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Incompatible Land Uses and the Topology of Cumulative Risk

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ABSTRACT / The extensive literature on environmental justice has, by now, well defined the essential ingredients of cumulative risk, namely, incompatible land uses and vulnerability. Most problematic is the case when risk is produced by a large aggregation of small sources of air toxics. In this article, we test these notions in an area of Southern California, Southeast Los Angeles (SELA), which has come to be known as Asthmatown. Developing a rapid risk mapping protocol, we scan the neighborhood for small potential sources of air toxics and find, literally, hundreds of small point sources within a 2-mile radius, interspersed with residences. We also map the estimated cancer risks and noncancer hazard indices across the landscape. We find that, indeed, such large aggregations of even small, nondominant sources of air toxics can produce markedly elevated levels of risk. In this study, the risk profiles show additional cancer risks of up to 800 in a million and noncancer hazard indices of up to 200 in SELA due to the agglomeration of small point sources. This is significant (for example, estimates of the average regional point-source-related cancer risk range from 125 to 200 in a million). Most importantly, if we were to talk about the risk contour as if they were geological structures, we would observe not only a handful of distinct peaks, but a general ``mountain range'' running all throughout the study area, which underscores the ubiquity of risk in SELA. Just as cumulative risk has deeply embedded itself into the fabric of the place, so, too, must intervention seek to embed strategies into the institutions and practices of SELA. This has implications for advocacy, as seen in a recently initiated participatory action research project aimed at building health research capacities into the community in keeping with an ethic of care.

In every large metropolitan area, there arise choice places to which flock residents and business owners who can pay a premium for them. These places are not hard to miss, and one need only scan the real estate section of the local dailies to get a sense of where they are. At the same time, there arise within the same metropolitan area, places that develop as a residual category for the less well-heeled buyers and lesser-valued land uses. These lesser-valued places arise in the interstices between choice areas, in the periphery of the metropolis, or somewhere deep in its inner core (see Alonso 1964, Anas and others 1998, Martinez 1992, Vandell 1995, Wei and others 2000 for an account of these land use dynamics).

These lower-valued places exist not just as a residual for more marginal land uses, but they also serve as recipients of the various externalities that have been pushed out of the choice areas (Liu 1997, Lai 2003). Some of these externalities occur as land uses that serve the larger metropolis and yet are not allowed in the higher valued areas; these include businesses such as recycling facilities, junkyards, truck depots, storage warehouses, power plants, and others. In many of these cases, these types of land uses sit close to, or even beside, residences. The phenomenon of incompatible land use regimes is thought to expose residents to undue risks due to air and water pollution, noise, physical hazards, and traffic due to normal operation of these types of businesses (Bolin and others 2002, Bullard and others 1997, Buzzelli and others 2003, Pastor and others 2005, Rhodes 2003). By land use regime, we refer to the mix of residences, businesses, and industrial facilities allowed to occur side by side because of the local zoning ordinances. Incompatibility simply refers to any nuisances or other negative impacts posed by one of these uses to nearby others. In this article, we focus on the dimension of incompatibility posed by air toxics emissions from commercial and industrial facilities to nearby residents.

The environmental justice literature points out that these places are not simply the result of a land use

KEY WORDS: Cumulative risk; Risk assessment; Air toxics; Environmental justice

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*Author to whom correspondence should be addressed; *email:* rplejano@yahoo.com market portioning out land uses according to supply and demand; it is also the result of choices (whether made deliberately or unknowingly) by local officials, business owners, and developers [see Pulido and others (1996) and Broome and Modarres (1999) for historical accounts]. Just as the choice areas are consciously nurtured and supported, so, too, are the residual areas chosen and deliberately allowed to take these types of noxious land uses. The form of disparate treatment may take the form of more lenient zoning, more permissive site requirements, lesser code enforcement, and outright subsidies for these types of businesses to set up shop in these areas (Congleton 1996, Pastor and others 2005). In addition to incompatible land uses, the literature speaks to another ingredient in the recipe for environmental injustice: vulnerability. That is, in these same places where the more noxious facilities gravitate, there tend to reside families and individuals who are the most vulnerable to injuries from these facilities. Vulnerability, in this case, is characterized by lack of means for avoiding or minimizing risks, and this includes poverty, social or political disenfranchisement, lack of health care access, immigration status, language barriers, and others. There is, by now, ample evidence from the environmental justice literature showing the disproportionate siting of noxious facilities in vulnerable areas, particular areas of lower income and higher proportion of minority residents (Cutter 2001, Kriesel and others 1996, Lejano and Iseki 2001, Mohai and Bryant 1992, Neumann and others 1998, Pastor and others 2004, Sadd and others 1999, Satterfield and others 2004).

Although the logic of the environmental justice narrative is clear enough, there is still need to more clearly describe how vulnerability and incompatible land use intersect. This is straightforward enough when a community is protesting a single, large source of pollution. An example of the latter is a recent campaign of Communities for a Better Environment (CBE), an environmental justice advocacy group, which teamed up with residents in Santa Fe Springs, California, to successfully block the construction of the new CENCO power plant. In this case, the potential risks due to the new facility were plain enough, and there were ample studies and documents (e.g., the environmental impact report) to use in making the case against the facility. More problematic, however, is the case when the community is beleaguered by a large agglomeration of small potential sources of risk, none of them large enough to warrant a study on its own, but all of them potentially adding to significant cumulative risk. In the rest of this article, we will refer to these as small potential generators of air toxics as minor sources. These facilities do not show up in the Federal TRI (Toxics Release Inventory) database, because they all fall below the TRI reporting threshold (i.e., production of at least 25,000 pounds of a toxic compound per year, otherwise use of at least 10,000 pounds per year of the same, or total employee work hours of at least 20,000 a year; according to the Emergency Planning and Community Right-to-Know Act, 40 CFR 372). Cumulative risk has been described as the phenomenon of risk that arises from exposure of a receptor to multiple pollutants from multiple sources from possibly multiple pathways (USEPA 2002).

In this article, we study in depth the nature of land use in one such area of California known as Southeast Los Angeles (SELA). For reasons that will be clear enough, this area has also been dubbed by some advocates as Asthmatown (Bansal and others 1998). In SELA, we find exactly the phenomenon described above, a large agglomeration of small potential sources of toxics, almost all of which are small enough not to be regulated by the South Coast Air Quality Management District (SCAQMD). We will study how this pattern of land use leads to elevated cumulative risks. Lastly, we examine how the nature of the risk profile affects the strategy of groups such as CBE.

Present regulations do not require risk assessments or environmental impact reports for these minor sources. Similarly, these are the types of small businesses that are not required to conduct any environmental monitoring that might provide us with some idea of emissions. In short, no agency compiles information that might be used to monitor or estimate the types of risks that may build up from many such minor sources clustering together. It is the subtle, insidious effect of the reporting threshold that allows relatively small potential sources of risk to be located in an area, and this process is repeated time and again with no review of potential cumulative risk or consideration of risk reduction measures. In most cases, there is little thought given to the potential for incompatibility with regard to air toxics exposures in nearby residential areas. Although there has been enough work on the aspect of siting noxious facilities (see Boer and others 1997, Bansal and others 1998, Szasz and Meuser 2000, Morello-Frosch and Pastor 2001, Lejano and others 2002, CARB 2004, which talk about environmental justice issues in Southern California), it has not been shown exactly how serious the risks might be from smaller, minor sources, most of which are not regulated by the local air quality agency.

We developed a rapid risk-mapping procedure that allows us to reconstruct a spatial cumulative risk map of SELA. The reconstructed topographic map of risk allows us to visually assess the potential impacts to residents in SELA from hundreds of local, minor sources. It provides us with a sense of the magnitude and prevalence of these elevated zones of risk. Importantly, the rapid assessment procedure affords us a tool by which to begin quantitatively linking land use patterns to potential risk.

Context and Method

Cumulative risk is a complex phenomenon that begs a closer analysis. This requires that we study a particular context, and the area we have chosen is the neighborhood of Southeast Los Angeles (SELA) in California, USA. SELA is composed of eight municipalities—a misleading description, because these ''pocket'' municipalities (Bell, Bell Garden, Commerce, Cudahy, Huntington Park, Maywood, South Gate, and Vernon) are so small that their aggregate area is dwarfed by the nearby City of Los Angeles. The SELA region is particularly intriguing because of its recent shift in demographic composition, explosive growth of small manufacturing plants, and resultant health risks to workers and residents. The area, the residential population of which was predominantly white two decades ago, now consists almost entirely of Latino residents, a large cross section of this population being recent immigrants. Running through SELA is the 710 freeway, which is the main thoroughfare linking the Los Angeles/Long Beach Ports to the rest of the mainland and the Alameda Corridor, along which freight trains travel to and from the Ports. Aside from exposure to diesel emissions on I-710, residents in SELA are beleaguered by the confluence of hundreds of small, rail-related light industries that collectively generate nuisance conditions and cumulative health risks.

SELA has the characteristics of the classic environmental justice situation. If we exclude Vernon (which is an outlier having only 91 residents), we find that median household incomes across these small municipalities range from $28,941 to $35,888 a year, compared to $46,452 for the entire Los Angeles County. It is largely a community of color, with the Latino population ranging from 82.3% to 96.3% of the residents, compared to 44.5% for the County (U.S. Bureau of Census 2000). Importantly, SELA hosts a bewildering array of small- to medium-sized industrial and commercial uses, many of these related in some way to the Ports, I-710, and the Alameda Corridor. This mix of noxious land uses has caused some advocates to call SELA Asthmatown (Bansal and others 1998). Although claims of elevated asthma and other health effects are largely anecdotal, there have been some limited studies of these effects in SELA to date, and these do largely support the suspicion that health issues are serious (e.g., see Delfino and others 2002; CBE 2005).

We will focus on one particular area in SELA that seems to be particularly inundated by minor sources existing adjacent to or inside residential areas. The study area is the municipality of Huntington Park in SELA. Huntington Park is almost completely Latino (at 95.6% of the population) and lower-income (with the median household income at $28,941 per year) (U.S. Bureau of Census 2000). Less than 20% of the city residents are registered voters (NAPS 2003). It is a dense residential area, merely 3 square miles, in which is found a large number of small- to medium-sized businesses. In other words, the place, at least ostensibly, seems to be a classic site for environmental justice concerns. We illustrate this with an overlay map, prepared with Arcview, in which we construct a composite measure of elements of vulnerability and map this over Los Angeles County. The elements are a little arbitrary, but for purposes of illustration, we map the following: median household income, race, language, juvenile population, and age of housing. The darker the shade of gray, the more the area corresponds to the classic environmental justice setting.

The analysis involves estimating air toxics emissions for the hundreds of minor sources, most of which are not regulated by the SCAQMD, that are found in the fairly small area of Huntington Park. In order to do this, we develop a rapid risk mapping procedure that allows us to systematically develop emissions estimates for these minor sources. We then model the dispersion of these emissions throughout Huntington Park and map the resulting risk contours.

The researchers began working with groups in SELA, particularly CBE, as part of a grant-funded project with First 5 LA on health linkages to the school readiness of children in the 0–5-year age range. The risk mapping conducted herein is being used by the research partners to assess risks in the area and to begin developing intervention strategies. The first part of the analysis involves obtaining addresses for businesses in the area from the Dunn and Bradstreet database and geocoding the same into a Geographic Information System (GIS) map. Of these businesses, we select those belonging to Standard Industrial Classification (SIC) codes that have been historically associated with air toxics emissions in the TRI (Toxics Release Inventory) database. The resulting mapping of potentially risk-bearing facilities in Huntington Park, which constitutes the study area, is shown in Figure 1. It is evident, at this scale, the kind of agglomeration of small potential

Figure 1. Map of study area (Huntington Park, California) showing minor sources of air toxics.

sources of air toxics that is found in Huntington Park. It provides a graphic illustration of what land use patterns look like that might lead to cumulative risk.

We then zoom in further and examine the pattern of land use on the scale of the block (i.e., one representative 12-block area in Huntington Park). At this level of specificity, we obtain even greater insight into the specific land use patterns that can lead to cumulative risk. To carry this out, we surveyed land uses in the 12-block area on foot and subsequently geocoded and mapped the data on GIS. This is done simply to illustrate the extent to which incompatible land use is embedded in the very fabric of the residential communities in SELA.

The main part of the analysis entails estimating the type of risks that can accrue due to the agglomeration of minor sources. In order to do this, we developed unit estimates of air toxic emissions for each SIC code using the following procedure.

First, we developed a dataset that estimates an average amount of emissions per employee for industries throughout Los Angeles County. These emission factors were used to estimate standardized toxic air releases for specific Huntington Park employers. A similar approach was employed by Dolinoy and others (2004) for a single pollutant and by Kolodziej and others (2004) for soil toxics. In this article, we generalize this to cover all carcinogenic and noncarcinogenic air toxics emitted by point sources in the area. The rapid risk-mapping methodology developed for this research is designed to produce estimates of cumulative risk and the cumulative hazard index from multiple sources of air toxics.

Estimating Unit Toxics Emissions for Different SIC Codes

In this section, we describe how we utilized the TRI and D&B datasets to develop estimates of per capita emissions of various toxics for different types of industrial and commercial facilities (identified by SIC code) found in Los Angeles County.

The dataset was developed using four input data tables: a 2004 D&B Enhanced Telemarketing Los Angeles County employer dataset (downloaded November 23, 2004; N = 40,742); a 2002 reporting year nationwide TRI dataset (high-level summary downloaded from RTK.net; N = 261,274); a table of benzene carcinogen chemical (N = 276) toxic equivalency potentials (TEPs) (OEHHA 2004); and a table of toluene noncarcinogen chemical (N = 79) conversion factors (OEHHA 2003).

We obtained unit emission factors (normalized on a per employee basis) for a large number of four-digit SIC codes in the TRI dataset. To allow some comparison of the relative toxicities of different SIC codes, we also calculated equivalent benzene and toluene TEPs. Air toxic unit risk factors (URFs) for the carcinogens

Table 1. Estimated annual emissions in benzene and toluene equivalents for US firms by selected four-digit SICs, 2002

	Estimated annual emissions, toluene toxic equivalents					
SIC[a]	Facility count	Mean (lb)	SD	Facility count	Mean (lb)	SD
2099	24	1138	1813	62	293,185	845,723
2511	19	166	484	174	10,575	15,153
2752	20	80	288	116	38,643	136,583
3089	71	1351	8955	839	27,144	219,612
3471	115	689	1369	207	110,575	369,648
4953	513	10,293	181,546	795	25,682	240,712
5169	266	81	795	1713	7345	105,833

Data source: 2002 EPA TRI; OEHHA 2003 and 2004.

[a]2099 Food preparations; 2511 Wood household furniture, except upholstered; 2752 Commercial printing, lithographic; 3089 Plastics products; 3471 Electroplating, plating, polishing, anodizing, and coloring; 4953 Refuse systems; 5169 Chemicals and allied products.

Table 2. Descriptive statistics of on-site employment by Los Angeles firms by selected four-digit SIC and per capita TEPs, 2002

	Per capita TEPs				
SIC[a]	Facility count	Mean (employees)	SD	Benzene	Toluene
2099	165	29	45	38.7	9972.3
2511	182	22	45	7.6	485.8
2752	1314	12	35	6.9	3323.5
3089	363	34	61	39.2	786.9
3471	332	23	55	29.9	4794.4
4953	458	14	32	710.5	1772.8
5169	355	10	22	7.8	700.5

Data source: Dun and Bradstreet 2004.

[a] 2099 Food preparations; 2511 Wood household furniture, except upholstered; 2752 Commercial printing, lithographic; 3089 Plastics products; 3471 Electroplating, plating, polishing, anodizing, and coloring; 4953 Refuse systems; 5169 Chemicals and allied products.

and reference levels (RELs) for the noncarcinogens were obtained from the Office of Environmental Health and Hazard Assessment (OEHHA) database (OEHHA 2003, 2004). We then averaged the benzene- and toluene-weighted air releases by SIC. Note, however, that the calculation of TEPs is only for comparison of SIC codes relative to each other; otherwise, the dispersion modeling estimates ambient concentrations for each individual air pollutant. Cancer risk is then calculated by multiplying each carcinogen by its corresponding URF, and hazard index is calculated by dividing each noncarcinogen concentration by its corresponding REL. The total cancer risk and total hazard index are then obtained by summing across the individual pollutants.

Because the TRI does not provide information on the total number of employees by firm, average on-site employee estimates by SIC were therefore calculated using firm-level data in the D&B dataset. Unit emission factors or per capita TEPs were then calculated by dividing the mean SIC-specific benzene- and toluene-weighted air releases by the average number of employees within that SIC. Tabulated in Table 1 are descriptive statistics for the annual emissions estimates and in Table 2 employment estimates in the national TRI database for those four-digit SIC codes that are most common in Huntington Park. The standard deviations for the unit emission factors cannot be calculated because we do not have employee data for all of the firms represented in the TRI, although it is presumable that much of the variance seen in the emissions found in Table 1 is due to the variance in size of firm (as measured by number of employees in Table 2).

Estimating Cumulative Risks from Local Sources in Huntington Park, California

The D&B dataset was used to provide a list of firms in Huntington Park that belong to industries that are ordinary sources of air toxics. More specifically, a total of 579 Huntington Park firms represented in the D&B dataset are distributed across 184 unique four-digit SICs or industry sectors monitored by the EPA's TRI pro-

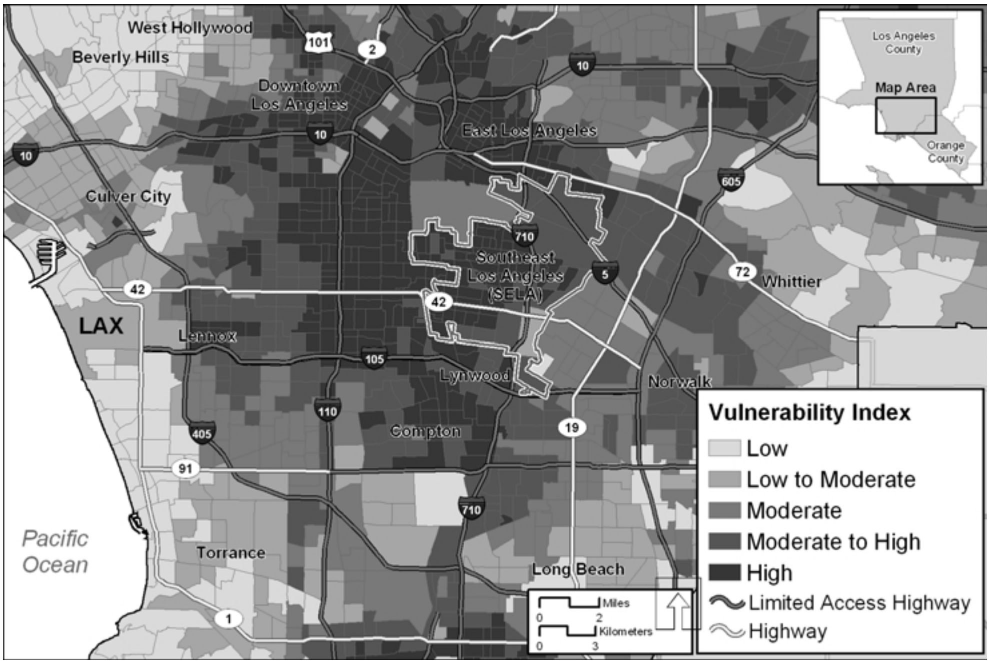

Figure 2. Overlay mapping of components of vulnerability (Southeast Los Angeles compared to the rest of Los Angeles County).

gram (Figure 2). These businesses include: manufacturing (Standard Industrial Classification (SIC) codes 20 through 39); Metal mining (SIC code 10, except for SIC codes 1011, 1081, and 1094); Coal mining (SIC code 12, except for 1241 and extraction activities); Electrical utilities that combust coal and/or oil for the purpose of generating electricity for distribution into commerce (SIC codes 4911, 4931, and 4939); Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste treatment and disposal facilities (SIC code 4953); Chemicals and allied products wholesale distributors (SIC code 5169); Petroleum bulk plants and terminals (SIC code 5171); Solvent recovery services (SIC code 7389 limited to facilities primarily engaged in solvent recovery services on a contract basis). For each firm in Huntington Park, their respective number of employees was multiplied by the per capita TEPs (benzene and toluene) for the corresponding SIC code to obtain an estimate of the potential rate of emissions of air toxics for each firm (Table 3). In all, 410 minor sources of carcinogenic air toxics and 498 minor sources of noncarcinogenic air toxics were found in the study area.

We then modeled the transport of these potential emissions by entering all the source data into ISCST3, a nearfield air dispersion model. We utilized hourly wind data for a nearby weather station in Vernon, California and modeled pollutant levels over a 30 × 30 Cartesian grid with each node spaced 300 m apart over the Huntington Park area. The dispersion model provides pollutant concentrations over the study area grid. The concentrations of carcinogens were then converted to risk and noncarcinogens converted to hazard index as previously described. The cancer risk and hazard contours were then plotted on Arcview, and three-dimensional images were prepared using Surfer.

In addition, emissions from the nearby I-710 freeway were modeled to estimate the additional risk burden due to the freeway. Estimated emission rates of carcinogenic and noncarcinogenic air toxics were developed by multiplying vehicle traffic rates by per vehicle unit emissions of pollutants. The average daily traffic levels were obtained from the California Department of Transportation (CALDOT 2000, 2001). Unit emission factors for cars and trucks were obtained from USEPA (1992) and CARB (2000), respectively. Emissions from diesel trucks were modeled as particulate emissions composed of two size fractions, 5% of the mass fraction assumed to be 0.1 micron in diameter, and the rest of the mass fraction assumed to be 1.0 micron, as suggested by results from Morawska and others (1998).

Results and Discussion

When we map indices of vulnerability across Los Angeles County, we find SELA to be among those few areas where all the classic elements of vulnerability are found. Vulnerability, defined as ‘‘combined risks from aggregate exposures to multiple agents or stressors’’

Table 3. On-site employment characteristics and estimated annual emissions in benzene and toluene equivalents for Huntington Park firms by two-digit SIC

		On-site employment characteristics		Estimated annual emissions, benzene toxic equivalents		Estimated annual emissions, toluene toxic equivalents	
SIC[a]	Facility count	Mean (employees)	SD	Mean (lb)	SD	Mean (lb)	SD
2099	10	43	65	1645	2502	423,823	644,623
2511	13	38	61	285	463	18,236	29,572
2752	15	3	2	22	11	10,635	5210
3089	13	19	17	748	670	15,012	13,448
3471	17	11	13	331	395	53,020	63,276
4953	12	18	21	12,967	15,085	32,354	37,638
5169	12	27	48	207	375	18,622	33,651

Data source: Adapted from 2002 EPA TRI; OEHHA 2002 and 2003; Dun and Bradstreet 2004.

[a] 2099 Food preparations; 2511 Wood household furniture, except upholstered; 2752 Commercial printing, lithographic; 3089 Plastics products; 3471 Electroplating, plating, polishing, anodizing, and coloring; 4953 Refuse systems; 5169 Chemicals and allied products.

(USEPA 2002), is more explicitly defined in terms of socioeconomic status and its mediating role in environmental risk exposure (Evans and Kantrowitz 2002). Although vulnerability is not an objective measure, a review of the, by now, voluminous literature on environmental justice (e.g., see USGAO 1983, UCC 1987, Bullard 1990, Lavelle and Coyle 1992, Been and Gupta 1997, Boer and others 1997, Mohai 1996, Morello-Frosch and others 2001, Lejano and Iseki 2001, among others) has consistently brought up the same elements repeatedly: lower-income communities of color, often characterized by aging housing stock and a high percentage of children in the population. When we map a composite of these variables across the County, we do see how SELA is among those places that rate particularly high in these correlates of vulnerability (Figure 2). Note, however, that there is no one single way to measure vulnerability (e.g., we could have used purchasing power instead of median household income), and that the concept is used for illustration's sake and not as a precise index. The point is not to single out these places and categorize them in this manner, but to seek out areas where the greatest and most urgent needs for intervention exist.

When we produce a similar mapping of toxics-generating land uses for a ''comparison area,'' we get a sense of how inundated Huntington Park is with sources. The comparison area we chose is that of nearby Lynwood, which is of a slightly higher median income bracket and somewhat lower Latino resident population; in other words, Lynwood appears less vulnerable than Huntington Park. The mapping for Lynwood is seen in Figure 3, which shows a much less dense agglomeration of risk-generating land uses. Figures 1, 2, and 3 illustrate a point made in the voluminous environmental justice literature, which is that noxious facilities aggregate more densely in the more vulnerable areas.

We get an even greater sense of how small sources of air toxics are embedded in the fabric of the residential areas of SELA. In Figure 4, we take one small representative area, the northernmost portion of Huntington Park, and map its land uses on a parcel-by-parcel basis. It is easy to see how prevalent the phenomenon of incompatible land use is in Huntington Park. In this specific case, we see how the local zoning code allows a mix of commercial, light-industrial, and residential uses even within the same block. The commercial and industrial areas pose potential air toxics exposures to the nearby residents, e.g., from the truck parking lot. These contribute to the cumulative risk profiles described below.

The major portion of the analysis concerns estimated risk levels in the study area, Huntington Park (Figure 2). The resulting cumulative risk maps for Huntington Park are shown in Figures 5 and 6. It is important to explain exactly what these figures represent. Figure 5 depicts the cumulative cancer risk, over a lifetime of exposure, due to the joint action of hundreds of small, potential sources of carcinogenic air toxics in the vicinity of Huntington Park. The units are on a per million basis. For example, a ''peak'' that corresponds to a measure of 400 on the vertical axis represents a cumulative lifetime risk of 400 in a million (also expressed as 400×10^{-6}) to residents living at that point *due to air toxics emissions from local sources.* These are additional cancer risks due only to the small point sources we modeled, and it is important to note that the total cancer risk to residents would be considerably higher, because people are exposed to carcinogens from many more sources than the small, minor sources being modeled (e.g., the background cancer risk due

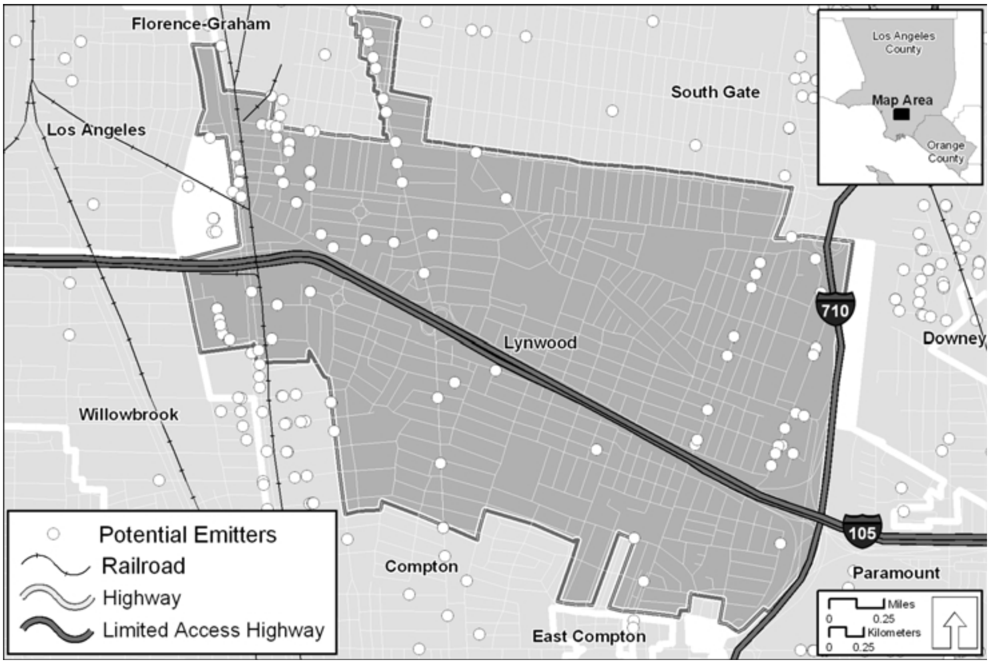

Figure 3. Map of comparison area (Lynwood, California) showing minor sources of air toxics.

to food and drinking water or the regional background levels of air toxics are not included herein). In general, the threshold of what constitutes a significant risk is the Federal guideline of one in a million (1×10^{-6}), as found in Section 112(f)(2) of the reauthorized Clean Air Act (40 CFR 63). In Southern California, however, the SCAQMD applies a less stringent threshold of 25 in a million for existing sources, as set in Rule 1402 (SCAQMD 2000a). In either case, whether we use a threshold of one in a million or 25 in a million, we see that cumulative risks due to small, point sources in Huntington Park are well above these levels over most of the vicinity. Of course, the present threshold of 25 in a million would not require the SCAQMD to act on the level of risk in this case, because these thresholds (as well as the Federal guideline) have thus far only been applied to specific facilities, and not to the cumulative effect of multiple facilities.

Figure 6 depicts the cumulative effect of the agglomeration of hundreds of small, potential sources of noncarcinogenic air toxics. The units are expressed in terms of the hazard index, which is the ratio of the pollutant's concentration to the reference exposure level (the latter being the No Observed Adverse Effect Level of the chemical divided by a suitable safety factor). For example, a ''peak'' of 14 means a total hazard index of 14 to residents living in that area. In the Southern California air basin, the regulatory threshold for hazard indices is three (or HI = 3) for existing sources as set in Rule 1402 (SCAQMD 2000a); this threshold is presently applied to individual point sources, but is useful here as some sort of rough gauge of the level of severity of cumulative risk. As we see in Figure 6, the cumulative hazard index due to small, point sources exceeds this level over most of the general vicinity of Huntington Park.

What Figures 5 and 6 represent is significant. It is the link between land use patterns in Figure 1 and the risk contours in Figures 5 and 6 that illustrates how the aggregation of minor sources can translate to elevated areas of cumulative risk. This provides some validation of the claims of environmental justice advocates who maintain that the agglomeration of many, even small, sources of air toxics can create serious cumulative risks. The figures show a number of distinct peaks, corresponding to the handful of larger point sources (or clusters of point sources) in the study area. However, more meaningful is the fact that, even when we ignore the peaks (or assume that regulatory action will eliminate these), the rest of the vicinity is still generally characterized by ''hills'' and elevated plains all throughout the landscape, particularly with regard to the risk map shown in Figure 5. Even if we removed the few highest emitters in Huntington Park, the resulting ''topography'' of risk would essentially remain that shown in Figure 5. In other words, the phenomenon of cumulative risk in Huntington Park is a general and ubiquitous one.

The authors maintain that, although these risk contours are important in and of themselves, it is also

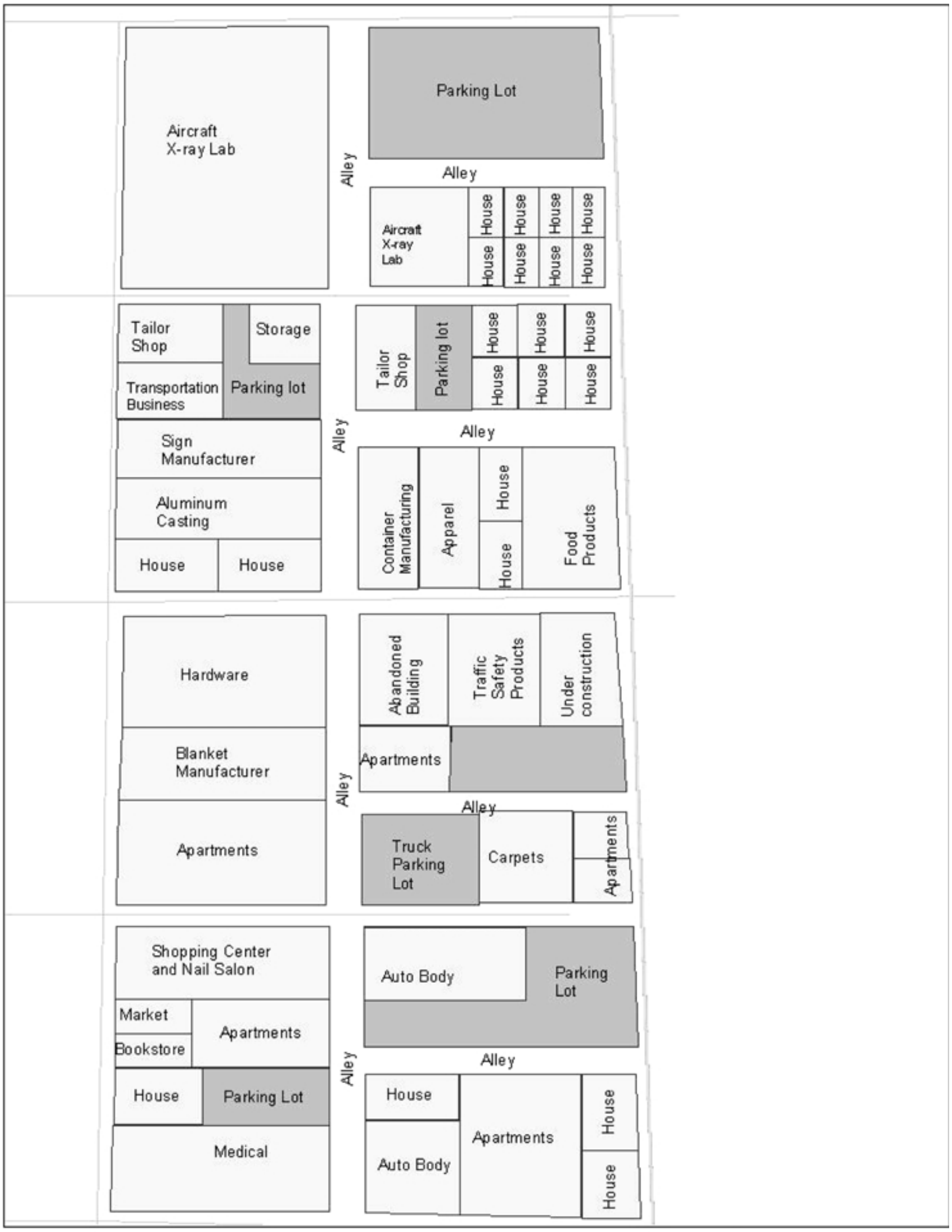

Figure 4. Close-up of a portion of Huntington Park, California.

instructive to compare these against the average measured cancer risks (due to air toxics) in the Los Angeles area. Recent air toxics monitoring data from the SCAQMD suggest that the average cancer risk in the Southern California area, from point source–generated pollutants, ranges from about 125 to 200 in a million over the course of a year (SCAQMD 2000b). We then see that our estimated risk levels in Huntington Park (Figure 5) are significantly higher than the areawide average. Actual risks in Huntington Park are, of course, even higher than what we estimate because we only account for local sources.

We also wonder whether our cumulative risk estimates are close to reality. Although there are no regularly collected ambient air toxics data for this area, the SCAQMD did conduct a one-time measurement of point-source-related air toxics at one location in Huntington Park, at which the measured total cancer risk came to 160 in a million (SCAQMD 2000b). This location falls in between four of the nodes in our dis-

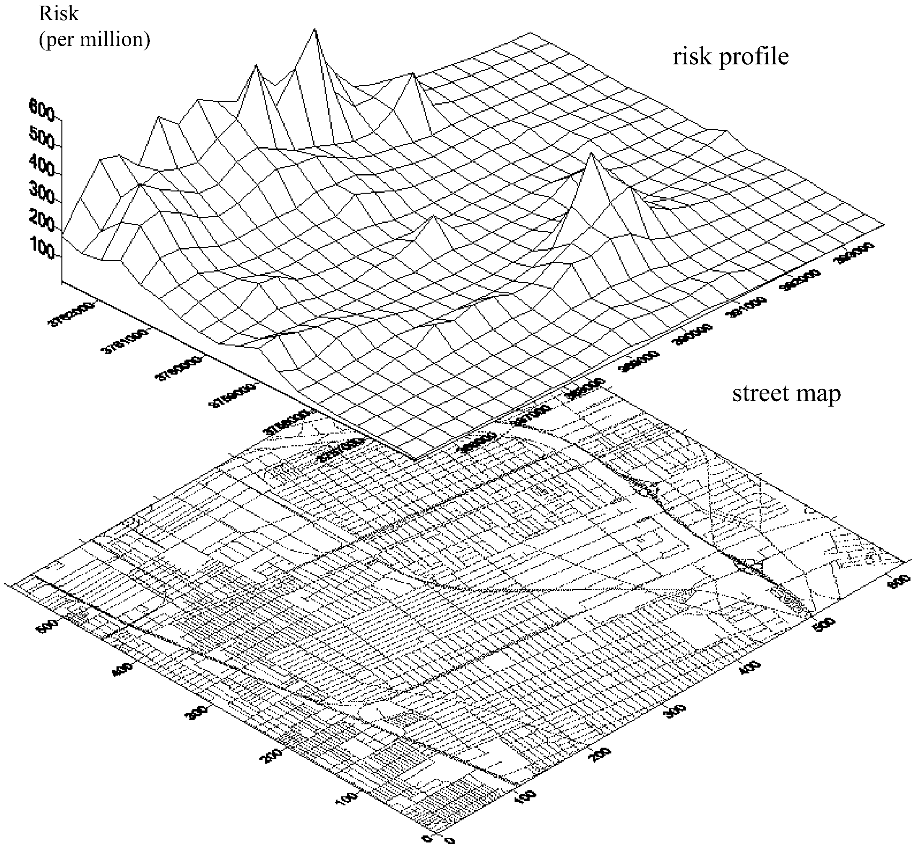

Figure 5. Topographic map of cancer risks due to local minor sources in study area (Huntington Park, California).

persion model, at which we estimated total risks of 109, 115, 135, and 150. This suggests that our estimates may be reasonable. Note that, because we only account for local point sources in our model, it is reasonable to expect the actual measured risk to be a little higher, which is indeed the case.

The hazard indices shown in Figure 6 suggest that attention to single sources (around the location of the peak) can effectively address the problem. The ''terrain'' of cancer risk seen in Figure 5 in Huntington Park is even more ominous because, if we spoke of the risk contour as if it were topography, Figure 5 shows not just a handful of distinct peaks but a general mountain range running throughout the study area. The cumulative risk levels in Figure 5 range from 11 in a million to 800 in a million. The median of the distribution over the City of Huntington Park is about 59 in a million, more than twice the SCAQMD action level of 25 in a million for existing (individual) sources and much, much higher than the Federal guideline of one in a million cancer risk (also for individual sources). The topography of noncancer hazard indices is less widely distributed, ranging from 0.5 and 600, with a median hazard index of about 4, which is a little above the SCAQMD action level of 3 (SCAQMD 2000a).

To avoid confusion of these risk contours with actual topography, perhaps it is more appropriate to refer to these as topologies of risk. We should make it clear that Figures 5 and 6 are representations of very real phenomena, but they are partial images of the total experience of risk. First of all, it is no secret that risk assessment, as practiced currently, captures only a small fraction of risk, given that the State of California only regulates about 300 chemicals as carcinogens (even though we are exposed to many thousands). Moreover, there is a dimensionality to risk that cannot be completely captured by any representation, e.g., things like stress, dread, stigma, or nuisance (CBE 2005). At any rate, Figures 5 and 6 are vivid and partial representations of the reality of risk which, though not geologic structures, are every bit as omnipresent in the everyday lives of these residents.

The ubiquity of risk in Huntington Park suggests a number of things with regard to intervention. Traditional approaches that focus on controlling single sources may need to be shored up by more general land use and health measures aimed at areawide

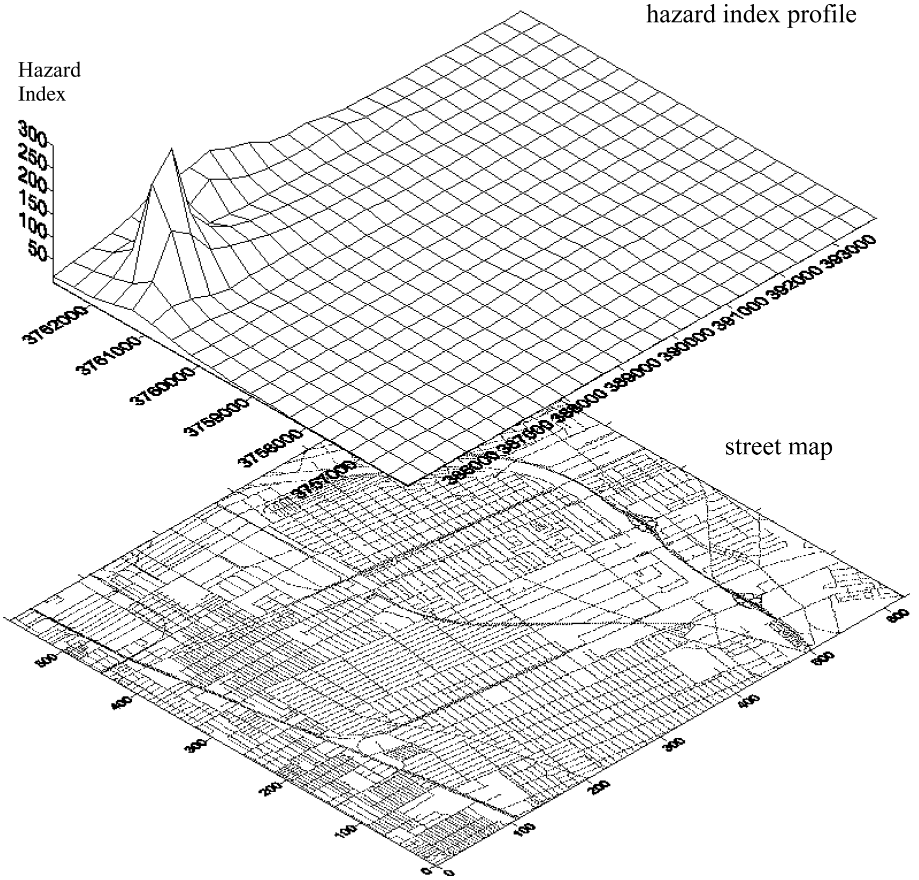

Figure 6. Topographic map of noncancer hazard indices due to local minor sources in study area (Huntington Park, California).

intervention. At the same time, point source controls for small sources may be another strategy but, given the large number of minor sources, its feasibility is an open question. Solutions might potentially involve altering the pattern of land use or transportation in the area. The situation may warrant relocating sensitive uses (e.g., daycare centers, parks, senior centers) away from more risk-prone areas to ''lower-lying'' places in the risk terrain. On the other hand, it may call for comprehensive changes in land use classifications and zoning policies. Although we cannot conclude that any specific suite of strategies will be most effective, suffice it to say that the present regulatory regime does not deal with these minor sources adequately, and that intervention programs may need to include strategies aimed at reducing risk on an area-wide basis.

What does the topology of the resulting risk contour, represented in these maps, suggest about the origin of risk and directions for intervention? First, the intimate proximity of residences and noxious facilities (as seen in Figures 2 and 3) means that, in each of the risk ''peaks'' seen in the profiles, there will be some residents who will be right at or beside these points of highest risk. The possibility of physically separating residences from these land uses, or moving these land uses to blocks where there are no residences, could prevent exposure of any resident to these risk zones. This means that strategies aimed at physical separation (relocation, increasing setbacks, provision of corridors) may greatly reduce risks to these few maximally exposed individuals. At the same time, the feasibility of relocating land uses (from both a cost-effective and regulatory perspective) may be problematic. On the other hand, the generally elevated ''terrain'' of the rest of the risk contour, even away from the peaks, suggests that the origin of the bulk of the risk is broadly dispersed and evidently due to the agglomeration effect of many sources. It suggests that the pattern of land use that leads to such a profound buildup of risk is a systemic one that occurs over most of the area of Huntington Park. In this case, physical separation of a small number of point sources alone will not suffice (that is, short of closure of multiple facilities) because the nature of the risk is broadly distributed over large portions of Huntington Park. This suggests that programmatic measures that deal with land use patterns, in general, are needed. By programmatic, we envision measures such as a general rezoning or redevelopment of Huntington Park, risk prevention programs in school, and other measures.

Still, there are broad areas over Huntington Park where the risk topology is relatively flat (the ''valleys''). There are chances to route sensitive uses through or in these areas and away from the elevated portions of the risk contour. As mentioned before, sensitive uses such as hospitals, daycare centers, schools, and others could be limited to these low-lying areas. The movement of children, the elderly, and residents in general can be designed around these low-risk areas, so long as provisions for access are also put in place. These suggest that places for public assembly, including markets, fairs, parks, and others should be planned around these areas. Pedestrian traffic patterns can be designed to avoid the elevated areas of the risk contour and to make the most use of relatively risk-free areas, such as seen in the figures. Parents and school officials, for example, can draw up routes for children and parents to walk to and from school using such topographic representations of risk. In contrast, in those areas that correspond to the crest of the risk contour, further research activities (such as environmental monitoring or health research) can be carried out, along with more focused area-specific intervention measures (e.g., door-to-door campaigns, air quality monitoring, indoor ventilation programs, etc.).

It would be interesting to add the effect of the nearby I-710 freeway and see what this does to the risk contour. We portray this in Figures 7 and 8, which illustrate the risk maps side by side (i.e., with and without the effect of the I-710). We see that, to some extent, the freeway acts as a background store of risk that serves to generally elevate the entire risk spectrum. However, the I-710 only really adds to the risk spectrum fairly close to the freeway (around 400 m and closer to the freeway). Away from the freeway, the freeway adds only an incremental amount to the risk contours. At more than a kilometer away from Huntington Park, the I-710 freeway does not cause elevated peaks (as we would find right next to the freeway) but a small, general increment of risk that adds a base layer of risk to the cumulative effect. Granted, the impact of the I-710 on the area within about 400 m on either side of the freeway is tremendous (also, consider how large an area is that falls within 400 m on either side of the corridor). However, for Huntington Park, we see that the bulk of the risk contour is due to the many diffuse point sources within the city; this runs counter to some claims that the only major source of risk to communities is from freeway traffic (SCAQMD 2000b).

What does this imply for advocacy? Consider the work of CBE, a grassroots advocacy group whose mission is to address the disproportionate burden of environmental risks on lower-income communities of color. CBE utilizes a three-pronged approach involving grassroots mobilization, legal action, and technical research. The group has one of its headquarters in Huntington Park. It has, to date, succeeded in a number of campaigns in SELA such as the following (CBE 1998):

- La Montaña: This is a large impoundment (once up to 30 m high) of used concrete in Huntington Park. The material is stored in a large parcel on Cottage Street, where it is broken up, the metals recycled, and the crushed aggregate hauled off for use as fill material at construction sites and road paving. Over several years, CBE worked with residents to protest La Montaña, finally convincing the City to declare the site a public nuisance.
- Glass Recycling: A few miles from La Montaña is an area where small glass recycling operations had set up shop. The crushing operations involved grinding the bottles to an almost fine power, which usually drifted into the air and onto the surrounding homes. CBE joined residents in lobbying for changes in this land use. Eventually, the company decided to close its plant.
- Suva Schools: Suva Elementary and High Schools are crowded institutions that have been operating in Bell Gardens, SELA, as far back as the 1930s. On the same parcel as the schools are the locations of two chromeplating plants, the Chrome Crankshaft and J&S plating plants. Beginning in 1988, teachers and parents at Suva began complaining about a rash of miscarriages around the school. Conducting their own health survey, the neighborhood group discovered clusters of cancer and birth defects around this area (LADHS 1989). Working with CBE organizers and legal staff, the teachers and parents began lobbying several agencies to investigate the site. When the South Coast Air Quality Management District finally took air samples, they found, at the school playground, one of the most elevated concentrations of ambient hexavalent chromium (290 ng/m^3) measured in Los Angeles County. CBE and the local community lobbied to have the plants closed and clean-up initiated.

By and large, CBE's strategy has involved targeting specific sites and mobilizing around them. In fact,

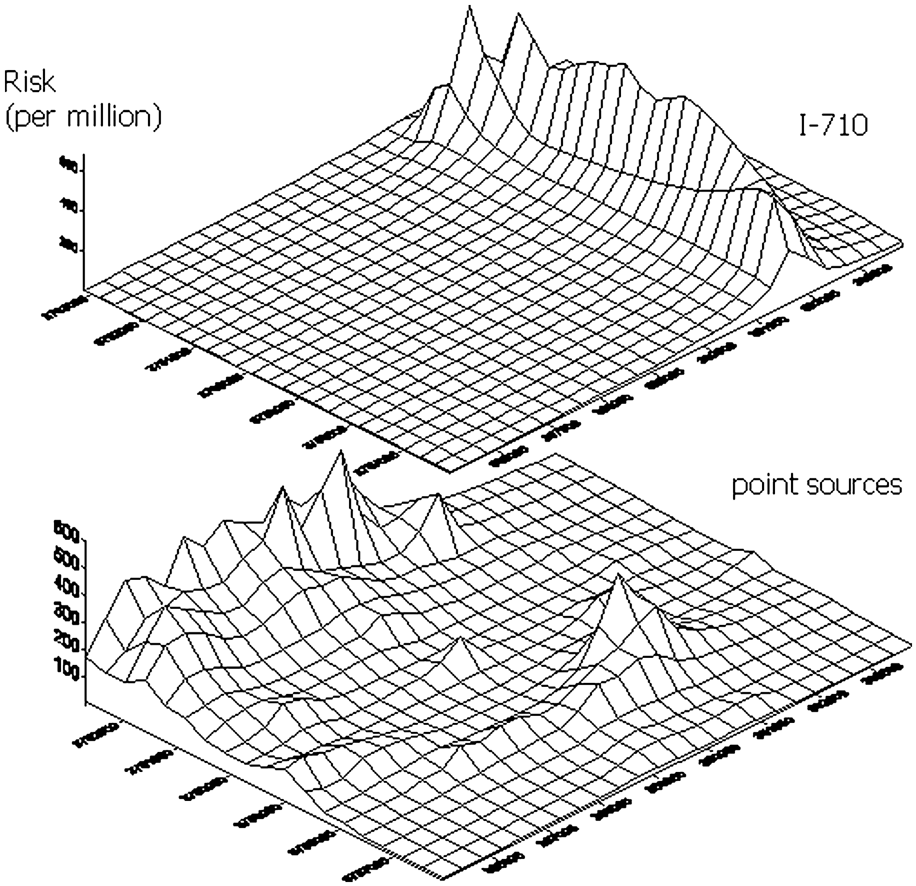

Figure 7. Comparison of cancer risks due to local minor sources and I-710 freeway in study area (Huntington Park, California).

CBE's use of the word ''campaign'' suggests how they have traditionally viewed these struggles: as concerted, vigorous action around specific sites. To do this, they have combined techniques in mass resistance from traditions dating back to Alinsky (1972) and Cesar Chavez (Willis-Rivera 2001) and have become an exemplar in mobilizing mass actions to protest public decisions.

The situation at SELA, however, has evolved into new arenas for advocacy, and CBE is finding that, aside from the single-issue campaigns they have been fighting, there is also the larger, more endemic phenomenon of cumulative risk that lingers in the neighborhood. The systemic nature of cumulative risk does not simply yield to site-by-site action as has been the case in CBE's campaigns in the past. Rather, the problem facing SELA currently is general, embedded everywhere in the landscape and suggesting that intervention needs to be more programmatic, more comprehensive, and truly community-based in scope.

As a response, CBE has started utilizing methods of participatory action research in SELA. Bahram Fazeli, former Southern California director for CBE, says ''Well, I think ... one of the themes of our work is addressing cumulative impact. ... Now sometimes we have big sources like in Wilmington, we have a lot of refineries, then sometimes we have a lot of smaller sources dispersed, big and large, like in Southeast LA. I think there are two aspects to using participatory action research to address cumulative impact. ... One, is the benefit it has for the community, and two, is the benefit it has for the research. The benefit it has for the community is that ... the cumulative impact problem is very complex. ... You're talking about gas stations, dry cleaners, small chromeplaters; this is where people in the community work, this is intertwined in people's lives. This is not something we can go to AQMD and simply say, we need a cumulative impact rule next week, it is something that requires a lot of participation by the community. ... And they participate through this process of defining the problem and finding the solutions. So that develops the capacity of the community to find solutions, from things like correlating pollution to health outcomes, to learning to interact with policy decision-makers.''

In CBE's community-based participatory action research in SELA, the focus is not the single-issue campaign, but engaging residents in long-term pro-

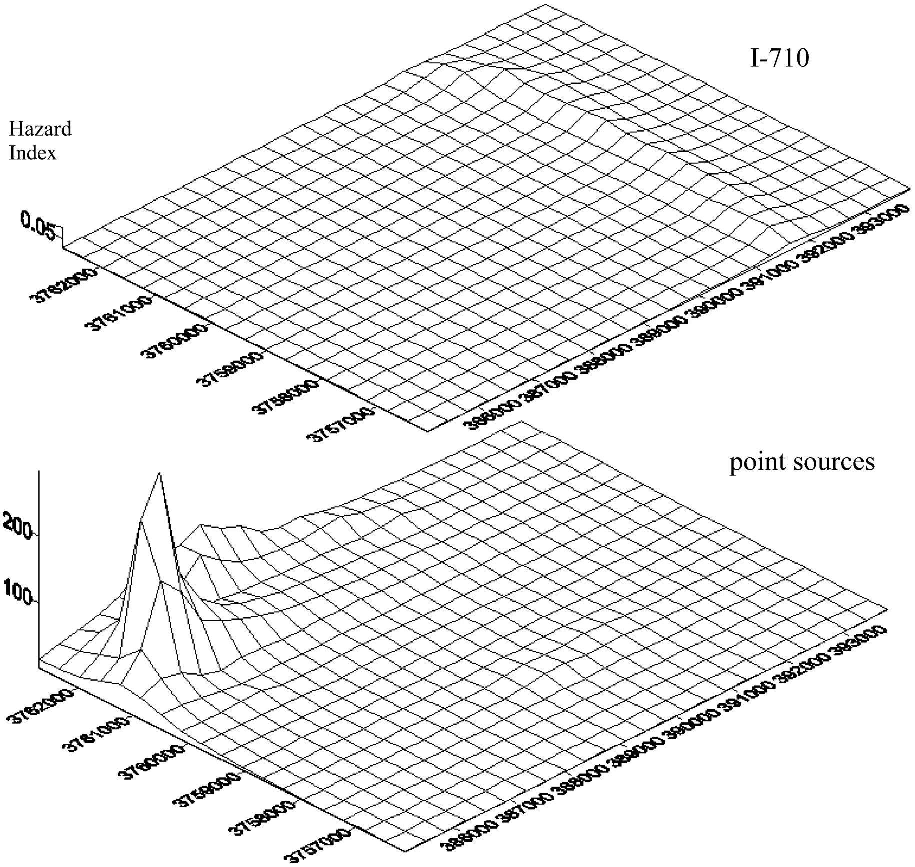

Figure 8. Comparison of noncancer hazard indices due to local minor sources and the I-710 freeway in study area (Huntington Park, California).

cesses of self-education, critical thought, and capacity building (see CBE 2005 for an account). The near-term objective is to establish and maintain research activities within the community around environmental health. These activities include conducting a community-designed health survey, resident interviews, and other activities that one would classify under research, not mass protest. In doing this, CBE is drawing from a different tradition, not that of Alinsky, but of Freire (1973) and his experiments at a pedagogy that is designed and run by the people. The hope is that this process of participatory action research will embed, in the community of SELA, activities that will get at the source of cumulative risk in manifold ways. Being deeply rooted, the problem of cumulative risk requires many points of attack, which is the goal of participatory action research. This approach links research to action, where action should take on many forms, from parents improving conditions in the home (such as improving ventilation or initiating lead removal), city officials improving traffic patterns (such as rerouting trucks and truck depots away from residential areas), to more aggressive regulation. For example, already city planners in Huntington Park have begun contemplating more stringent conditions for building permits for so-called vulnerable areas where the risks are already known to be elevated (NAPS 2003).

The approach is to match intervention to the phenomenology of the risk. Because cumulative risk arises from a multitude of sources and routes of exposure in SELA, intervention should also attack the problem from a multitude of directions. Because risk is not simply site-specific but systemic in SELA, so, too, must the intervention strategy target system-wide or programmatic levels of action, along with the traditional single-issue campaign. Participatory action research (PAR), such as the type being carried out by CBE, is an appropriate instrument by which to develop mixed-strategy interventions, because PAR involves the accumulation of multiple sources of knowledge and, over an extended period of reflection and strategizing, linking this knowledge to action. In fact, the multiple lines of intervention inherent in PAR may serve as a counterpoint to the more formalistic, mono-strategy approaches found in the classic regulatory model. The authors suggest that the inherent philosophy of PAR, more so than the legalistic rule-based ethic of the regulatory model, reflects an ethic of care in which action results from the fostering of relationships and capacities within community (Gilligan 1982). That is, along with strategies that are juridical in nature (e.g., demanding stronger AQMD regulations), there must also be those that are primarily relational (e.g., strengthening ties within the network of policy actors). Similarly, we can conceive of the agency as not just a rule-setting institution, but also a caring one.

The PAR process is a long-term one, and activities such as CBE's participatory action research project need to be institutionalized into the very fabric of the community, just as risk has embedded itself into this very fabric. Says Fazeli, ''Probably, there should never be an end, you know, because the action piece can go on for ever and ever and ever, and one action piece can lead to other questions, like, let's say... we came across this fact that, yes, there are all these unregulated sources. Well, we ask one question and create ten new questions. Why are there all these unregulated sources? ... Action leads to more research and then more action. ...It can be a mode of operation, we never stop (seeking) different forms of knowledge, coming from the community, coming from very strong technical training, new forms of knowledge. There doesn't seem to be an end.''

Conclusion

The contention that serious pockets of cumulative risk can occur due to the agglomeration of many small sources of air toxics is a logical but largely untested proposition. In this article, we develop a rapid assessment mapping protocol to be able to systematically estimate cumulative risk levels from such situations.

We applied the procedure to an area of Southern California that, because of the phenomenon of incompatible land use, has been dubbed by some as Asthmatown. This area, Southeast Los Angeles, is a classic case of environmental justice, where a bewildering array of incompatible land uses sit side by side in an area where groups of people reside that are thought to be among the most vulnerable to environmental exposures.

The procedure affords us dramatic representations of the risk contour of SELA. In these depictions we find that, although distinct peaks of risk occur within the study area, in general, the level of risk over most of Huntington Park is elevated. To use the analogy of topography further, the entire neighborhood resembles an extended mountain range. The topographies of risk that we develop in this article are but some of the multiple representations that we can attempt to capture different aspects of the experience and phenomenology of risk. To put it another way, risk is a phenomenon that exists in the manifold dimensions and aspects of experience. What we endeavor to achieve is a thick description (Geertz 1973) of this experience.

Beyond simply capturing aspects of the experience of risk, the procedures employed herein allow one to incorporate considerations of vulnerability and cumulative risk in systematic ways for land use planning processes and environmental management. In the end, the risk contours portrayed in this research are not solid topographies of rock that lie immobile on their pediments but, rather, dynamic, shifting, and organic potentials of risk that can be reshaped through vigilance, care, and progressive intervention. It remains, for future research, for us to peer more deeply into the effects of various types of intervention on these topologies of risk. The intuition is that, just as the broad ranges of elevated risk evolve over many different land use decisions over time, along with the concerted effect of private and public actions, so, too, will the solution come about through the application of multiple points of intervention. In fact, what it calls for are new ways to reform regulatory strategies, so as to incorporate an ethic of care for the most vulnerable.

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