Determining Green Infrastructure Potential and Benefit Allocation in Oakland, California

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ABSTRACT

Cities face a variety of stormwater runoff issues resulting from the prominence of impervious surfaces in the urban landscape. Green infrastructure (GI) is a method of urban stormwater management that uses soil and vegetation to treat and/or capture the resulting runoff. GI installations provide a host of benefits, including improved water quality, flood control and decreased localized air pollution. In this study, I conducted a GIS-based suitability analysis using physical, social and demographic factors to assess the potential for public GI implementation in Oakland, California. I then interviewed non-profit workers and municipal employees to situate my results within an Oakland-specific policy context, while also drawing upon examples from other US cities. My GIS analysis found widespread opportunity for GI implementation, with many priority consideration areas in West Oakland and East Oakland. Additionally, my policy analysis examined the complexity of addressing displacement issues associated with urban greening in low-income areas. While GI installations are not a comprehensive prescription for social ills, a thoughtfully implemented, large-scale GI program could provide the residents of Oakland with tangible environmental and public health benefits.

KEYWORDS

urban greening, public health, water quality, environmental justice, ArcGIS

INTRODUCTION

Cities face a variety of stormwater issues resulting from the prominence of impervious surfaces in the urban landscape (U.S. Environmental Protection Agency 2007). Twentieth century development practices—largely indifferent to natural hydrology—severely altered runoff patterns, creating a host of environmental, infrastructure and public health issues (Benedict 2002). Within these environments, cement and asphalt cause stormwater to flow on top of the constructed surfaces rather than be absorbed into the water table. In the course of its flow across an impermeable cityscape, runoff collects trash, heavy metals, bacteria and other pollutants (Benedict 2002). These contaminants in turn degrade water quality in the receiving bodies and negatively affect ecological health. Green infrastructure (GI) seeks to offset stormwater issues resulting from conventional design through the use of natural landscapes for localized stormwater management. In accordance with the principle of low impact development (LID), GI focuses on restoring or minimizing changes to pre-development hydrology. GI installations, which include bioretention planters, permeable pavements and constructed wetlands, were officially endorsed by the EPA in 2007 and are gaining popularity in urban design worldwide (U.S. Environmental Protection Agency 2007).

GI is considered a holistic stormwater management technique due to its multitude of environmental and public health benefits. Use of GI to counter impervious surface coverage—particularly coverage exceeding 25 percent—is shown to substantially reduce levels of waterborne ammonia, nitrates, heavy metals and other toxins (Yang et al. 2013). Filtration of pollutants is achieved as the collected stormwater passes through vegetation and soil. The result of this reduction in waterborne toxins is overall improvement in aquatic system health (Yang et al. 2013). Additionally, GI has been demonstrated to reduce the volume of runoff by 85 to 100 percent and the rate of stormwater flow by 93 to 100 percent (Liu et al. 2014). Reduction in volume and rate of flow mitigates infrastructure flooding from storm events. This is of particular interest in the context of climate change due to predicted increases in storm intensity, sea level rise and surge events (Demuzere et al. 2014). Urban greenery involved in GI also has the capacity to reduce localized air pollution (Wang et al. 2014). Improvements in air quality are achieved through three processes: dry deposition, carbon sequestration and inhibition of smog formation (Wang et al. 2014).

Oakland faces many issues that could be addressed through large-scale GI implementation. Oakland's history of industrial production is accompanied by a legacy of air pollution, soil contamination and poor water quality (Adapt Oakland 2012). GI projects could play a significant role in transforming the city's toxic landscapes that are disproportionately inhabited by low-income residents and people of color (Adapt Oakland 2012). In addition, the City of Oakland—particularly due to its bay geography—has a vested interest in climate adaptation strategies. The City of Oakland's climate action plan has explicit adaptation mandates incorporating GI goals into their strategy (CA jurisdictions 2012). The 2014 passage of Proposition 1, which authorized $7.12 billion in state funding for water projects, could funnel money toward future GI projects in Oakland. While an Oakland-based nonprofit was recently awarded state funding to evaluate urban greening in the West Oakland community, much of the city's 78 square miles remain yet to be assessed for GI implementation (Adapt Oakland 2012).

In this study, I conducted a GIS-based suitability analysis for GI implementation in the City of Oakland, California. My analysis was based in part on San Francisco's progressive Urban Watershed Assessment, a recent study that used a complex array of physical, social and policy factors to prioritize citywide project location (San Francisco Public Utilities Commission 2014). Additionally, through research and interviews I examined the complexity of equitably distributing urban greening benefits in the historically marginalized communities of Oakland.

METHODS

In this study, I conducted a suitability analysis for GI implementation in Oakland, California. My GIS analysis for Oakland GI potential firstly assessed the study site for areas that met a minimum criterion of physical factors required for three different installation types. Then, from areas that met those initial constraints, I identified sites for prioritization based on environmental, social and demographic factors. After completing my composite analysis, I conducted interviews with non-profit workers and municipal employees to situate my results within an Oakland-specific policy context.

Study site

Oakland is a major port city in California's Bay Area. The 78-square mile urban cityscape is comprised of industry, commercial businesses, and mixed-density housing. The Downtown area resides at an elevation of 40 feet, with higher elevations eastward in the Oakland Hills and lower elevations near the waterfront in West Oakland (Figure 1). Stormwater infrastructure is currently overseen by the City of Oakland's Public Works Department. Due to a host of infrastructure, environmental and public health concerns, Oakland's stormwater management system is in need of retrofit. Inadequate runoff management has resulted in stormwater infiltration and inflow for East Bay Municipal Utility District's separate sewage pipes, a process that can result in sewage overflow.

Additionally, Oakland residents have inherited a landscape of pollution and environmental injustice resulting in part from the city's long history of shipping and industrial production. Residential areas surrounding the city's industrial sites and transportation infrastructure experience localized air pollution and water contamination (Adapt Oakland 2012). This industrial periphery also contains eight EPA-recognized toxic sites, all within various stages of remediation. As a consequence of political neglect and environmental racism directed at the low-income residents and people of color that have historically inhabited these neighborhoods, comprehensive remediation has never been successfully achieved (McClintock 2011). In 2010, California awarded Proposition 84 grant money to the City of Oakland and non-profit Urban Biofilter for the development of urban greening installations as a means of relieving runoff burden on the outdated sewer system while simultaneously addressing air quality issues and contributing to climate change resiliency. Planning is currently underway for projects in West Oakland and portions of the Downtown Oakland area.

Suitability analysis

In order to construct a GIS-based suitability analysis for determining GI site prioritization, I chose three common installation types and then established a two-pronged analysis process to assess their implementation potential using ArcMap 10.2. The three installation types, each with their own site constraints and associated benefits, included bioretention planters, flow-through planters and permeable pavements. Bioretention planters, commonly incorporated into medians and streetscapes, use soil and vegetation to facilitate stormwater infiltration. This process requires a slope of less than 5%. Flow-through planters, conversely, act to filter and slow the flow of runoff without capturing stormwater. Consequently, they are versatile in being unconstrained by slope, but must be used in conjunction with other installation types to capture runoff. Permeable pavements function similarly to bioretention planters and are subject to the same site constraints. Because they do not employ vegetation, permeable pavements do not have the urban greening and air quality benefits associated with the other installation types.

Knockout analysis

After establishing these installations as the subject of my analysis, I compiled a list of minimum site criteria for each type. Site criteria (Table 1) were compiled from San Francisco's Urban Watershed Assessment, a recent GI assessment document for the entire City of San Francisco (San Francisco Public Utilities Commission 2013). Using 2013 Landsat imagery, I performed an NDVI analysis to determine effective imperviousness in excess of 25%, an established threshold for polluted runoff generation. I then proceeded to isolate areas of public land ownership and public right of way, a mandatory factor for municipal projects, from 2015 Alameda County data. Additionally, I accounted for GI construction codes requiring a minimum 10-foot distance from existing buildings due to flooding potential (Bay Area Stormwater Management Association 2012). Building footprint data was taken from the City of Oakland, upon which I performed a 10-foot buffer function. Lastly, I incorporated slope because of the need for relatively flat sites to provide effective stormwater infiltration. Using NED raster data, I generated a slope model for the entire study site and selected qualifying areas. Areas satisfying all of the corresponding factors for each given installation type were then isolated and proceeded to the next step of analysis.

Table 1. Knockout constraints. Mandatory site criteria for three different GI installation types. Dot indicates factor applied to corresponding installation type.

	Bioretention planter	Flow-through planter	Permeable pavements
Effective impervious area exceeding 25%	•	•	•
Public ownership	•	•	•
10 ft. from buildings	•	•	•
Slope less than 5%	•		•

Prioritization analysis

I then compiled a list of environmental, social and demographic factors to determine which areas resulting from the initial analysis could most benefit from GI implementation. These factors (Table 2) were again adapted from San Francisco's Urban Watershed Assessment, with some social and demographic factors also derived from Urban Biofilter's recent public health risk factor map (Adapt Oakland 2015). For each factor satisfied, the corresponding area received a weight of +1.

Water body proximity and toxic site proximity factors both accounted for the ability of GI installations to filter pollutants from stormwater runoff before entering a receiving body (Hinman 2005). I sourced these datasets from the County of Alameda and performed necessary buffer functions on each. Low-elevation coastal areas are at additional risk from flooding due to anticipated sea level rise (SLR). Using NED raster imagery, I modeled a 4.5-foot SLR scenario based on the California Energy Commission's projections for 2100 (City of Oakland 2012). Due to the ability of flow-through planters to work in conjunction with existing stormwater infrastructure, I also modeled proximity to drainage inlets. This data was taken from the City of Oakland with a 25-foot buffer function applied to each point.

Due to the prevalence of air pollution and corresponding public health issues in Oakland, I emphasized the urban greening benefits of certain GI installations by taking into account two asthma factors. The baseline asthma rate factor was adapted from California's average (California Breathing 2013), with the second asthma factor indicating areas experiencing rates that exceed twice the state average. Asthma values were derived from 2012 TIGER/Line US Census Bureau block data. Additionally, I modeled a 500-foot buffer zone around major transportation infrastructure because of the potential for these sites to serve as a source for many airborne pollutants, including ozone, carbon monoxide, sulfur dioxide and other particulate matter (Wang et al. 2014). I also prioritized residential zoning areas due to the importance of achieving adequate air quality in the proximity of households. Data for both of these factors was sourced from the County of Alameda.

Table 2. Prioritization factors. Environmental, social and demographic factors determining which areas could most benefit from GI implementation. Dot indicates factor applied to corresponding installation type.

	Bioretention planter	Flow-through planter	Permeable pavements
200-ft. water body proximity	•	•	•
500-ft. toxic site proximity	•	•	•
SLR 4.5-ft. flooding	•	•	•
25-ft. drainage inlet proximity		•	
Asthma rate above 7.65%	•	•	
Asthma rate above 15.30%	•	•	
500-ft. freeway buffer	•	•	
Residential zoning	•	•	

After compiling all of the above-listed factors, I constructed a composite factor map displaying areas categorically by summed weights. I then selected areas that received summed weights within the fiftieth percentile for each respective installation type and isolated them for priority consideration. This selection process used a system of inclusive rounding to account for modeling sensitivity.

RESULTS

Suitability Analysis

My knockout analysis showed feasible GI sites widely dispersed throughout the study system with similar distributions for each of the three installation types (Appendices B, C, D). As a percentage of the total study site, total feasible area among installation types varied only by .33 square miles (Table 3). The highest density feasible areas were located in West and East Oakland. Streetscapes and scattered public parcels composed the thinner distribution present in North Oakland, Lake Merritt and the Downtown area, while the Oakland Hills were almost entirely excluded due to low effective imperviousness. Consequently, the slope constraint—which predominantly applied to the Oakland Hills—was rendered effectively insignificant in determining site distribution. Conversely, public land ownership appeared to be the most significant factor in determining site distribution.

My prioritization analysis identified areas of West Oakland, East Oakland and scattered freeway corridors as sites that could benefit most from GI implementation (Appendices B, C, D). The distribution of priority consideration areas for bioretention planters and flow-through planters looked almost identical, composing 5.34% and 5.60% respectively of the total study area (Table 3). The small discrepancy in distributions was largely explained by a scattered speckling of opportunity areas for flow-through planters to work in conjunction with drainage inlets. Permeable pavements, alternatively, amassed priority consideration areas summing a total of only 2.18%. Their distribution was predominantly determined by the SLR projection, with occasional corridors determined by stream proximity.

Table 3. Suitability analysis results by area. Explanatory information

	Bioretention planter	Flow-through planter	Permeable pavements
Feasible area (percent of total study site area)	10.73%	11.14%	10.72%
Feasible area (square miles)	8.37 sq mi	8.69 sq mi	8.36 sq mi
Priority consideration area (percent of total study site area)	5.34%	5.60%	2.18%
Feasible area (square miles)	4.17 sq mi	4.37 sq mi	1.70 sq mi

DISCUSSION

My GIS analysis showed widespread potential for GI implementation throughout the City of Oakland. The large area and wide distribution of suitable properties suggests planners can largely focus on how to most effectively allocate the many co-benefits provided by GI. Because low-income residents predominantly occupy many of the priority consideration areas identified, I devoted significant attention to exploring problems regarding urban greening as a means of environmental justice and ideas for addressing these issues.

Suitability analysis

The priority consideration areas identified by my GIS analysis corresponded with planned GI projects, a result that served to validate the effectiveness of my modeling. This held true for residential regions in West Oakland east of Interstate 880 where Urban Biofilter has designated greening project areas. Conversely, Lake Merritt was not identified as a priority consideration area because my analysis accounted for the greening features recently implemented there. My NDVI analysis was derived from 2013 Landsat imagery taken after the renovation of Lake Merritt, a construction project that restored some of the lake's natural hydrological features and incorporated GI installations surrounding the lakeshore. Consequently, due to low imperviousness, the immediate Lake Merritt area was disqualified from priority consideration during the initial knockout analysis phase. This finding also serves to illustrate the relative effectiveness of my model in accounting for existing greening projects and GI installations.

Additional analysis taking into account average income by census block showed that most all of the high asthma areas are located within low-income neighborhoods (Appendix E). Similarly, there was substantial overlap between toxic site proximity and neighborhoods categorized as low-income. These factors, which reinforce a historically observed lack of environmental remediation in low-income areas and areas inhabited by people of color, held considerable bearing on the distribution of priority consideration areas (Eckerd et al. 2012). While predictable and consistent with literature, this trend suggests planners and policymakers must exercise extreme care in leveraging what are commonly considered the economic benefits of GI installations and, more broadly, urban greening (Reich et al. 2007).

Planning and policy considerations

A recurring concern municipal employees and non-profit workers reported hearing from residents was the potential for GI projects to contribute to a process of "green gentrification" (Clement et al. 2015). Urban greening, including GI projects, has been documented to positively impact the value of surrounding real estate (Reich et al. 2007). This mechanism can result in the displacement of low-income residents and people of color, a process that negates intended environmental justice benefits. While GI projects generally aim to provide communities with a host of environmental and social benefits, some greening projects—including Detroit's Future City Strategic Framework—have been criticized as deliberately driving displacement and creating artificial property scarcity (Safransky 2014). Similarly, New York City's High Line aerial greening corridor, constructed in 2003, saw surrounding property values increase by 103 percent in a span of just five years (Wolch et al. 2014). Although greening initiatives in Oakland exist within a different context—smart growth development principles are being employed and the city has been generally receptive to community interests—resident concern regarding displacement should not be dismissed.

Municipal approaches to funding GI projects have also been the subject of equity concerns. Many cities—including Seattle, Portland and soon-to-be San Francisco—have implemented stormwater fees on impervious surface coverage. This model charges commercial and residential property owners for the stormwater runoff generated on their property. While a novel and innovative approach to encourage removal of paved areas, the fee system ignores socioeconomic trends in access to green space. Ironically, this in short describes the root environmental justice issue motivating urban greening initiatives. Because of the stratification of green space distribution present in urban areas, a fee on impervious surface coverage could shift the financial burden for project funding onto the low-income residents for whom the project benefits are intended. This point was substantiated by my GIS analysis in which the areas of concentrated vegetation, notably the Oakland Hills, showed average incomes substantially higher than the predominantly impervious flatlands (Appendix E).

Methods for addressing equity issues associated with urban greening are highly contentious. A recent study suggested impacts to surrounding real estate values could be mitigated by designing vegetated landscapes that are "just green enough" (Wolch et al. 2014). GI projects designed in accordance with this principle would be "explicitly shaped by community concerns, needs, and desires rather than either conventional urban design formulae or ecological restoration approaches" (Wolch et al. 2014). This framework reflected the comments of those interviewed who reiterated the need to seek public input in a way that empowers community members to shape greening projects. Some planners, however, have criticized the approach suggesting it encourages policymakers to deliberately withhold resources from low-income communities. Advocates of either position seem to condemn employing the rhetoric of sustainability in attempt to rationalize and greenwash environmental injustice.

More comprehensive policy solutions have been proposed for remedying inequitable benefit distribution, including the creation of community benefit districts. Community benefit districts are associations of local business and property owners that pay fees to a central non-profit organization in order to fund improvement projects from which all stakeholders derive benefit (San Francisco Planning Department 2009). The community benefit districts model has already been adopted in the Downtown Oakland and Lake Merritt. Ideas for displacement prevention include levying fees on property value increases and allocating the resulting funds to affordable housing. Similarly, as gleaned from Seattle, community benefit agreements can mandate job provision requirements for those with barriers to employment and other assurances of equitable project benefit distribution. Past examples of community benefit districts and agreement have ranged in success, suggesting the framework is promising but imperfect.

Limitations

While my analysis was able to identify a wide range of Oakland land suitable for GI construction, I was limited by the available data and value judgments inherent to the suitability analysis weighting process. The area of feasible GI sites produced by my analysis was likely exaggerated by a few factors, including my use of state and federal public land, an overestimate of usable streetscape widths and missing building footprint data. Additionally, my analysis eschewed the complex hydrology analysis present in other GI assessment documents. Perhaps most importantly, my system of valuation for various environmental, social and demographic factors was synthesized from literature rather than the preferred method of compiling priorities through a community-based process. In this sense, my analysis was defined by the same prescriptive framework for which planners and policymakers have been criticized.

Future directions

Although the environmental benefits of GI have been thoroughly documented in scientific literature, social benefits remain less studied. Due to the relatively recent nature of GI technologies, questions remain regarding the long term social benefits of site implementation, particularly in cases of environmental injustice. For complex social issues such as these, quantitative measurement may be less favorable to a qualitative understanding of the underlying mechanisms. Two large-scale Oakland greening projects remain to be assessed in this way. After being designated a priority conservation area by the Association of Bay Area Governments, renovation of Lake Merritt and the surrounding area was completed in 2013. The Lake Merritt renovation poses a convoluted case study of "green gentrification" due to conflating market factors, including the desirability of the lake itself as compared with the recently constructed greenery. While surrounding real estate values have increased significantly since project completion, attempting to attribute this increase to urban greening would be difficult if not impossible. Another recently designated priority conservation area is the proposed East Bay Greenway. The 12-mile pedestrian corridor is slated to run beneath elevated BART tracks, though construction was halted due to unanticipated expenses associated with remediation and removal of contaminated soil.

Conclusion

Despite their many benefits, GI technologies are not a panacea for the complex array of environmental and social issues faced by the world's cities. This point is easily obscured among the utopian rhetoric that pervades GI and, more broadly, urban greening literature (Safransky 2014). In spite of these shortcomings, however, a successfully implemented GI program could provide the residents of Oakland with many tangible benefits. While metrics for success vary between stakeholders, an ideal program would incorporate and synthesize the complex diversity of resident interests and avoid imposing prescriptive policy. Most significantly, careful attention must be afforded to ensure that neither environmental health nor social equity is sacrificed to achieve the other. As evidenced by examples of other municipal GI programs, attaining this balance is a difficult task. As the pace of urbanization steadily increases and smart growth development principles firmly take root, GI programs can play a pivotal role in ensuring city environments support healthy, empowered communities.

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APPENDIX A: Study Site

Figure A1.

APPENDIX B: Bioretention Planter Suitability Results

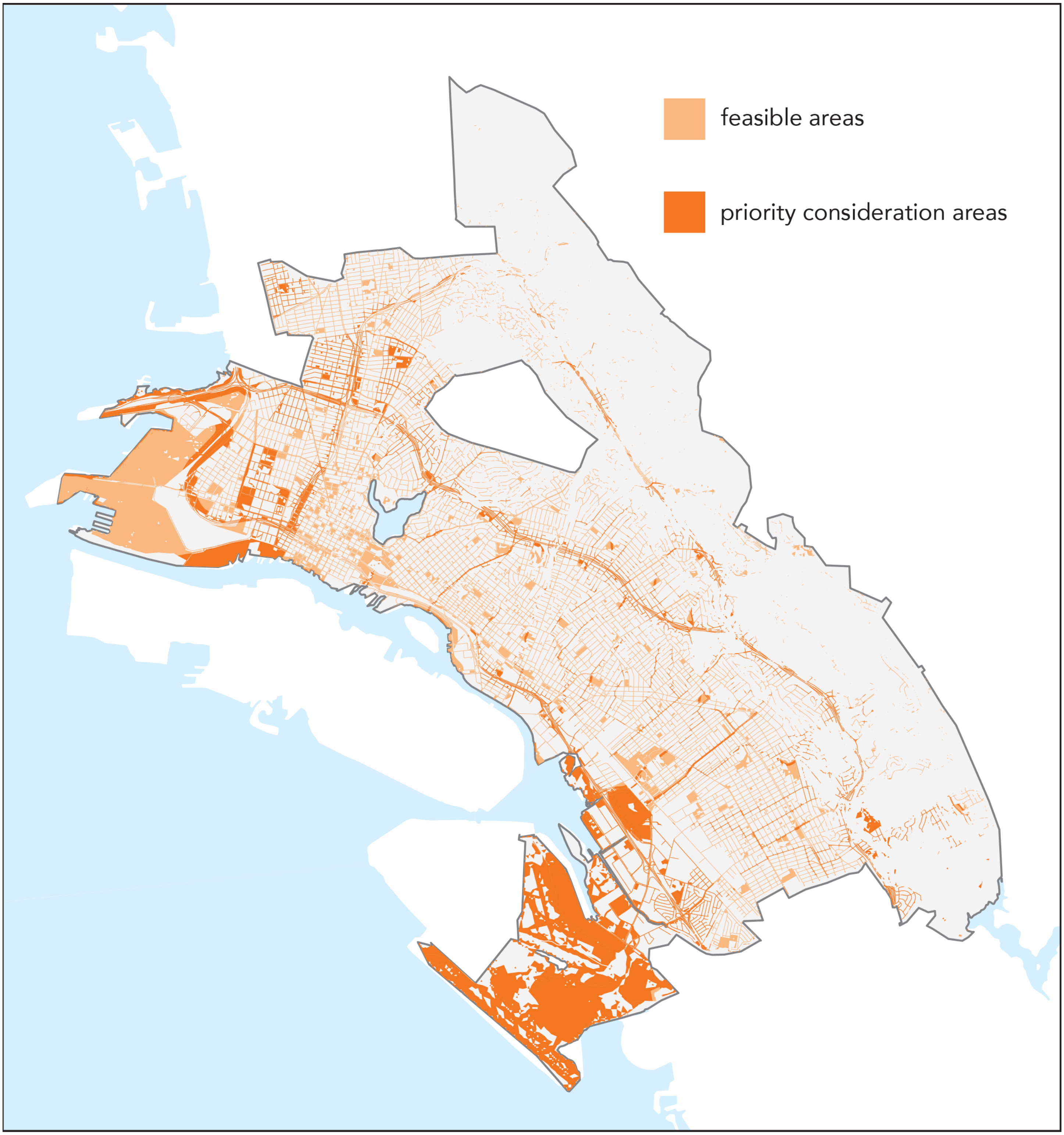

Figure B1.

APPENDIX C: Flow-through Planter Suitability Results

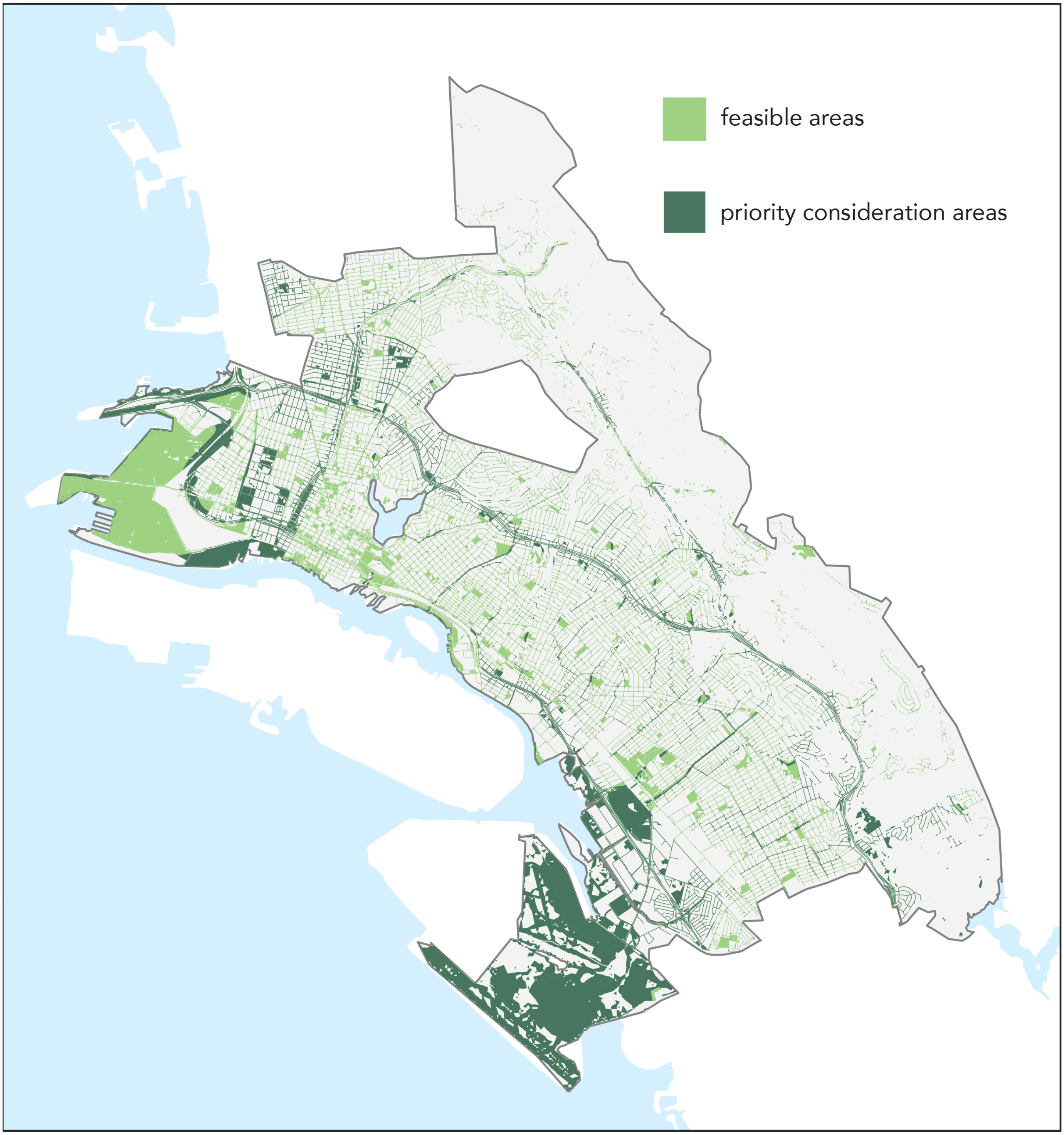

Figure C1.

APPENDIX D: Permeable Pavement Suitability Results

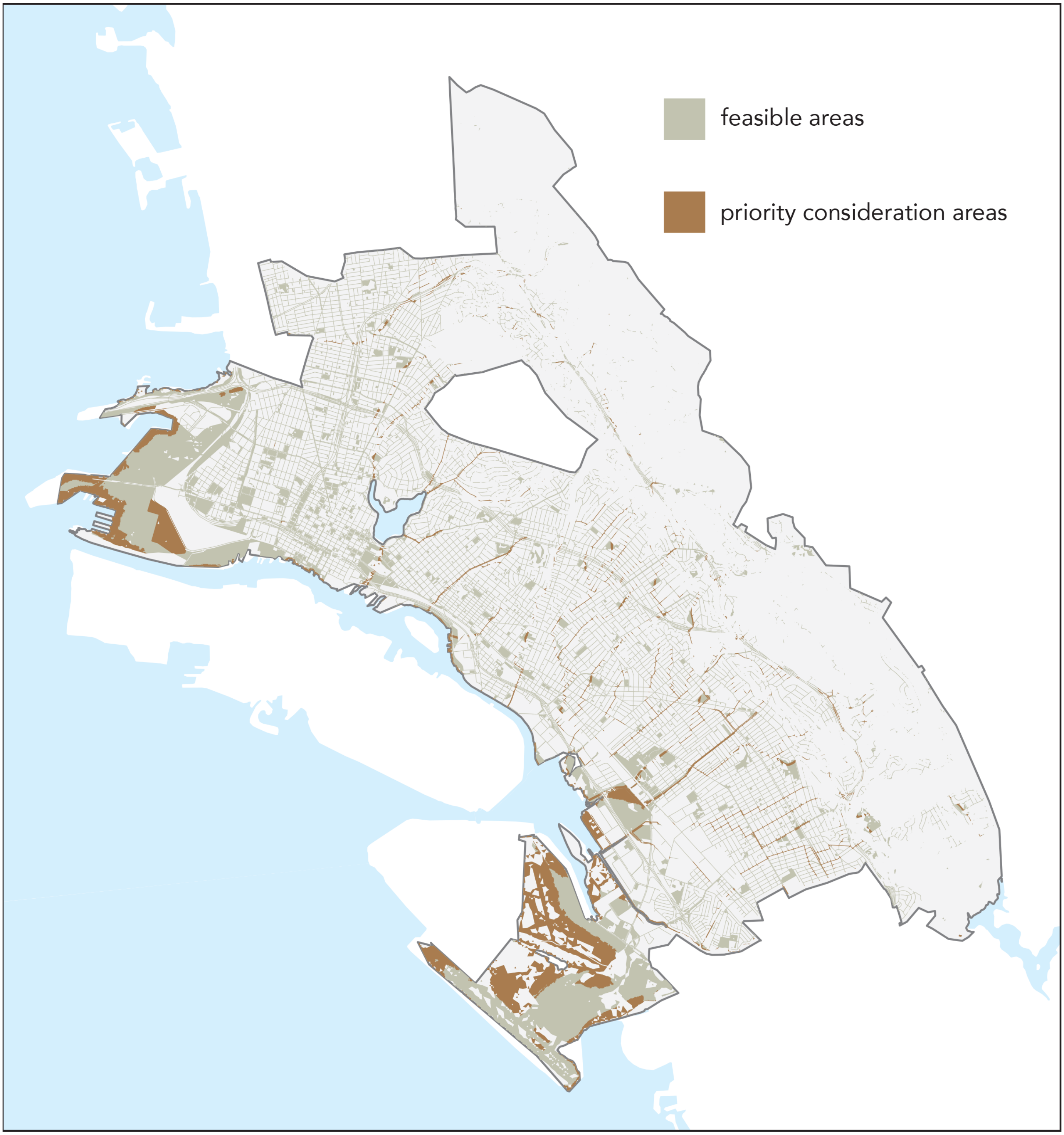

Figure D1.

APPENDIX E: Asthma and Income Distribution

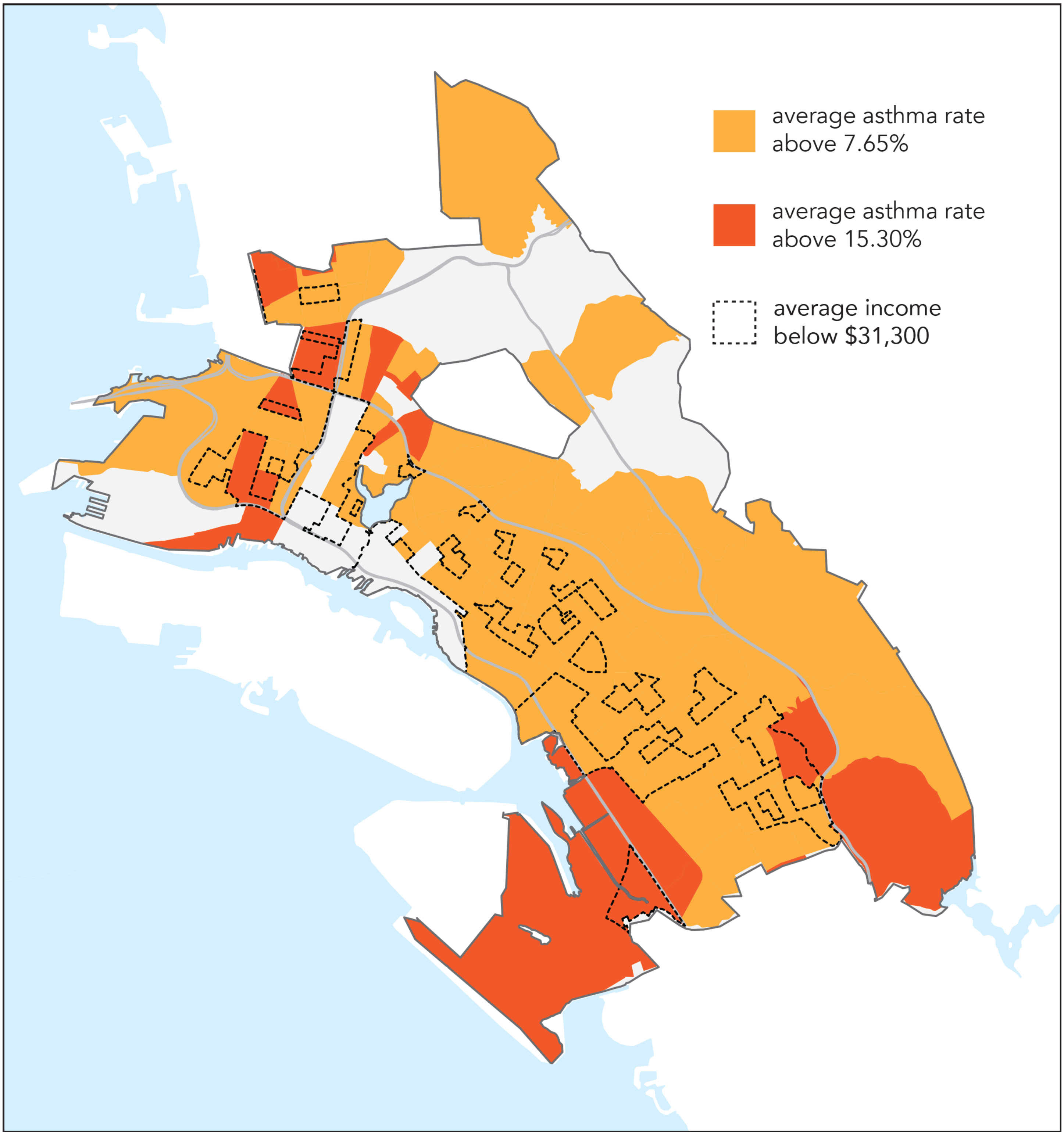

Figure E1.