urban ecological processes in the Los Angeles Basin. Four journal publications (Bijoor et al. 2008, Riley et al. 2008, Djuricin et al. 2010, Wang and Pataki 2010a) and 1 book chapter (Pataki et al. 2010b) have been published, and several more are in review. The study also produced 7 conference presentations and 3 undergraduate student theses, and contributed to 2 completed and 2 ongoing Ph.D. dissertations. Broader impacts included presentations to K-12 and community college teachers during training workshops, a presentation to high schools students in a program for underserved communities in Los Angeles, and a presentation to state policy makers at a meeting of the California Energy Commission.

Pincelt was the PI on NSF HSD 0624177 Collaborative Research: A study in the dynamics of human behavior in institutional innovation and learning. 9/1/06 – 8/31/09, $758,712. PI's Pincetl, Saatchi, Pataki, Saphores. This project, which was just completed, focused on the Los Angeles Million Tree Initiative as a case study for basic research on impacts of a large-scale tree planting program on local greenhouse gas mitigation and climate, economic valuation of the costs and benefits of these services, and the coupled dynamics of environmental and institutional changes. The project consisted of an institutional social learning study of the Los Angeles city government and agency and NGO partners conducted by Pincetl, economic valuation of ecosystem services conducted by Saphores, estimation of urban tree water use and carbon sequestration by Pataki, remote sensing of the urban canopy by Saatchi, and analysis of historical data by Gillespie. The overall goal was to determine how complex systems involving urban ecosystems, social organizations, and individuals grow, learn, and change in reaction to environmental problems. In our broader impacts, we disseminated our results directly to the Los Angeles city government and to the non-profit tree planning organizations in two different sessions, one at City Hall that was attended by government agencies and non-profits, and one at UCLA that also included university students. We also conducted a seminar on urban tree physiology and monitoring for a group of high school students working as summer interns with a tree planting non-profit organization, and provided them with career counseling on urban ecology related fields. We also trained 5 at risk youth employed by the Los Angeles Conservation Corps that trains youth between 18 and 24. One of our post-doctoral students developed the curriculum and the youth learned tree identification, how to measure tree functions in the urban environment, and how to input the data into spreadsheets linked to a program that calculates tree values in the urban environment. The project supported 14 graduate students, 2 post-doctoral researchers, and 15 undergraduate researchers, and resulted in 10 publications.

PROJECT CHRONOLOGY

Year One

Establish the theoretical social framework for analyzing the projects

- Urban theory
- Redevelopment
- Ideas of urban nature
- Sustainability
- Environmental justice
- Political Economy and Ecology

- Develop history of each place (1945 to present)
  - Urban development
  - Flood control
  - Freeway and highway development
  - Local urban and industrial development policies and politics

Perform initial atmospheric dispersion modeling
Establish transects at each sample location

- Perform canopy analysis

Conduct quarterly monitoring campaigns, lab analyses and data reduction

- Real time monitoring
- Biomarker analysis
- Passive sampling: NO, NO_2
- Legacy samples: soil and leaf isotopes

Engage local teachers; contribute to Ecological Literacy projects
Analyze biophysical data
Bi-monthly team teleconferences; annual team meeting
Participate in BES annual Open House

Year Two

Examine and analyze contemporary plans for river restoration/revitalization and driving forces

- Environmental groups and organizations
- Development interests
- Local political interests
  - Document funding streams for plans
  - Examine locations and freeway adjacencies
  - Couple findings with biophysical analyses
  - Direct undergraduate student research

Conduct quarterly monitoring campaigns, lab analyses and data reduction

- Real time monitoring
- Biomarker analysis

- Passive sampling: NO, NO_2
- Legacy samples: soil and leaf isotopes

Analyze biophysical data
Curriculum development, classroom involvement
- Contribute to Environmental Literacy Projects

Bi-monthly team teleconferences; annual meeting
Revise dispersion models
Participate in BES annual Open House
Synthesis: First Approximation
- Evaluate progress

Begin manuscript preparation
Annual progress reporting

<u>Year Three</u>
Conduct quarterly monitoring campaigns, lab analyses and data reduction
- Real time monitoring: NO, NO_2
- Biomarker analysis
- Passive sampling
- Legacy samples: soil and leaf isotopes

Analyze biophysical data
Curriculum development and classroom involvement
Bi-monthly team teleconferences; annual meeting
Revise dispersion models
Participate in BES annual Open House
Synthesis: Second Approximation
- Evaluate progress

Annual progress reporting

Submit manuscripts for peer review