Development of a Web GIS for Urban Sustainability Indicators of Oakland, California

By

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LIST OF ABBREVIATIONS

ACS	American Community Survey
AGI	Ambient Geographical Information
API	Application Programming Interface
CBG	Census Block Group
DOT	Department of Transportation
EGPR	Environmental Goals and Policy Report
EPA	Environmental Protection Agency
EPI	Environmental Performance Index
GHGRP	Greenhouse Gas Reporting Program
GMS	Green Map System
GIS	Geographic Information Science
HUD	Department of Housing and Urban Development
LEHD	Longitudinal Employer-Household Dynamics
NIMBY	Not In My Back Yard
NRPI	Natural Resource Project Inventory
NSIP	Neighborhood Sustainability Indicators Project
PPGIS	Participatory Planning Geographic Information Science
REST	Representational Estate Transfer
SCI	Sustainable Communities Index
SCP	Santa Monica’s Sustainable City Plan
SI	Sustainability Indicators
SLD	Smart Location Database

SoVI	Social Vulnerability Index
SUD	Sustainable Urban Development working group
SUV	Sustainable Urban Village
TIGER	Topologically Integrated Geographic Encoding and Referencing
URL	Uniform Resource Locator
USGS	United States Geological Survey
VGI	Volunteered Geographic Information
xhtml	Extensible HyperText Markup Language

ABSTRACT

Anthropogenic climate change, growing populations, the decrease of essential resources, and the availability of funding to deal with these emerging conditions, provide the incentives for cities to mitigate and adapt through urban sustainability programs. Though web GIS applications visualizing features of sustainability do exist, few visualize actual sustainability indicators, and almost none visualize performance on the refined scale of the city. A web GIS application targeting such objectives with urban sustainability indicators was developed for Oakland, California. The application demonstrates a tool for planners and the public by creating a starting point for a time-referenced spatial view for the pace of progress. The six broad indicator elements determined by the city of Oakland's Annual Sustainability Report worked as the foundation to customize spatially related indicators meeting specifications of quality in representation and function. These customized indicators are climate change vulnerability, employment availability, housing, public transit accessibility, natural resource project inventory, as well as culture and community. Another application with editing capabilities informs the culture and community indicator with volunteered geographic information (VGI). The features demonstrated in the applications' functions include classifying methods of performance, a strategy-based approach informed with municipal policy, access to indicator attributes, as well as basic map capabilities allowing for zoom to neighborhood, toggling of individual indicator visibility, and an integration with social media resources. An overview of the steps in the application development process was documented. The application was made available for testing with a survey for feedback that was both utilized and acknowledged for future considerations.

CHAPTER ONE: INTRODUCTION

Sustainable development as presented in the *Brundtland Report* is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," offering an illustrative model of a triangle equally sided with ecological, social, and economic factors (Brundtland 1987, 37). Overall, this project integrates existing methodologies to demonstrate GIS sustainability using three techniques. First, the study conducts limited spatial analysis where needed to improve or geocode indicator measurement. Second, this study builds and documents an interactive web application for visualization of spatially sensitive indicators. Third, as appropriate for given indicators, this work develops a portal to volunteered geographic information (VGI), to invite public participation and gather necessary data that may not exist. The principal objective of this web GIS project is to demonstrate whether and how geographic information science and technology can provide a visualization platform for the evaluation of urban sustainability based on spatial criteria that enrich analysis of existing and customized indicators.

This chapter discusses the motivation for developing a GIS web application for urban sustainability at the local level of the city. Indicators developed at this scale for Oakland, Ca., were developed with the inclusion of Public Participation Geographic Information Systems (PPGIS) via social media outlets such as Twitter, Instagram, YouTube, Flickr, and Webcams.travel. A demonstration of the application will discuss these features as well as the programming results and future implications to expand and improve upon this body of work.

1.1 Motivation

Sustainability has become a global pursuit with government agencies in the United States offering programs, technical assistance, and funding opportunities for strategic growth within cities. Such partnerships include federal sustainable community revitalization incentives by the Department of Housing and Urban Development (HUD), Department of Transportation (DOT) initiatives for the promotion of walkable communities, and support from the Environmental Protection Agency (EPA) towards the protection of environmental and human health (EPA, 2013a).

The development of a web GIS application could aid in the efforts of sustainable urban planning and development by offering a visualization of performance and measurement towards municipal targets of sustainability indicators. Using Oakland, California as the case study location, the purpose of this application design and documentation is to reveal the strengths and weaknesses of the city's urban environment in a spatial context towards the goals and efforts of sustainability. This project seeks to establish a measurement of sustainability indicators, visualized to demonstrate performance at the spatial extent of the city of Oakland.

A web GIS application based on quality indicators of sustainability offers a tool for planners and the public to utilize potential state and federal sustainability opportunities by identifying need, demonstrating performance, and evaluating effectiveness. The tool may be a resource to the community of Oakland as well as an example of spatially visualizing and measuring sustainability for an urban environment. The application could act as a springboard to initiate similar projects in other cities or to expand for Oakland. Sustainability would also be more effectively promoted, recognized, and understood, with accessible geographic information readily available for view among planners, developers, and the citizenry.

Managing the database with new data throughout the years could display a reference for pace of progress in the city over time.

Spatial science and technology practitioners would benefit from the project by having transparent access to the methodologies and data used for its completion. Just as other GIS projects have been utilized and expanded upon within this work, a customization of applicable methods provided here may offer support to other related efforts. Other municipal agencies and departments may also find value and relevance in the determination of spatial indicators, the measurable scale of performance incorporated, or the method of development for the technology utilized here. Code, scripting, and functionality of web GIS components would also offer a template resource with a working version of what to expect from programming techniques.

1.2 Urban Sustainability

Growing human populations worldwide are increasing urbanization and sprawl making more imperative the need to address sustainability in these systems. In general, sustainability is about regenerating the means of living within a psychologically and physically healthy environment. Many of the resources on sustainability planning trace the examples and concepts of their models to the writings of Ebenezer Howard in 1898, To-Morrow: A Peaceful Path to Real Reform. His book inspired the “Garden Cities” of Letchworth, England established in 1903, followed by the Welwyn Garden City in 1920. The foundation behind the designs and concepts outlined by Howard focused its city planning emphasis on the preservation and enrichment of social and natural environmental relationships involved with the functioning and continuing of human development. His design plans can be described as a series of small, self-sufficient townships, interconnected through a mass transit system with a cultural center located at the core (Howard 1898).

Many proponents of sustainability remark on the opportunity of cities as large resource consumers to have the most influence in countering the implications of that consumption. Wheeler (2013) describes the problem of meeting such goals, as caused by allowing developers control over the design of large portions of land and building construction. This lightly regulated private sector control has fragmented development into suburbs and cut-off communities; creating development lacking in sustainability fundamentals across the country.

Sustainability proponents argue that the authority of local officials to approve or deny applications of such development should be utilized to advance sustainability features within communities. Such features should include mixed use zoning favoring pedestrian and public transit accessible to a diverse demographic of income levels, age, and ethnicities targeted for a dense availability of housing. Green space should be located nearby with a diversity of recreation for children, elderly, teens, gardeners, fitness fans, and naturalists.

Every neighborhood also has the potential for ecological preservation of biodiversity, perhaps from a creek that could be restored, small ponds or lakes, pockets of fields or woodlands connected with wildlife corridors, and even back yards filled with native plants. This inclusion of pedestrian networks and green space also benefits public health by promoting activity and countering the epidemic of obesity (Wheeler 2013). Web GIS can provide a valuable tool towards such goals, capable of offering a spatial perspective of these conditions. While the above objectives occur within the city, visualizations at the level of the neighborhood is where the work towards sustainability will be greatest.

1.2.1 Scale of Planning for Sustainability

The intrinsic geographic nature of implementing sustainability lies in the essential role of scale in planning. Wheeler (2013) discusses the scales of planning ranging from international, national, state and provincial, regional, local, neighborhood, and site planning. At the local level, which cities fall into, municipalities typically have control over land use, vehicle, bicycle, pedestrian networks, green space, parks, housing, education, and waste collection. Though the ability to actually implement sustainability measures is greatest at the local level, an issue with political systems capable of encouraging sustainability regionally or beyond, stems from the fragmentation and folding of urban boundaries creating suburbs and competition over jurisdictions and tax revenues (Wheeler 2013). A geographic application can visually manage these evolving boundaries to compare data within each, with analysis specific to actionable elements under the city's influence to adapt.

As Wheeler (2013) explains, these local level planning and development priorities for urban sustainability should be implemented through the connection of pedestrian friendly roadways, parks and recreation, mixed land use zoning that facilitates affordable housing, economic opportunities and community services. Other sustainability measures also typically under the local jurisdiction of cities, is over buildings and related systems, codes, and development guidelines to require and incentivize sustainability in materials, efficiency, and density.

The neighborhood level of planning contains the building blocks of cities and is needed to incorporate the beneficial measures in the power of city officials to change and improve. This web GIS application can bridge the communication gap by giving the city and public a tool for understanding and incorporating neighborhood provisions by providing data which residents can use to voice influence on governmental and municipal planners. Not In My Back

Yard (NIMBY) collaborations of residents and development with weak public regulation have carved out the tragedy of the suburban plight, cutting into more biologically rich regions to expand the trafficked reach of humans. Neighborhood design and in-fill potential to incorporate density is embedded into the census block group (CBG) and analyzed at the neighborhood scale allowing for the planning of street-scape design, open space availability, equity, public health and other such elements that urban form and design have influence over.

According to Wheeler (2013), although sustainability of some sort is included in the general plans of more and more cities, measures are often symbolic rather than substantive. Portney's (2002) analysis of 24 major U.S. cities using an established index of taking sustainability seriously found that actual implementation and actionable initiatives were lacking in the majority of them. The findings pointed to the need for real goals and tools, such as sustainability indicators to measure progress. Climate Change specifically was an area most essential to the need for implicit measures, such as facilitating recycling, pedestrian and public transit, and reducing greenhouse gases through the certification of public structures and conversion of city vehicle fleets to efficiency standards. To be effective, these initiatives should be meaningfully associated with policy and programs that can be monitored, evaluated and institutionalized to endure over the long-term (Wheeler 2013). Customizing sustainability indicators provides the ruler by which to measure progress or regression of sustainable development and communicate meaningful progress.

1.2.2 Sustainability Indicators

The complexity of determining appropriate measurement indicators of sustainability is that there are so many credible models that exist, though none is universally accepted or utilized. In Hecht's (2006) discussion of whether indicators and accounts can really measure sustainability, the definition of sustainability itself is questioned, noting that unjust dictatorial societies have been sustained historically for hundreds of years. Adding social equity to the contemporary definition of sustainability entails that subjective decisions must be incorporated to include values that such a system might attempt to achieve. In environmental and economic terms, would sustainability goals imply continuing current living standards and practices or adjusting them into the adaption of viable practices for continual resource-use at a perpetual state without considering advancements such as new technologies?

Taking a deeper look at the ability of existing indicator systems to actually determine sustainability, Hecht (2006) begins with the international system of the United Nations, based on 58 metrics meant to measure social, economic, and environmental sustainability. However, as much as we care about data such as life span, child mortality, green house gas emissions, species diversity, or GDP, these parameters are individually and collectively unable to tell us whether a society is sustainable. Although one of these, for example air pollution, may be able to provide insight into what is not sustainable, since pollution at a certain level will cause sickness, beyond that upper limit, is there a measurement that would be an indicator that the environment is sustainable?

This raises the question of whether it would be appropriate to suggest that any metric based on the crossing point where human damage is observed should be considered sustainable. Other indicator systems use a goal-oriented approach in which progress can be charted away or towards targets over a period of time. Being based on an ideal notion of sustaining or improving economic, environmental, and social goals, the argument of subjectivity again arises as such targets are based on decisions of value. As there is no devised system that can irrefutably determine a sustainable society, the best that can be hoped for is that any sustainability indicator system generates information about whether current practices lead in a direction that is not sustainable or draws attention towards problems that may conflict with predetermined ideals of quality in the welfare of our economic, environmental, and social conditions (Hecht 2006).

Developed by both experts and citizens, the use of sustainability indicators (SI) has grown rapidly since their inception in the 1990's. Turcu (2013) discusses some of the complications associated with the use of SI in urban areas; such as the reliance of cities on outside resources contradicting the very definition of sustainability and that the objective for sustainability is not feasible. However, urban SIs are arguably a useful tool to measure and communicate conditions to drive more efficient use of human and environmental resources. Such information can be used to improve quality of life and replenish natural capital propelling cities into role models of sustainability. As the underlying nature of SIs is political and social, an integration of the expert-led, top-down model with the participatory citizen-led model is required. After analyzing over 170 indicators, discussed by over 60 'sustainability experts' and hundreds of residents from three urban areas in the UK, Turcu found that integrating both models worked best to make measurable progress towards resource goals while considering value-based neighborhood elements important to local perspectives (Turcu 2013).

The integration of expert and citizen derived data is included in the indicators developed for the city of Oakland to be used in this application, with indicators that are informed by empirical metrics as well as from community and social media resources. The determined indicators with municipally set targets and objectives would ideally be updated to evaluate progress over time. To make a meaningful contribution towards implementing a measure of sustainability in cities, a geographic understanding of current circumstances and site potentials should be specifically customized to local values, needs, and regulations.

1.3 Participatory Planning

Cilliers (2014) outlines the importance of involving the actual inhabitants of neighborhoods with the decisions and plans affecting their area. The qualities of ‘experience’ and ‘feeling’ are sought by urban planners using place-making strategies to influence social dynamics. The inclusion of local stakeholders works to accentuate the creative process to more effectively determine and bring about such design. Cilliers (2014) also notes that engaging the citizenry is an act of democracy that meets a basic human need for participation, improving the psychological health and happiness of an involved community (Cilliers 2014). Collecting data by the people and making it transparent to the public supports the expansion of equity into the urban fabric by revealing conditions that may provoke action where the data suggests it lacks. Incorporating public participation into this application design intends to do that.

1.3.1 Public Participation Geographic Information Systems (PPGIS)

The field of public participation geographic information systems (PPGIS) is an important element in the response to the call for participatory planning. A key subset of PPGIS is known as volunteered geographic information (VGI). As labeled by Goodchild (2007), VGI builds geographic data through large-scale use of people contributing geographic intelligence due to the willingness to participate. Data researchers, community planners, and emergency response have utilized the power of VGI by gathering and structuring of crowd-sourced data. Acquiring data through PPGIS would bring great benefit to the evaluation of contemporary sustainability through the inclusion of social variables.

Flint (2013) discusses the mapping of neighborhood assets as anything a resident might view as adding value to their community or would consider to hold cultural meaning and importance. Asset mapping is defined as a community-based tool to identify anything from people, places to organizations that improve the quality of life for the people exposed to them

(Flint 2013, 122). In determining the sustainability of such assets, evaluating criteria including the community's self-sufficiency and local production ability such as urban gardens, recycling, and certified structures can be included to define features in a PPGIS application.

A pilot project in Oakland, documented in "Ecocity Mapping Using GIS: Introducing a Planning Method for Assessing and Improving Neighborhood Vitality" provides an example of spatially accessing neighborhood vitality and assets (Smith and Miller 2013). The project used GIS with twenty-three variables to evaluate neighborhoods and recommend a site for an affordable housing development or Sustainable Urban Village (SUV). PPGIS technologies offered a platform for the input and rating of attributes for locations of value to participants (Smith and Miller 2013).

In another example, the Flathead Indian Reservation in Montana utilized a Web-based mapping technology to characterize and rate the places important to residents, along with their perceptions of the threats to these assets in the pursuit of resource management and cultural valuation of the landscape. These contributions were incorporated, expanding the boundaries determined by managers for conservation to include areas of cultural meaning (Stewart et al. 2013).

Examples featuring the accuracy and relevance of such crowd-sourced distribution of geographic information can be seen especially in events of crisis such as earthquakes, hurricanes, or disease outbreaks like the H1N1 flu. These data chains derived from PPGIS, have proven invaluable, with the crisis-mapping platform Ushahidi used in Haiti as a specific testament to open, decentralized, real-time data captured publicly. The data even proved to be so reliable that the platform was found to be more useful than the established authoritative maps for government and aid workers to find open routes and areas in most need of distribution of emergency services (Roche & Mericskay. 2013).

In an attempt to inventory community resources, PPGIS will also be used in this project to deem assets as determined by residents themselves. The accuracy of such methods has been shown in similar projects and can be evaluated even further for credibility through the inclusion of social media.

1.3.2 Social Media and Ambient Geographical Information (AGI).

As distinct from volunteered geography, Stefanidis (2011) defines social media data collection using geographic keyword trails defined as ambient geographical information (AGI). Though such messages may not be expressly geographic, geographic footprints can still be found in the metadata that often is attached with author, time, and geolocation. More often however, this locational information is contained in the geotag or keyword in the title referencing an area or location that can then be associated and mapped. The Arab Spring demonstrates this vividly, in which tags such as Tahirir Square communicated clearly to the outside world the relevance of the location as a hotspot of activity. Harvesting such data can provide not only human relationships with the landscape, but also the evolution of these relationships over time. The power of using crowd-sourced AGI can elude the burdens of “up to 85% of the cost” typically accounted for in traditional GIS data capture.

One important critique of AGI is that it is derived from a selective sample of social media users. However, more and more individuals participating in such contributions are steadily moving these activities into the mainstream with the increasing deployment of GPS in mobile devices and tablets. As such, the use of AGI can then be considered as a means of analyzing the evolution of “the human social system” as it adapts and changes over space and time (Stefanidis et al. 2013).

Determining keywords to query such social media resources as well as a valuation of such results from metadata tags from sources such as Flickr, Instagram, and Twitter reflect the semantics of geography, which can demonstrate relevance of returned results by number of photos uploaded per location, number of individuals uploading photos per location, and the commonality in tags used. From these insights, it is then inferred that the more photos, by the more users concentrated in specific areas, is more likely a greater representation of place that can be established by social media (Mackaness and Chaudhry 2013). The combination of PPGIS and AGI to provide an inclusive social metric in the valuation of locations considered as assets to the community can be attained in such a way through social media. The mapping of these data can provide information at a glance of which areas may be more socially vibrant and closer to the ideal of sustainability in culture and community.

CHAPTER TWO: RELATED WORK

This project seeks to create a visualization resource depicting sustainability that could offer support to planners, decision-makers and the public with insight for future planning. Although many cities use some form of sustainability indicators, few utilize a web GIS application. Representing the National Center for Biotechnology Information, Visser (2014) documents the collaboration with U.S. National Library of Medicine, and The Associated Press, of research on attention span with findings that ability to focus on a given task has been decreasing over the past decade (Visser 2014). In terms of web page interaction, Weinreich et al. (2008) studied 59,573 page views, and found that users only read an average of 49% of the words on sites with 111 words or less. Attention drops further on longer web pages, with only 28% of the typical webpage, with around 593 words, actually getting read. For each additional 100 words on a webpage, approximately 4.4 seconds is spent (Weinreich et al 2008).

To realize the benefits of reporting sustainability indicators, visualization is key. A web GIS is important because it easily communicates a great amount of information visually with the need for fewer words, links, and pages to navigate through. As most cities with SI programs already have webpages for reporting, an interactive map application would offer a practical complement that easily conveys data while keeping the users attention through interactivity.

This chapter starts with a brief review of an indicator classification method, followed by Oakland's SI program and web resources, a review of sustainability indicators as they are presented online for other urban areas, and examples of other web GIS applications. Each area provides background needed to understand the development of Web GIS for urban SI programs.

2.1 Quality Standards in Indicator Methods

Following the 2010 World Urban Forum in Rio de Janeiro, Brazil, the White House Office of Urban Affairs and U.S. HUD Department, with support from the Ford Foundation, coordinated a group of stakeholders from government departments along with private and non-private sectors throughout North America to evaluate approaches to sustainable urban development in the U.S. and Canada. This became the Sustainable Urban Development working group (SUD), which investigated, prepared, and detailed an analysis of indicators used in the United States. From this effort, they determined a standard of quality in indicator systems, documented by Lynch et al. (2011). They explored urban sustainability indicators through the lens of the environment, economy and society, determining multi-element indicators to be more effective than single element schemes and recommending a lean concise system with a goal-oriented framework.

The SUD working group also recommended a classification of indicators as a pressure, state, or response. A pressure is an act or threat against sustainability, for example, carbon release. These measurements would be based on minimizing such threats that counter sustainability. The state indicator is a current measurement, typically numeric, of existing conditions in relation to sustainability objectives. Response measures evaluate programs or efforts designed to respond to the states and pressures that contradict sustainability objectives. These classifications may overlap with each other when one indicator falls into two or more categories (Lynch et al. 2011). Utilizing the recommendations offered by the SUD working group can work to establish methods of producing quality indicators with a categorization that offers a standard of measurement and tracking of sustainability objectives away or towards target goals.

2.2 Oakland's Sustainability Indicators (SI) Web Reporting Program

In Oakland's pursuit of sustainability, an array of data, maps, and indicators are made accessible online. The Sustainable Oakland Report, prepared by the city since 1999, provides the basis for this hosted data and covers six focus areas that work as indicators for sustainable objectives. These are buildings, energy and climate; economic prosperity; education, culture and community; health, safety, and wellbeing; housing, land use and transportation; and natural resources, waste, and environmental health. Figure 1 below is a view of the sustainable Oakland home webpage. Clicking on the link for each focus area reveals more details concerning the indicator with highlights of progress made concerning the area of interest and followed by measurement status of performance.

Figure 1. Sustainable Oakland Home Webpage- Links to focus areas on the left.

Figures 2 below provides an unscrolled view of the Housing, Land Use & Transportation focus area with a synopsis of the indicator and highlights including Affordable Green Developments, Transit-Oriented Development, and Bicycle Plan Implementation. The bottom of the page contains a section of measured performance and links for additional resources related to the focus area.

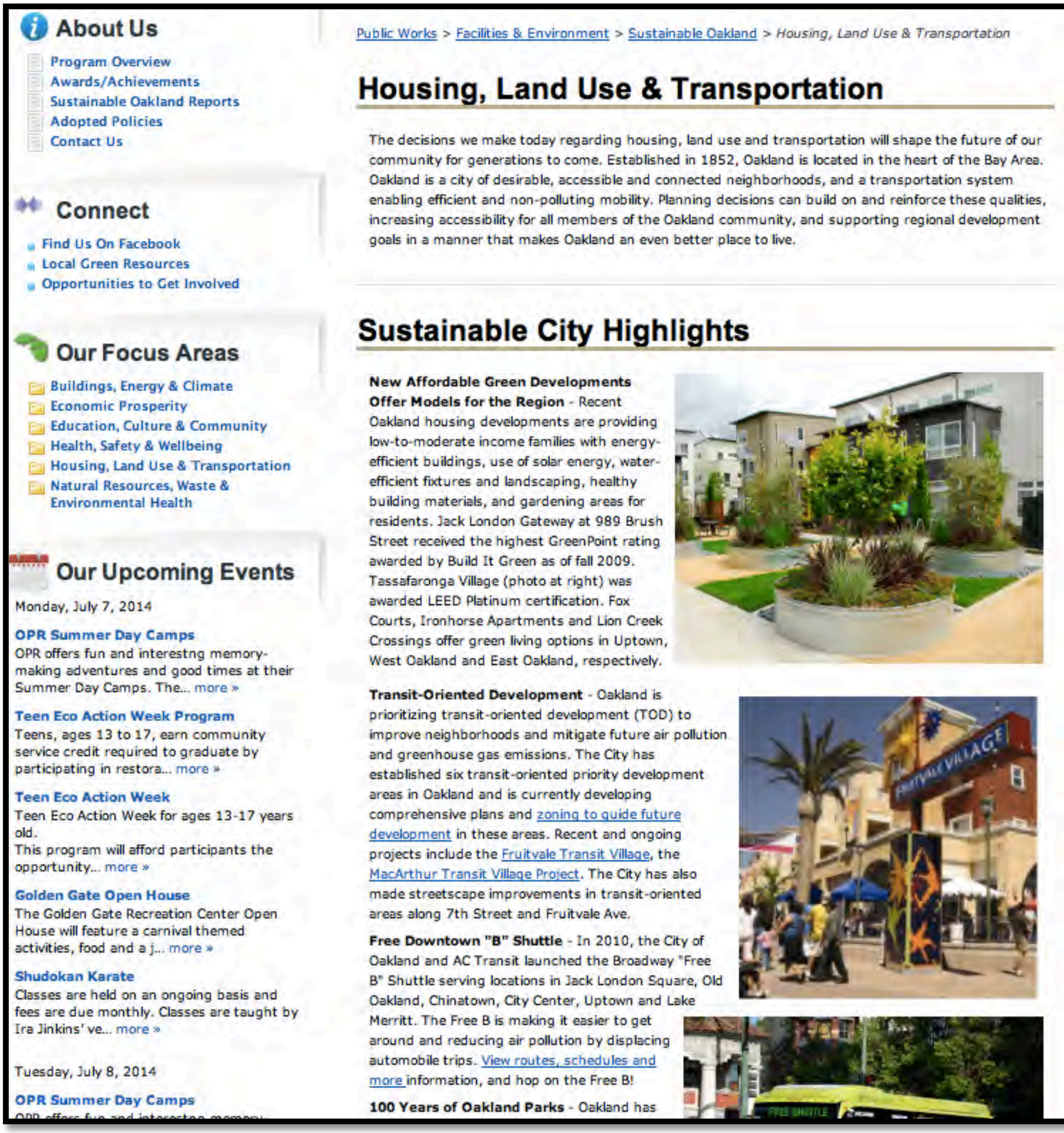

Figure 2. Housing, Land Use & Transportation Webpage- Top of page view with brief description of the focus area and highlights of related city progress.

The SI program for the City of Oakland provides multiple links and webpages with a vast array of words, graphs, and images for each of the SI focus areas (City of Oakland 2013). A web GIS application could provide an overall summary of this detail to communicate the indicator metrics at a glance.

2.3 Urban Sustainability Indicators Online

In selecting examples with the multitude of cities that use sustainability indicators, it is useful to begin with cities that rank high on sustainability measures. Corporate Knights, Inc. (2013) provides a list ranking the most sustainable cities in North America. The five categories: environmental quality, economic security, governance and empowerment, infrastructure and energy, and social well being, were measured using 27 indicators, such as population density, pollution, and education. Of the United States cities included in the assessment, San Francisco, Washington DC, and Boston ranked the highest for sustainability (Corporate Knights inc. 2013). The SI programs and associated web page resources for these three cities are briefly reviewed here.

2.3.1 San Francisco

Indicators for San Francisco are based on the Sustainable Communities Index (SCI). This indicator system uses over 100 measures based on the five evaluation requirements of measurability, appropriateness of scale, motivation, responsiveness to action, and relevance to human health and sustainability. San Francisco's Department of Public Health maintains data for the city's main indicator categories: environment, transportation, community cohesion, public realm, education, housing, economy and health systems. Each indicator includes sub-categories of action-oriented goals, which each also include additional child sub-categories of primary indicators. Figure 3 is the homepage view of this hosted data with the main indicator of Environment visible, along with the action-oriented goal, "EN.1. Decrease consumption of energy and natural resources". Exposed below this goal are the primary indicators of natural gas use, electricity use, water use, solid waste disposal and diversion, and renewable energy production. Getting to all of the information for these indicators requires an extensive navigation of links through each indicator element, category and sub-category.

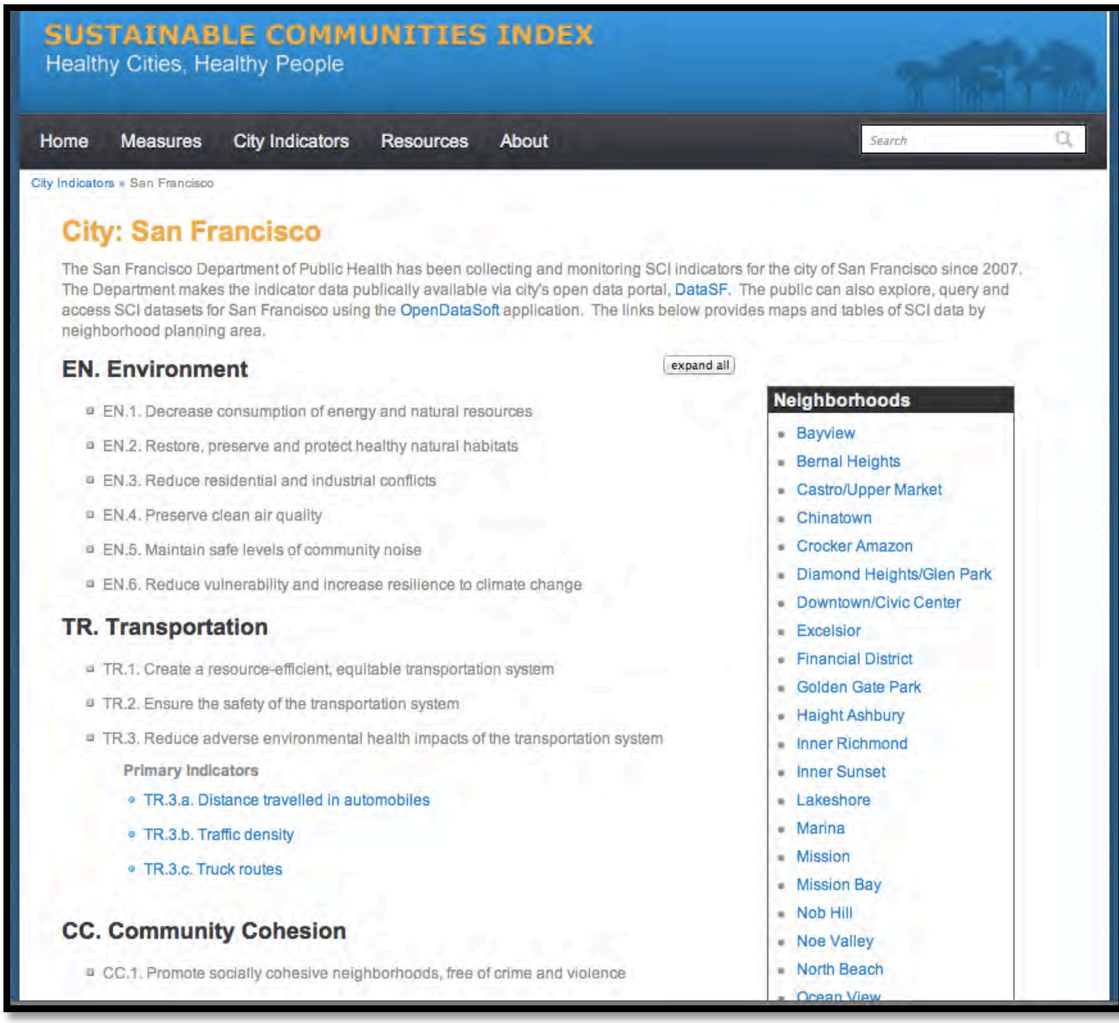

Figure 3. San Francisco Sustainable Communities Index indicators Webpage- Transportation primary indicators exposed in list showing the 3 levels of categories with additional resources.

Upon exposing the primary indicators, clicking on each reveals an analysis, an interpretative overview, data sources, and a table of the relevant data organized. The following figure is found on the web site upon clicking the Open Space primary indicator, which is a child of the “EN.2. Restore, preserve and protect healthy natural habitats” action plan, which is a sub-category of the main indicator, Environment. Open spaces and natural areas are color-coded in the map below when clicking this primary indicator.

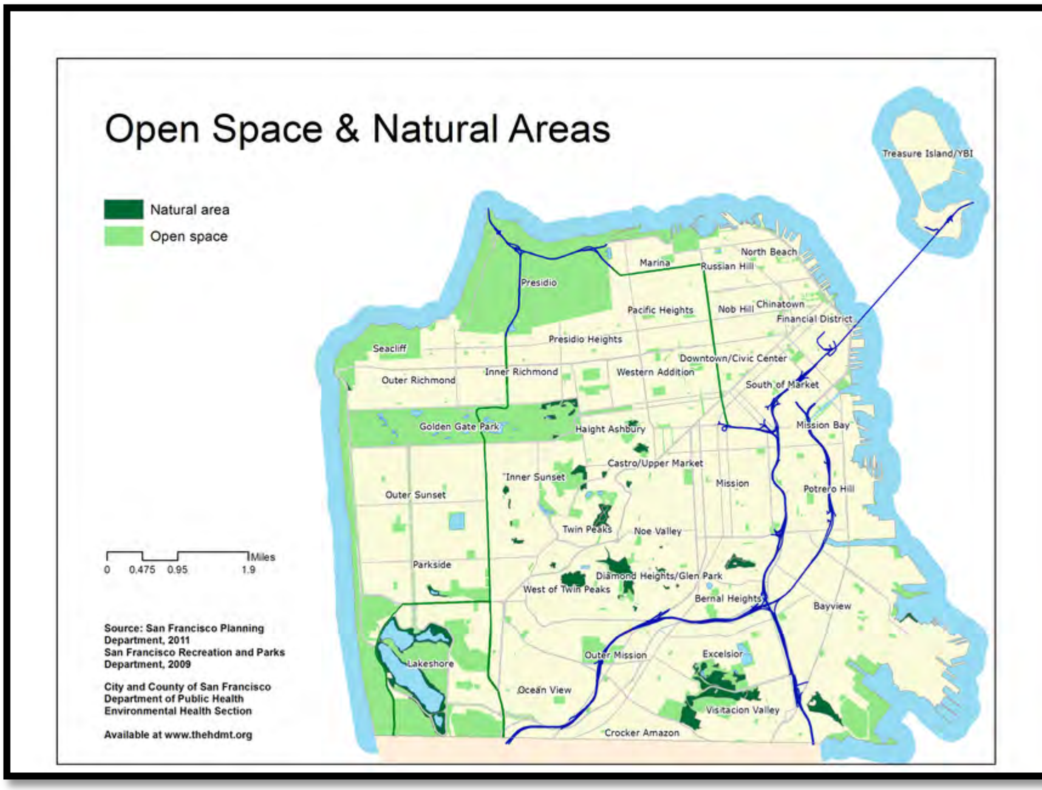

Figure 4. Graphic GIS Map Image for San Francisco- From the Environment indicator, a geographic analysis communicates part of the Open Space primary indicator.

Although other San Francisco indicators are informed with static maps, they lack the interactive experience and level of detail needed at a glance to inform decisions of sustainability. Scrolling down to the middle of the Open Space primary indicator page is the indicator's interpretation and data sources with an analysis table of the data for open space in terms of acres and percent according to neighborhood. A section for interpretation and analysis followed by data sources is at the bottom of the page. A total of 90 links to similar pages for primary and secondary indicators is available from the webpage.

2.3.2 Washington, D.C.

Next on the Corporate Knight list of sustainable U.S. cities is Washington D.C. An overview of the Washington D.C. indicators is available at their webpage for Neighborhood Sustainability Indicators Project (NSIP) (2009). These indicators were developed through a participatory process with the local citizens. Categories of energy, environment, mobility, economy, and social capital, were established as the framework for goals for each neighborhood. A baseline of indicators under each category is represented as a measure of conditions to work from, beginning with 2009 and 2010 data. The goals developed are: increase energy conservation, increase production of renewable energy, increase environmental management of buildings, increase water conservation, increase water quality in neighborhood streams, restore, enhance and protect tree canopy, increase use of greener modes of transportation, increase the number and quality of local green businesses, and expand the community's green social capital. The figure below displays the list of goals on the webpage as it initially appears, with the option to expose the related indicators of each by clicking the plus sign.

Exposing the sub-categories to each listed goal reveals the primary indicators, targets, and progress to date. It also suggests actions for the community and individuals of each. Figure 5 below demonstrates the opening of "Goal 9: Expand the Community's Green Social Capital," revealing the primary indicators as the number of NSIP participants and activities with a table of the targets and current status of progress, and the suggested community and individual actions listed below.

\- Goal 9: Expand the Community's 'Green Social Capital'

Primary Indicators

- Number of participants in NSIP Pilot activities
- Number of NSIP Pilot activities conducted

Targets and Progress

2011 Target: 100 Participants in workgroup-led activities

2010 Attendance/participation	Current Status (2013)
• Total 700 participants* • 400 during the 2009 and 2010 Expos • 200 during 4 workshops • 100 at the workgroup and TAC meetings • 18 Workgroup Meetings * as of October 2010 ** attendance can be double counted and is estimated	• 5th Annual Expo was held in partnership with UDC Sept 7 with > 500 attendees • Mailing list – 138 members • Facebook page – 195 fans • Soapstone Creek Cleanup was held in partnership with RCC April 6 with > 20 participants

Suggested Community Actions

- Establish a Saturday Swap "Freecycle" facility using temporary urbanism opportunities
- Create a resource that summarizes existing and promotes new sustainability curriculum / education opportunities available in neighborhood.
- Create new and improve existing community gardens
- Educate / engage community through green journal / newspaper / website – See the Forest Hills Connection
- Organize seminars showcasing community sustainability efforts and best practices
- Create an interactive sustainability map to include farmers markets, compost piles etc.

Suggested Individual Actions

- Participate in Washington DC's freecycle group
- Actively participate in the neighborhood community garden program – See Melvin Hazen Community Garden
- Subscribe to the Green Living DC email list, follow the Facebook page and keep up with the Forest Hills Connection sustainability news

Figure 5. Screenshot for Washington D.C. Indicator Format- Additional information available for each goal as displayed clicking the plus sign next to Goal 9: Expand the Community's 'Green Social Capital'. (Green Living DC 2014).

2.3.3 Boston

Another example, also hosted online is the Boston Indicators Project. For over a decade, the city has tracked data in 10 primary Sectors with six cross-cutting topics into 70 broad goals with sub-categories of 150 indicators and almost 350 measures. The primary sectors are civic vitality; cultural life and the arts; economy; education; environment and energy; health; housing; public safety; technology; and transportation. Clicking on each sector opens up its own webpage with a description of the indicator with links below the description for a sector overview; key trends and challenges; and accomplishments and developments. The following section provides a spotlight of the indicator with maps, blogs, data and other relevant links with additional information on the sector. Figure 6 below displays the top of the Housing sector webpage.

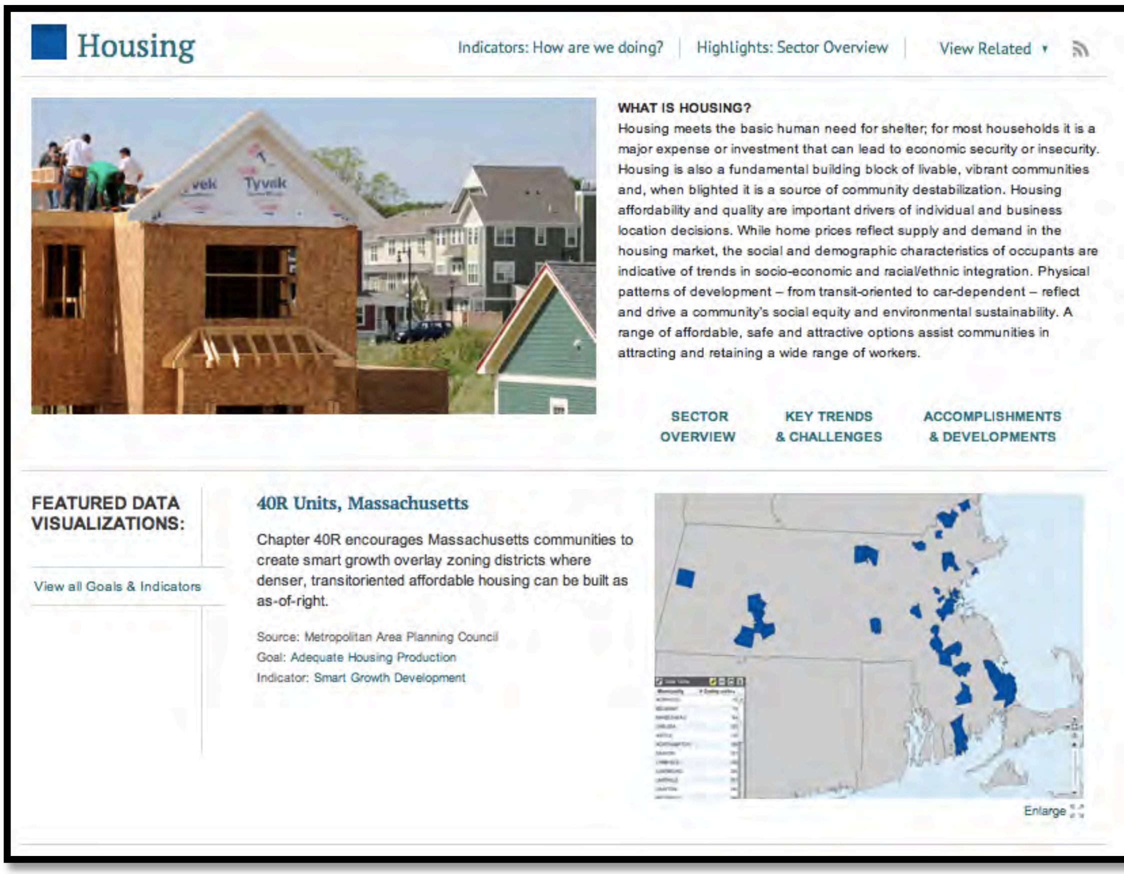

Figure 6. Top of the Housing Sector Webpage for Boston.- Details the sector with additional links and a featured data visualization section if scrolled to below.

The use of maps is abundant throughout with the communication of data and information displayed visually. Scrolling down the Housing web page is a dispersal of geographic analysis with a multitude of links. It is clear that within each indicator are even more links and a vast number of clicks that would be required to get to every map offered within each of the ten sectors represented, truly testing the user's attention span.

An even greater extent of data, information and detail on each of the cross-cutting topics is included in the city of Boston's sustainability methods. The cross-cutting topics are: Boston neighborhoods, children and youth, competitive edge, fiscal health, race and ethnicity, and sustainable development. For each topic, a multitude of indicators hosting a pop-up with more details can be expanded or collapsed. The figure below is a view of the Children and Youth topic, which hosts an additional 34 indicators. The view in Figure 7 below has expanded indicator "3.3.5 Families Living in Poverty".

Figure 7. Screenshot of the Children & Youth Crosscut Topic by the city of Boston- Displays the pop-up for the Families Living in Poverty indicator.

(Boston Foundation 2014).

The use of maps here again in this indicator subcategory is more graphical than as an interactive focal point. Much of the same data presented in the multitude of maps throughout the Boston website is included in the Oakland Sustainability Indicator web GIS. The extensive navigation required in all of these urban examples of sustainability, could all be more comprehensively represented as multiple layers in an application all found under one uniform resource locator (URL).

2.4 Web GIS Applications

One example of providing sustainability indicator metrics at a glance is from the Santa Monica Sustainable City Plan (SCP). Since the program began in 1994, targets have been designed and redeveloped over the years with a strategy to minimize negative social and environmental impacts. The SCP indicator system has evolved to provide specific goals that can be measured for progress over time. By visually indexing a simple scale of 100 and using the spider diagram in figure 8 below to illustrate such results, city staff are able to present progress and results for easier comprehension.

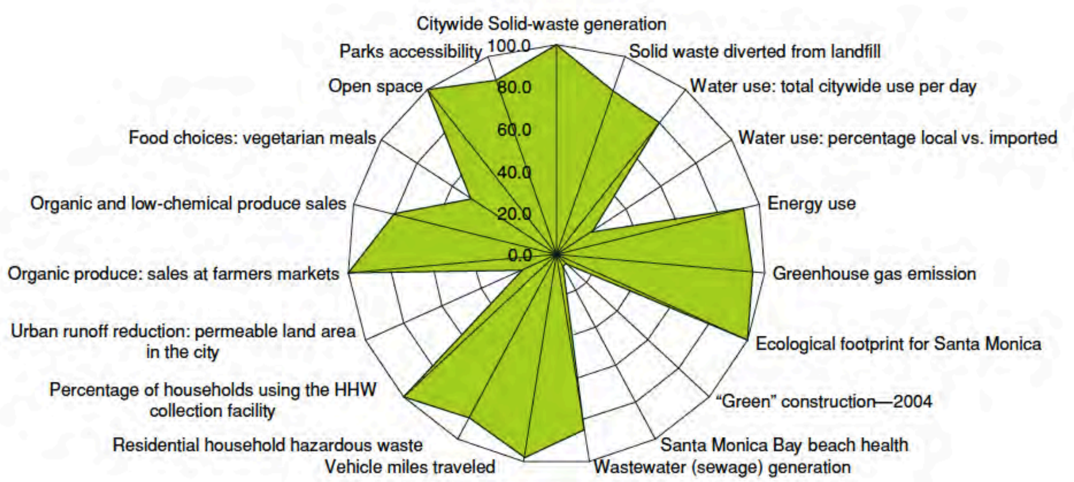

Figure 8. Santa Monica Spider Diagram of Sustainability Indicators

(Bertone et al. 2006).

Though such a diagram meets the intention of easily communicating data, a mapping application also combines the complexity of understanding the geographic element of a city as well as allowing for interaction to engage the user and provoke greater interest.

There are very few interactive web GIS maps representing progress in sustainability or any kind of classification, evaluation or analysis of metrics. The Explore Santa Monica GIS Applications does offer the interactive component, allowing users to zoom to neighborhood, move the map, add mark-ups for remote viewing, and toggle selected layer visibility. There are 12 layers under their Sustainable City folder including locations that can be classified as alternative vehicle fueling, community garden, green business, and oil recycling centers. The screenshot below offers a view of the interactive map with these layers selected for view.

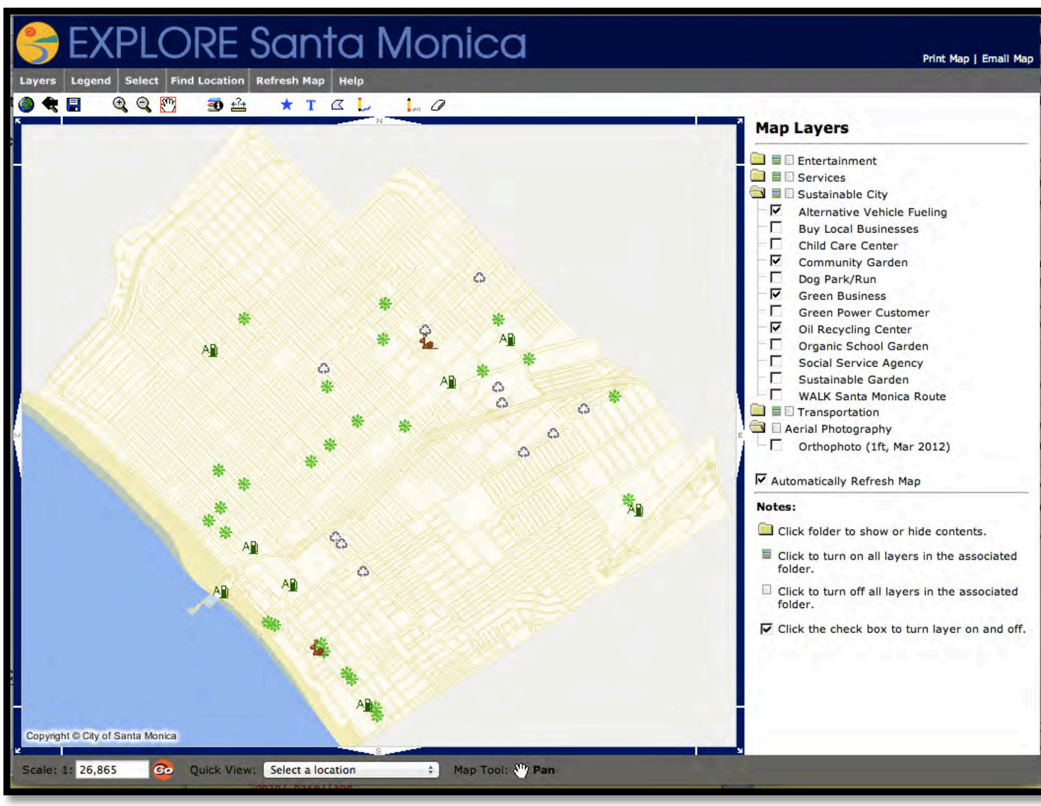

Figure 9: Screenshot of Explore Santa Monica web GIS Application- View with all but the sustainable city folder collapsed.

(City of Santa Monica 2013).

The Open Green Map System (GMS), has hundreds of participants from cities around the world utilizing their methodology with mapping tools and legend of icons signifying sustainability. This symbology includes graphic representations for recycling, urban gardens, renewable power, and public transit to name a few. Some of the U.S. cities taking part in this initiative include Baltimore, Long Beach, Detroit, and Jersey City, which host interactive versions of this mapping technique. Figure 10 below is an interactive web GIS application using this methodology for Baltimore, Maryland.

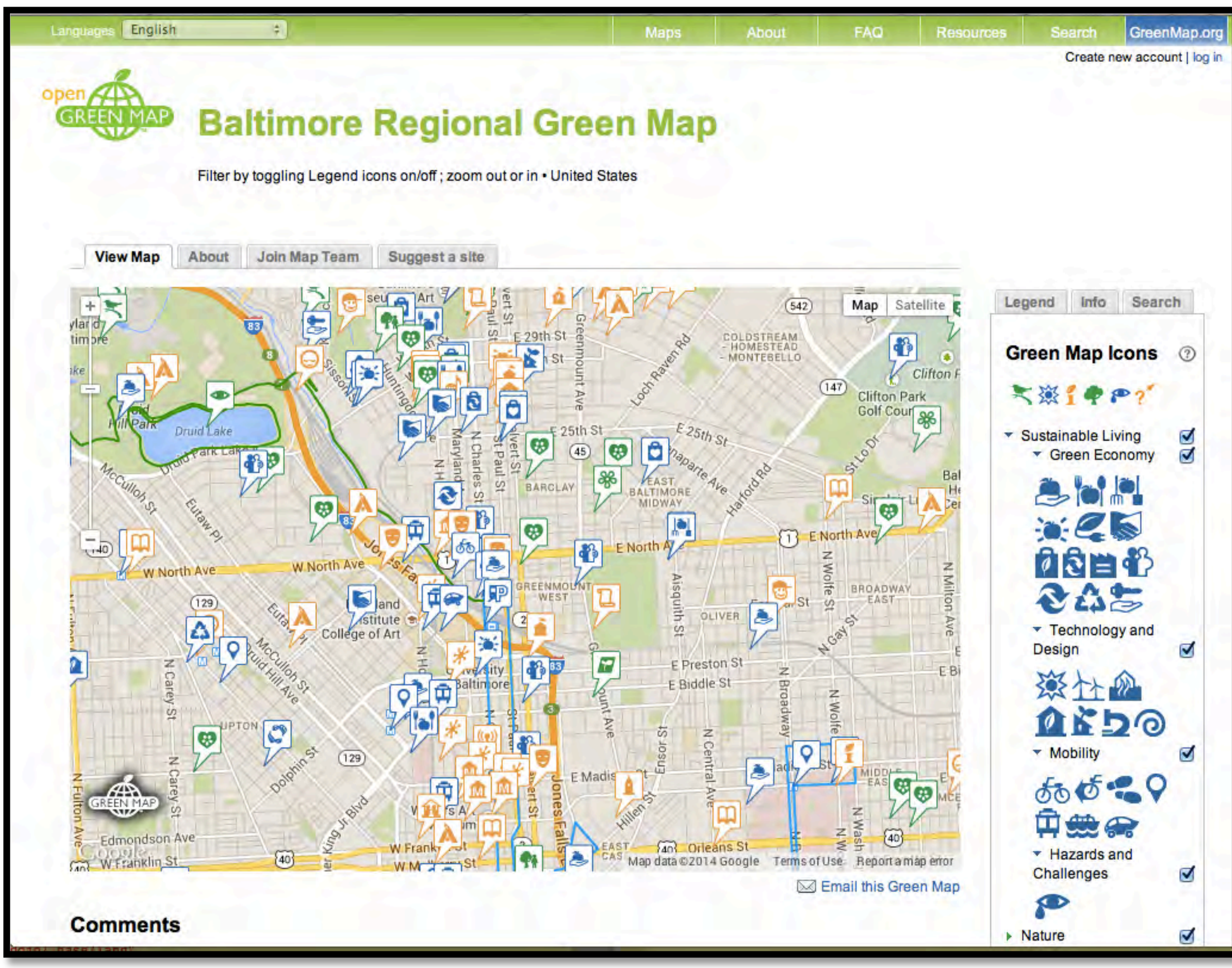

Figure 10. Baltimore Maryland's Web GIS- Uses the Open Green Map methodology.

(Green Map 2014).

Although the symbology in the Santa Monica and Open Green Map applications represent an extensive array of locations associated with sustainability, they provide no metrics or criteria to demonstrate any type of performance index. A user of these maps may be able to find locations in a city that have been categorized as sustainable, but such maps offer no way to differentiate conditions between neighborhoods or inform efforts to improve sustainability.

In another web GIS example of sustainability, the Canadian city of Surrey provides comparative data of performance over time in indicator themes including transportation, energy, housing, and more, though much of the spatial information is not represented as such. For example, figure 11 below demonstrates choosing the ecosystems theme in the list on the left of the webpage, and the park land indicator from the associated drop-down box. This reveals a graph of acreage by type, although this type of indicator would be well suited for geographic representation.

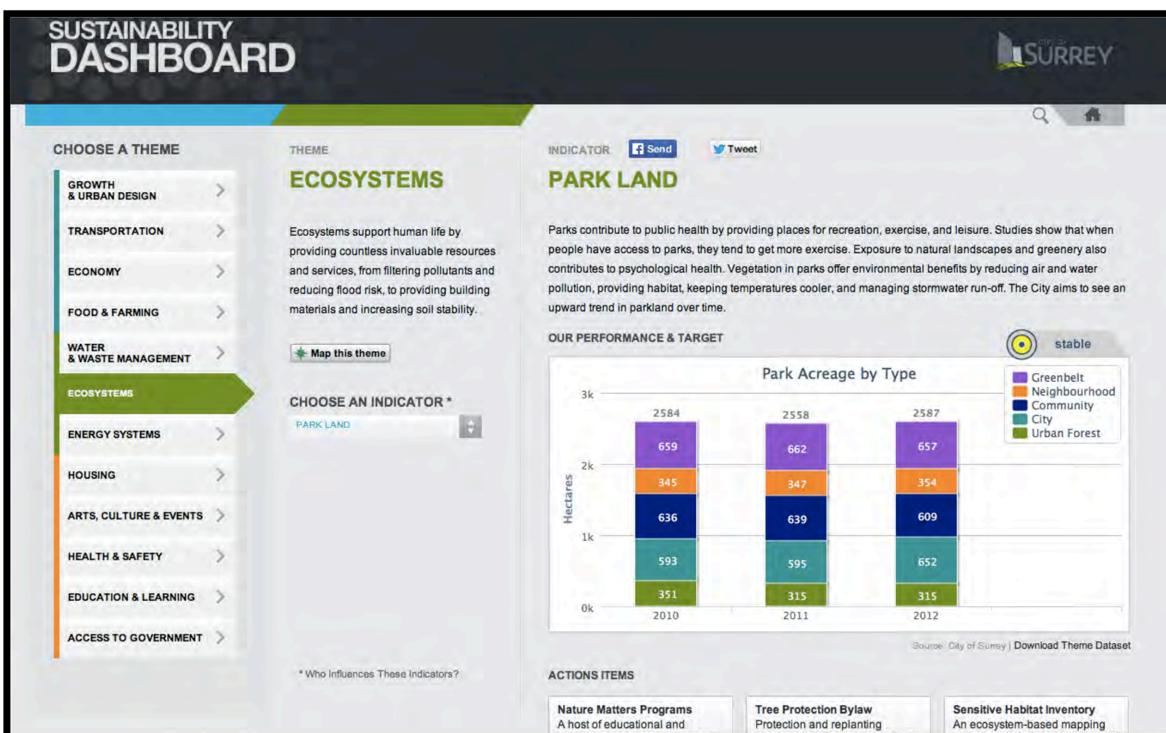

Figure 11. City of Surrey's Sustainability Dashboard- Demonstrating the park land indicator.

For indicators that are displayed geographically, similar to the Santa Monica and Green Map methodologies, they simply display certain locations rather than any type of evaluation. For example, under the growth and urban design theme, the interactive map simply shows the locations of transit, town and city centers and green space (City of Surrey 2014).

The only interactive web GIS application found for comparison that is based on a visualization of performance in sustainability indicators is the Environmental Performance Index (EPI) developed by Yale University. The map covers an exhaustive list of indicators that combine into an EPI score. These are classified into categories with sub-categories of indicators. For example, the forests category is characterized by the forest loss, forest cover range and growing stock change indicators. Figure 12 below is a snapshot of this application displaying the sulfur dioxide emissions per capita, which is an indicator of ecosystem vitality.

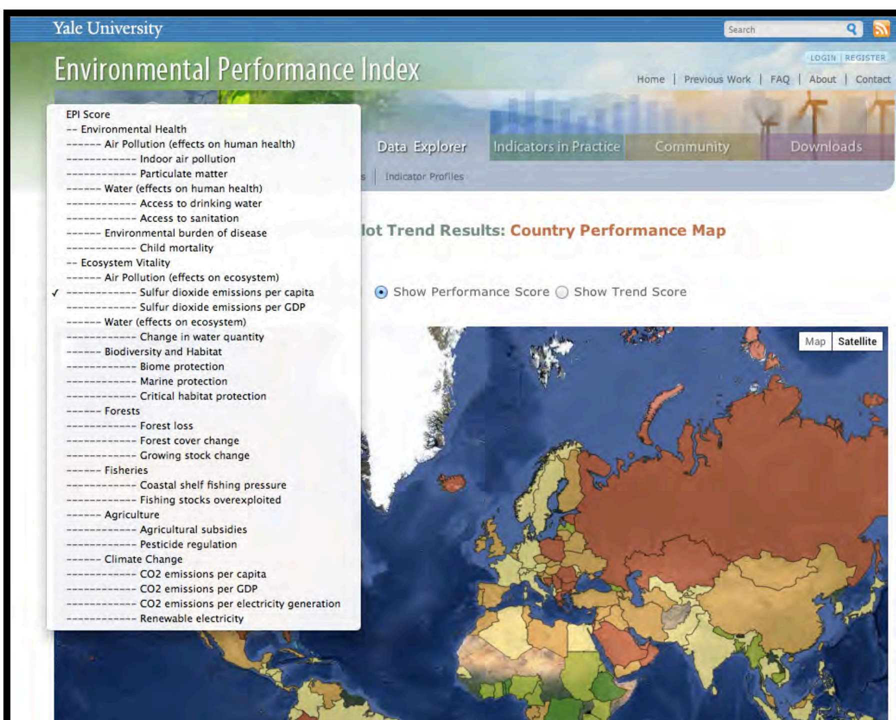

Figure 12: Environmental Performance Index Web GIS- Displaying layer for sulfur dioxide emissions per capita.

(Yale University 2013).

Although this application does provide an analysis of indicators as a measure in a quality classification system, and could also be utilized to chart progress over time, the extent is only available at the global scale so that these indicators can only be selected and viewed in terms of countries. Overall, the reviewed web GIS applications for sustainability found for comparative example, either lack as a measure of performance, are limited in spatial context, or are not available at the extent of the city. This project intends to meet these criteria.

CHAPTER THREE: STUDY METHODS AND APPLICATION DEVELOPMENT

The following chapter will discuss the study methods used to process the sustainability indicators and the development of the web GIS application from data to browser. There are three interactive maps on the hosting webpage, each using the data visualization capabilities of GIS, delivered as interactive content to the public through the internet. The first map is based on data provided by the Smart Location Database, Natural Resource Inventory Projects database, and the Vulnerability Index created by the Pacific Institute, as well as social media resources. The second is based on California landmarks from USC's Geoportal and a .kml file of Google "culture" and "community" keyword results. The third map is based on EPA data accessed through the EPA application programming interface (API) and is described at the end of this chapter.

This project builds customized spatial metrics for Oakland's sustainability indicators based on already available data. Several elements in Oakland's existing set of sustainability indicators were confirmed to have pre-existing spatial data sets suitable for a web GIS application. Indicators are mostly based on existing data and analysis provided by a combination of non-profit organizations and government departments. The Web GIS application draws its credibility from the analysis and methodology employed by each.

The data determined representative of sustainability indicators were processed through ArcMap and published to ArcGIS Representational Estate Transfer (REST) services. With access to the ArcGIS spatial database server, the processed data layers representing the indicators were customized into web applications. The application for the first map was selected to enable the AGI component of the culture and community layer via the social media keywords, while displaying the sustainability indicators. The second map uses a template enabling the PPGIS component of the culture and community indicator, allowing for edits and feedback to be collected from user input. The API for ArcGIS and the EPA were used to publish the components of the web applications which were then all coded into an Extensible HyperText Markup Language (xhtml) document with Adobe's Dreamweaver and then published to USC's student server at http://www-scf.usc.edu/~gblackle/OaklandSustainability/index.html. The applications were tested and are functional in Safari, Chrome, and Firefox browsers. Figure 13 illustrates this process of authoring the data for representation, hosting it on a server and programming the method of delivery for use.

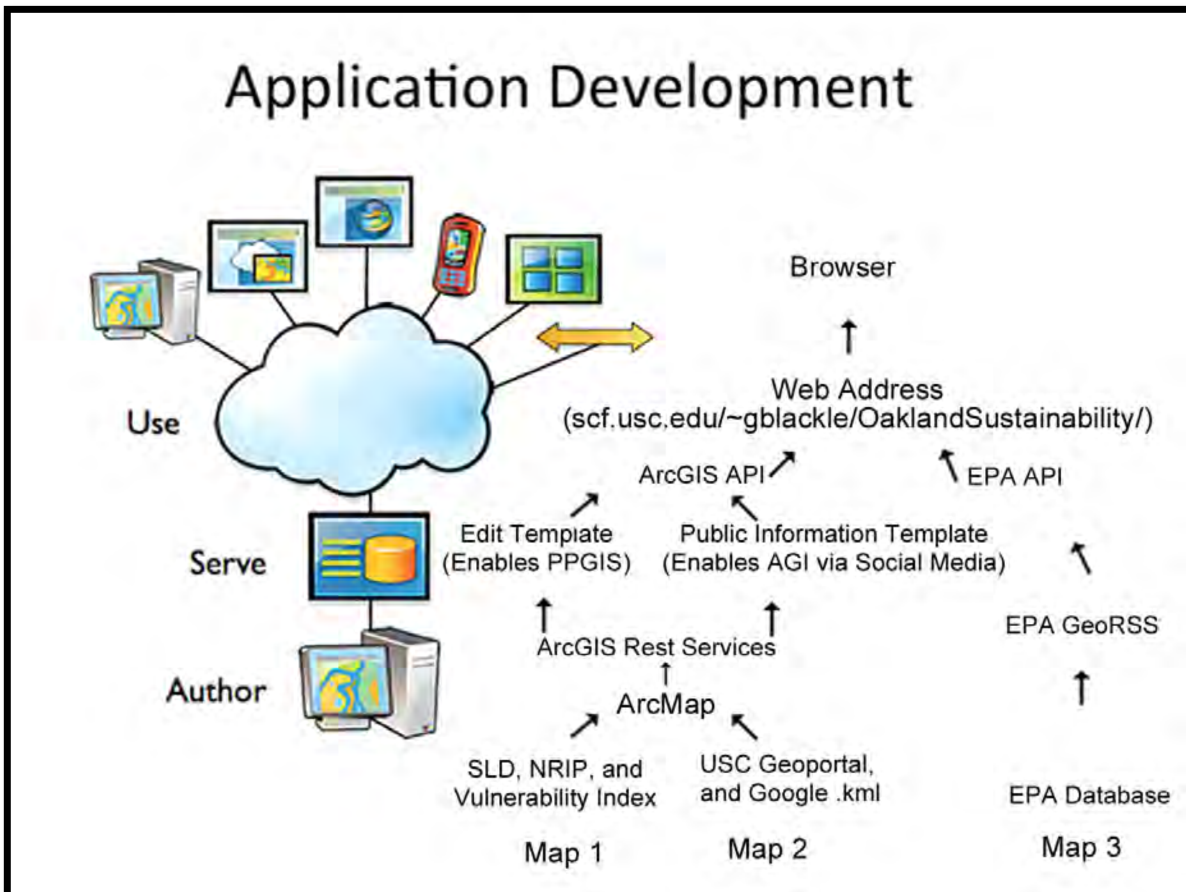

Figure 13. Flowchart- Illustrating Application Development from data to visualization.

3.1 Oakland Indicators

The city of Oakland has produced an Annual Sustainability Report since 2001 featuring six general elements highlighted in their publications. The elements in Oakland's Sustainability Report are: buildings, energy, and climate; economic prosperity; education, culture, and community; health, safety and well-being; housing, land use and transportation; natural resources, water and environmental health (City of Oakland 2013). Though the city of Oakland has determined targets of sustainability, these are slightly altered to accommodate spatial visualization. Of the various approaches available, working with the City of Oakland to incorporate local and national sustainability targets into this web GIS application would be the preferred means of evaluating sustainability for the indicators based on the elements listed above.

Working from the established elements in Oakland's Sustainability Report, my research focused on combining existing strategies and tools of sustainability into an application accessible through a web-based environment. For the purposes of this project and based on available data, the following established elements of Oakland’s Sustainability are spatially represented as: climate change vulnerability; economic availability; housing; transit accessibility; natural resources project inventory; culture and community. As a note, although the Oakland Sustainability Report combines housing and transportation into one indicator category, a spatial visualization of these elements is more clearly represented as individual layers. The indicators and the customized spatial metrics for this web GIS are listed in Table 1 below.

Table 1. Sustainability Indicators customized from Oakland's Sustainability Report.

Indicator Categories from Oakland's Sustainability Report	**Customized Indicators for Web GIS**
Buildings, Energy and Climate	Climate Change Vulnerability
Housing, Land Use and Transportation	Housing
	Transit Accessibility
Economic Prosperity	Employment Availability
Natural Resources, Waste and Environmental Health	Natural Resources Projects Inventory
Education, Culture, and Community	Culture and Community

Versioning, or documenting changes over time, could work to provide the means with which a measure can be established. This could be done by visualizing the differences between past and emerging data from the future, or according to targets either established through additional research or set by the city of Oakland. The various formulas and measuring strategies of these indicators are intended as spatial measurements of sustainability. The following describes existing transparent methodologies and/or customizations of these elements, for a brief summary of how the above goal can be met. This is followed by a section on the programming and preparation of the spatial data.

3.1.1 Climate Change Vulnerability Indicator

Because energy and climate data were not readily found to inform such an indicator definition, the most related GIS download freely available is the report, "Social Vulnerability to Climate Change in California" documenting a GIS analysis of the state of California with complete availability to the data used and maps created. The report contains literature reviews of the techniques used in the indexed measurement produced by the Pacific Institute.

The impacts projected through the study include extreme heat, sea level rise, drought, flooding, erosion, wildfires, infectious disease outbreaks, degradation to air quality and diminished water availability. Along with geographic and environmental factors, social and economic factors such as age, socio-economic status, and transit accessibility are also considered in the analysis of community preparation, response, and ability to recover from climate change conditions.

The methodology employed is based on studies that show how social factors affect the responsiveness of various communities to natural disasters such as those expected and predicted from climate change. Researchers analyzed geographic tracts according to factors (i.e. elderly, low income, outdoor workers, treeless areas etc.) that would affect the community response to climate change conditions (i.e. natural disasters, sea level rise, heat waves etc.). The table in figure 14 organizes these conditions into attributes (Cooley et al. 2012).

Table

Oakland Vulnerability

Tract	Hslds	TotPop	Alone_65	Renter	Under18	LttleEng	InPvrty	PplColor	Diploma	Instnlzd	Births	Umplyd	ForeignBor	OutdoorWkr	FoodDsrt	Imprvious	Ovr
06013352202	941	2248	0.00185	0.156217	0.201512	0.031	0.109875	0.187278	0.964	0	0.104046	0.003	0.157	0.018537	0	0.109688	0.1
06013353001	1372	3883	0.00041	0.109329	0.284059	0.069	0.043781	0.200103	0.99	0	0.034839	0.013	0.183	0.046475	55	0.043854	
06013354001	638	1793	0.00072	0.047022	0.281093	0.021	0.011712	0.089236	1	0	0.076543	0.029	0.065	0.104651	5	0.016628	
06001408800	1527	5267	0.0014	0.560576	0.336245	0.407	0.597185	0.990507	0.5	0	0.049825	0.069	0.369	0.173985	46.75	0.706626	0.5
06001407200	1604	5313	0.00039	0.670823	0.311877	0.457	0.590439	0.918878	0.47	0	0.007759	0.073	0.519	0.170046	22.5	0.741442	
06001400300	2626	4964	0.00071	0.594821	0.140612	0.064	0.187953	0.285858	0.908	0	0.030909	0.029	0.171	0.017376	31	0.647678	
06001400200	902	2076	0.00114	0.342572	0.191715	0.031	0.112236	0.232177	0.986	0	0.121514	0.013	0.089	0.008696	0	0.51792	0.4
06001401500	961	2493	0.00083	0.598335	0.255515	0.112	0.512234	0.901725	0.838	0	0.038251	0.117	0.151	0.029817	30.333333	0.734966	
06001400700	1672	3901	0.00141	0.604665	0.213791	0.054	0.442451	0.643168	0.864	0	0.071498	0.068	0.136	0.053172	47	0.684289	0.4
06001403400	2960	4685	0.00149	0.853716	0.053148	0.247	0.459979	0.653148	0.897	0	0	0.034	0.401	0.094195	55	0.766573	
06001406100	1310	3415	0.00073	0.712977	0.274963	0.346	0.377745	0.875549	0.574	0	0.070727	0.107	0.373	0.113433	0	0.816545	0.4
06001403000	1211	2441	0.00304	0.757225	0.122081	0.763	0.646047	0.971733	0.557	0	0	0.055	0.788	0.061662	12	0.855503	
06001403900	2415	3905	0.00115	0.585921	0.066069	0.015	0.179257	0.39283	0.938	0.073239	0.01216	0.038	0.085	0.011298	0	0.607329	
06001404200	1456	3400	0.00096	0.163462	0.257647	0.047	0.087059	0.274412	0.987	0	0.084791	0.002	0.119	0.013699	32.666667	0.298791	0.3
06001403300	1936	4196	0.00092	0.77686	0.127026	0.481	0.481082	0.738322	0.724	0	0.076444	0.033	0.546	0.031001	45	0.817304	0.2
06001410000	1202	3038	0.00093	0.103161	0.203423	0.086	0.18104	0.753785	0.875	0	0.014993	0.037	0.102	0.063523	47	0.22238	0.5
06001403100	500	1107	0.00146	0.592	0.054201	0.354	0.500675	0.836495	0.602	0.330623	0	0.093	0.389	0	0	0.785559	
06075017902	643	2530	0	0.982893	0.172332	0.173	0.44126	0.554941	0.929	0.020949	0	0.126	0.358	0.064246	56	0.483528	
06001405400	2682	6874	0.00127	0.873229	0.192319	0.375	0.569064	0.91737	0.694	0	0.050901	0.07	0.474	0.065611	34.166667	0.757392	0.3
06001432400	1558	5033	0.00084	0.464056	0.260083	0.296	0.315936	0.785019	0.78	0	0.042493	0.065	0.385	0.045041	0	0.65699	0.2
06001432700	961	2379	0.00098	0.259105	0.210593	0.116	0.063892	0.435897	0.952	0	0.011146	0.036	0.13	0.11264	22	0.589182	0.4
06001409200	782	2729	0.00096	0.395141	0.313302	0.285	0.444485	0.992305	0.617	0	0.06657	0.128	0.26	0.129101	21	0.566492	0.4
06001426200	1481	4470	0.0006	0.161377	0.338479	0.067	0.053351	0.295078	0.991	0	0.035509	0.043	0.139	0.037362	10	0.39847	0.2

1 (0 out of 142 Selected)

Oakland Vulnerability

Figure 14: Climate Change Vulnerability Attributes- View of data included in vulnerability analysis.

3.1.1.1 Spatial / Web GIS Value

The analysis detailed by Cooley et al. (2012) results in a vulnerability index combining ratings on nineteen indicators into a single climate vulnerability score and mapped for census tracts. In all, the social vulnerability index used 19 different factors for 7,049 census tracts across California. Geographic data featuring the severity of projected climate change impacts and data representing social vulnerability indicators was used. These were overlaid to indicate areas where exposure and vulnerability were rated according to a customization of the Social Vulnerability Index (SoVI), formulated by Cutter et al. (2003). The composite is divided into three ranges of overall scores with the lowest vulnerability falling below the 33rd percentile, medium between 33rd and 66th percentile and the highest vulnerability falling above that range. These rankings are translated as scores of high, medium, and low vulnerability. (Cooley et al. 2012).

The ability to view this data and analysis as a geographic representation, allows for planners and city officials to clearly see which areas may be most prone to changing climate conditions. Making this information locational, can help to determine where resources should be deployed and for what to investigate in certain areas as conditions related to climate change emerge.

3.1.1.2 Data Source

Data and analysis for the Climate Change Vulnerability indicator is provided by the Pacific Institute. Based in Oakland, Ca., the Institute was founded in 1987 with a mission to create sustainable communities. The institute conducts research to advance sustainability through environmental protection, economic development, and social equity with science-based solutions. By partnering with stakeholders, publishing reports, advocating for recommendations between decision makers and advocacy groups, the Institute works to contribute social and political change. The 2012 report, “Social Vulnerability to Climate Change in California” illustrated the need for adaptation planning using study maps for projection analysis (Cooley, et al. 2012).

3.1.2 Housing

The Smart Location Database (SLD) managed by the Environmental Protection Agency (2013) informs the indicator for economic availability. The HH variable provides the count of occupied household units as documented in the 2010 census. Wheeler (2013) discusses the potential of infill development to bring sustainability into the places that citizens call home. As the contemporary definition of sustainability considers the value of equity, planning should consider the location of hazards, pollution, affordable housing, poverty, traffic noise and other externalities affecting urban residents.

To implement in-fill development Wheeler (2013) recommends reinvigorating old downtowns with buildings that support shops and businesses at the sidewalk level and residential towers in the upper three to five floors as an example of such in-fill potential. While existing single floor buildings, parking lots and failed shops are good candidates for such renewal, accommodations should be made to preserve existing residential housing and historic buildings.

Arterial strips with fast and wide lanes of heavy traffic lined with single story stores, gas stations, and fast food restaurants are another candidate to in-fill for sustainability by becoming pedestrian centered with plazas, narrowed streets, mini parks, and courtyards. Some have even become strictly pedestrian allowing deliveries to businesses only in the early morning. Duplexes and townhouses with wide set back walkways could introduce residents to such areas that often have been restricted with outdated zoning laws that should be revisited and updated.

Even existing neighborhoods can become more dense by allowing for the remodeling of basements and attics, often already done, to legally allow housing for elderly, students, and single people that need less space, providing affordability for them and income potential for the homeowners. Often, integrating shops and businesses into these communities also requires an update to old restrictive laws unnecessarily separating them from residential development.

For more blank slate development, reusing the sites of old malls, railroads, military, factories and so forth, offers another opportunity for in-fill. Though often these areas are categorized as brownfields, the cleanup required does make a contribution to the ecology of the city and may even qualify for federal support as a superfund site (Wheeler 2013).

3.1.2.1 Spatial / Web GIS Value

A visualization of the density that housing units and residents are currently located can aid planners in determining where infill potential may exist, where housing may be lacking or where housing is abundant and in need of nearby businesses and services. Other benefits to the spatial understanding of this indicator could answer questions of equity where housing units exist. Are desired amenities of green space, fresh food resources, and public transit equally available throughout the urban landscape? Does economic development support diverse employment with businesses that hire locally for living wages? The ability to map such features can offer a foundation for the mitigation of these issues to ensure these values. Putting a geographic context to housing also addresses some of the policy dilemmas brought up as well by Wheeler (2013). This includes re-visioning the future direction of development projects with the community, armed with studies that have shown how infill overwhelmingly increases property values and overall neighborhood amenities to help overcome opposition from NIMBY attitudes that may exist towards planning for density (Wheeler 2013).

3.1.2.2 Data Source

The Housing indicator is represented by data and analysis provided by the Partnership for Sustainable Communities (Environmental Protection Agency 2013). This partnership is between the U.S. federal agencies, Department of Housing and Urban Development (HUD), Department of Transportation (DOT), and the Environmental Protection Agency (EPA). “The Smart Location Database” is a GIS data resource developed nationwide to provide accessible performance measurement of sustainability indicators for U.S. communities. The basis of measurement standards fall under the established “Livability Principles” around transportation, housing, economy, mixed-use communities, the coordination of federal policy and funding, and the valuation of neighborhoods. This resource, designed by the EPA in 2011 and updated in July 2013, provides a summary of 90 attributes characterizing housing, demographics, transit, and urban economics. The data are acquired from the 2010 census, five-year demographic estimates from the American Community Survey (ACS), the Longitudinal Employer-Household Dynamics (LEHD), InfoUSA, and NAVTEQ, all at the Census Block Group (CBG) extent of analysis (EPA 2013a).

3.1.3 Transit Accessibility

This indicator was also informed through the Smart Location Database (SLD), with completed analysis done by the Partnership for Sustainable Communities. The Transit Accessibility indicator is based on distance from population-weighted CBG centroids to nearest transit stop. The D4a layer is converted to miles and displayed as the centers of block groups as 0.75, .0.50 and 0.25 miles or less from public transit services.

3.1.3.1 Spatial / Web GIS Value

Transit Accessibility translates easily into a spatial metric as the location of public transportation naturally conveys the potential for citizens to choose more sustainable travel options. Although it is noted by Moran (2013) that data generally shows public transit riders walking further than ¼ for service locations, it is also recognized that planners ideally like to adhere to a five minute walk rule, or ¼ mile, for residents to access stops and stations providing service. Keeping to this limit is promoted to improve environmental health by decreasing fuel consumption and exhaust while improving public health by incentivizing activity with the development of pedestrian access to these locations (Moran 2013). The transit accessibility layer of this web GIS clearly reveals the geographic locations in Oakland that either meet this rule of thumb or do not.

3.1.3.2 Data Source

Like the housing indicator, the public transit accessibility indicator is also represented by the “The Smart Location Database”, hosting data and analysis provided by the Partnership for Sustainable Communities.

3.1.4 Economic Availability

This indicator was also informed through the Smart Location Database (SLD), with completed analysis done by the Partnership for Sustainable Communities. Part of the Land Use Diversity variable, provides an analysis of jobs to population. This calculation labeled “D2r_JobPop” is based on the values of the total population and total employment quantified for each Census Block Group (CBG) and measured against a ratio of the regional average of jobs/population. The analysis ranks a percentage from 0-1 with 1 as a ranking of a more diverse job to population ratio. The symbology is classified into three natural break groups of 0.00-0.207441 representing the lowest ranking in Oakland, 0.207442-0.550470 as the mid-range and 0.550471-0.989072 as the highest score in their ranking calculation. From the SLD user guide documentation, figure 16 below illustrates the formula used for this measure (EPA 2013a).

Table 5: Detailed description of Land Use Diversity (D2) Variables

Field name	Description	Method of calculation
D2r_JobPop	Regional Diversity. Calculated based on total population and total employment by CBG. It quantifies the deviation of the CBG ratio of jobs/pop from the regional average ratio of jobs/pop.	**D2r_JobPop** = 1- |(b*(TotPop-TotEmp))/(b*(TotPop+TotEmp))| Where b=CBSA_Pop/CBSA_Emp

Figure 16: D2r_JobPop Land Use Diversity Segment from Smart Location Database-Table detailing the calculation of the Employment Availability Indicator by the Partnership for Sustainable Communities.

3.1.4.1 Spatial / Web GIS Value

The geographic representation of this indicator is visualized and mapped at the CBG level. The tracts illustrate diversity and density of employment in association with population suggesting more or less availability. The geographic representation of density, a sought after feature for sustainability, helps planners to better add the convenience of nearby jobs and businesses as well as cafes, shops, and restaurants for vitality to isolated neighborhoods or to find those with infill potential. Wheeler (2013) also advises that zoning considerations for sustainability planning restrict the size of retail distributors to reign in the tendency of big box stores to kill small and local businesses. This ensures that employment is available in a range of specialty and income levels that a diverse demographic would need (Wheeler 2013). Knowing where employment opportunities are more or less dense, can aid in planning for a diverse mix of many businesses to support a diversity of jobs for the diversity of people living nearby.

3.1.4.2 Data Source

Like the housing and transit accessibility indicator, the indicator for employment availability is also represented by the "The Smart Location Database", hosting data and analysis provided by the Partnership for Sustainable Communities.

3.1.5 Natural Resource Projects Inventory

The Environmental Goals and Policy Report (EGPR), released under the Governor's Office of Planning & Research defines targets and indicators aimed at a future scenario faced with the pressures of climate change and a population of 50 million. To "preserve and steward the state's lands and natural resources" is among the actions in the five metrics categories within the report, to fulfill the objective of sustainability. Further, to meet this broad vision of conservation, the report recommends increasing ecosystem services and biodiversity, promoting green infrastructure, and preserving agricultural lands and forestry (Governor's Office of Planning & Research 2013). In consideration of state policy objectives, the vague metrics of state environmental goals imply the increase of ecosystem services and diversity as correlating with recent policy. This layer is represented by an inventory of projects within Oakland aim to enhance and preserve the ecosystem and biodiversity within Oakland.

3.1.5.1 Spatial / Web GIS Value

This indicator of sustainability focused on the increase and preservation of natural resources can be informed by showing where projects intending to do so have taken place. As all neighborhoods should in some way host its own variety of ecology, mapping projects adhering to the Governor's directives, communicates which areas may not be meeting this policy objective to increase biodiversity and so forth. Also, overlaying this feature layer on a basemap of the terrain, may reveal areas in Oakland with the potential to meet this policy goal to a greater degree by hosting larger areas of environmental assets.

3.1.5.2 Data Source

The natural resources projects indicator is represented by the Natural Resource (NRPI). This GIS resource is produced by the California Biodiversity Council and the University of California at Davis Information Center for the Environment. The collaboration has produced a comprehensive electronic database of conservation, mitigation and restoration projects. The NRPI is divided into three subcategories: The California ecological restoration projects inventory, a watershed projects inventory, and a noxious weed control inventory. This database includes an inventory of over 8,000 natural resource projects throughout California. A few of the 49 such projects located in Oakland include Alameda Creek steelhead restoration, lower watershed assessment and outreach program, Robert’s Landing marsh, Bridgeview meadows erosion control utilizing native plants, and Alameda County pungrass eradication projects (U.S. Department of the Interior 2013).

3.1.6 Culture and Community

A satisfaction grading survey has been offered to communities as a means to evaluate locations, cultural events, service spots and recreational sites for satisfaction as an indicator of sustainable communities. Other examples of rating of green neighborhoods include the Vital Signs for Metro Vancouver to quantify liveability and community vitality, Seattle's Happiness Report Card, and LEED-ND to rate green neighborhoods (Holden 2013; Bertone et al. 2006). To some degree, these other ratings systems are also crowd-sourced and rely on subjective impressions of community members. A layer of Oakland cultural sites and landmarks was used as the foundation for input of the collected information from photos to reviews of activities and events. These features are presented in an online format welcoming the public to document such surveys for locations and events they have attended in their communities. In some sense, a rapidly updateable spatial inventory of community cultural resources acts like a state indicator for this element in Oakland's SI framework. These options allow for a collective view of the value a place might hold to be demonstrated by user input.

3.1.6.1 Spatial / Web GIS Value

Integrating the application with VGI and AGI through social media to display the areas in Oakland that have been geo-referenced and cataloged with certain keywords goes further to increase the representation of Culture and Community as a spatial indicator for Oakland, Ca. Through social media activity, the number and areas where the most users show activity, acts as an indicator by demonstrating where and at what level specific areas are abundant or in what neighborhoods they may be lacking. Keywords were also used in Google Maps to combine additional features with the landmark layer so that libraries, museums and performing arts theaters not in the Ca_Landmarks layer could also be represented.

3.1.6.2 Data Source

Data for the Culture and Community indicator is provided by the U.S. Census Bureau, Google Maps, and the social media sites Instagram, Flickr, Twitter, Youtube and Webcam.travel. The USC Geoportal hosts a layer of California landmarks which is a part of the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) database. Results from a keyword search of culture and community locations in Oakland using Google Maps is combined with the landmarks layer to provide a starting point for the addition of volunteered geographic information. Other social media points informing the culture and community indicator are provided by user contributions to Instagram, Flickr, Twitter, Youtube and Webcam.travel. These sites share text, photos and videos which the web GIS application will select and display according to the recorded or ambient geographic data.

3.2 Preparation of Spatial Data and Programming

The spatial databases providing resources for this case study are indexed in table 2.

Table 2. Sustainability Indicator Data Sources and Preparation

Layer	Climate Change Vulnerability	Housing	Public Transit Accessibility	Employment Availability	Natural Resources Projects Inventory	Culture and Community
Source	The Pacific Institute	Smart Location Database	Smart Location Database	Smart Location Database	State of California GeoPortal	USC GeoPortal, Google Maps, Instagram, Flickr, Twitter, Youtube and Webcam.travel
Preparation	The social vulnerability index was symbolized in red from high to low climate change vulnerability risk levels.	The housing indicator is symbolized in three shades of orange for the natural breaks of housing units per CBG	The transit accessibility indicator is displayed in three shades of green with light green for under 0.25 miles, green under 0.50 and dark green for under 0.75 miles from transit.	Employment availability is symbolized in blue by three natural breaks from most to least workers ratio to jobs as compared to the regional average.	Natural Resource Projects are represented as green point locations.	The first map displays social media as Instagram, Flickr, Twitter, Youtube, and/or Webcam.travel point icons. The second editable PPGIS application displays landmarks and culturally relevant locations in purple polygons.

These customized sustainability indictors were each visualized in ArcGIS desktop and clipped to the city's municipal boundaries. The "Climate Change Vulnerability" layer was classified to display social vulnerability in red with three ranking categories from most vulnerable to moderately and least vulnerable areas. This classification is based on analysis performed by the Pacific Institute using social and spatial attributes to determine conditions in terms of vulnerability faced by populations under circumstances of climate change.

The “Housing Indicator” is based on the Smart Location Database (SLD) records from the U.S. census report of number of housing units per CBG. These range from 0-1389 units per CBG, which are symbolized in three natural breaks as shades of orange. The “Employment Availability” layer, informed by the SLD as well, is also ranked into three separate divisions, as most, moderate, and least availability of employment based on a classification of natural breaks to display ratio of jobs to workers as compared to the regional average. Also from the SLD, the “Transit Accessibility” indicator symbolizes the distance from the center of each CBG, as under 0.75 miles away from public transit services, under 0.50 miles away and under 0.25 miles away from public transit.

The “Natural Resources Projects Inventory” layer represents point locations of projects that are focused on the conservation, mitigation, and restoration of natural resources, clipped to Oakland, Ca. The attributes of each project are title, abstract, purpose, project date, survey date, cooperator, resource issue, species, county, habitat, programs, and contact. These are displayed as 49 yellow point location markers throughout Oakland.

For the “Culture and Community” indicator, the USC GeoPortal provided a layer of California landmarks (i.e., “Ca_Landmarks”) which were clipped to Oakland, Ca. The project also used Google Maps, searching the keywords culture, community, art, museum, theater, youth, urban, garden, and center. From these results, I added appropriate features representative of culture and community, aggregating all locations to create a customized map, exporting selected features as a .kml file to use with ArcGIS desktop. The points were converted into polygon features after converting the .kml into a shapefile. The data could then be merged with the polygon features of the Ca_Landmarks layer. Some of these feature locations include the Allendale Recreation Center, Brookdale Park, Foothill Meadows, Downtown Oakland YMCA, Oakland Center for the Arts, Oakland Museum of California, Oakland Zoo, and more, for a total of 89 feature locations.

The customized map for the “culture and community” indicator was then developed further as a base map for public participation GIS (PPGIS) tool. Many of the attribute columns were hidden or deleted, and five fields were added to allow for multiple feedback input from users. Using the ArcGIS USC_SSI account, a feature service layer was published with the capabilities in the service editor set to allow for users to create, query, and update features. This allowed for the “Culture and Community” indicator layer to serve as a starting point for the addition of volunteered geographic information of cultural events and activities. These capabilities allow users to click on the map to add and describe attributes of polygons as geometric features or to edit the attributes of existing features by clicking on existing polygons in the Culture and Community layer.

The feature service layers are hosted using the ArcGIS Server Manager through the REST protocol of the ArcGIS.com server. After making the services publicly accessible to everyone, I then logged into ArcGIS.com and added all of the published layers to a web map and configured them into a social media mapping application. The social media layer hosts markers from selectable social media websites geo-referenced to Oakland, Ca. and uploaded with the keywords culture, community, landmarks, and events. Figure 17 is this web map.

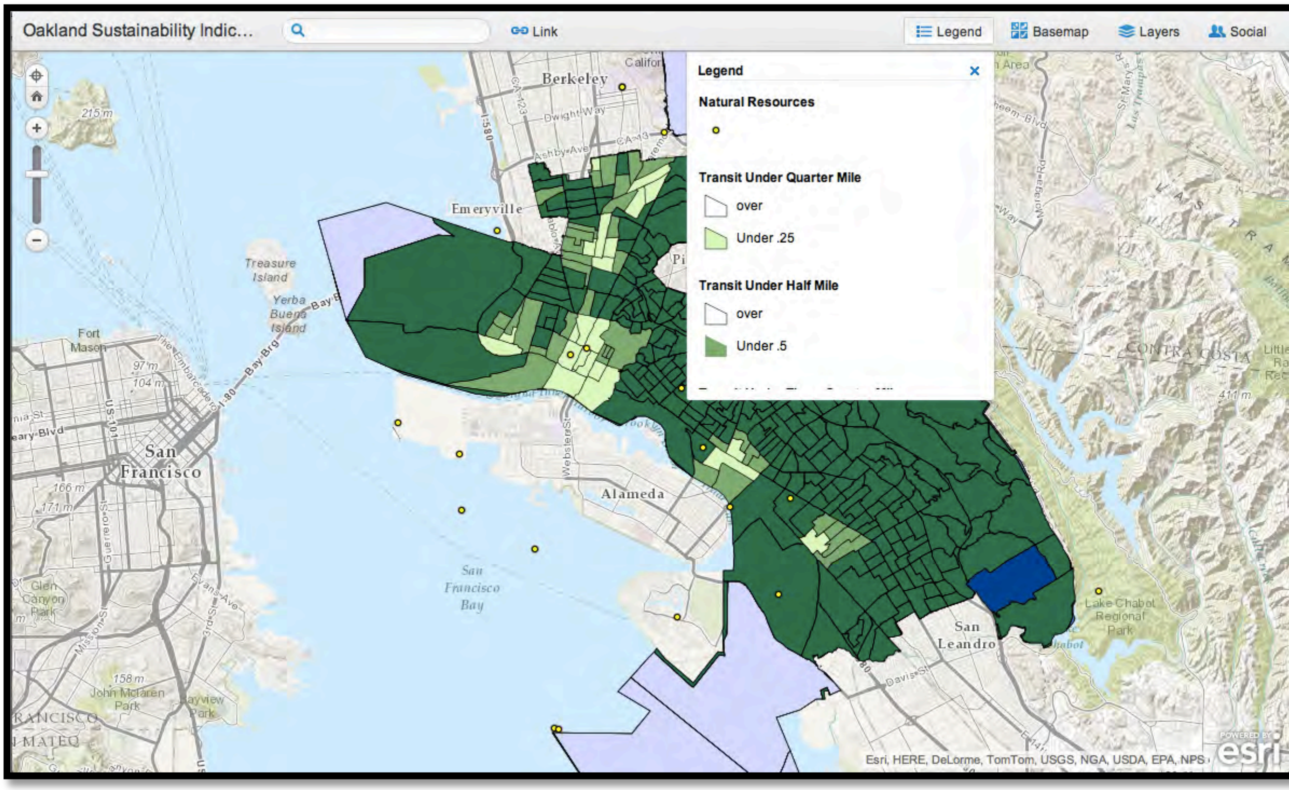

Figure 17. Oakland Sustainability Indicators Web Map Application- Hosted through USC_SSI ArcGIS REST Services at: http://uscssi.maps.arcgis.com/apps/SocialMedia/index.html?appid=7557e578281b4319a662705e211f8267

Table 3 below offers a summary of the steps involved in the reproduction, customization and maintenance of a web GIS for urban sustainability indicators.

Table 3. Web GIS application development. Steps, Overview and Process from data to maintenance.

Steps to WebGIS Application Development for Sustainability Indicators		
#	**Overview**	**Process**
1	Determine representative indicators of sustainability for municipal target	This project customized pre-determined indicators based on municipal sustainability program
2	Determine data to represent sustainability indicators	Data can be developed or existing. The Smart Location Database is a great resource developed by multiple government agencies with the intention of informing sustainable urban development

3	Prepare data	In ArcMap symbolize and prepare data as it should be viewed in mapping application. Save each data layer of the application as an individual layer in the Table of Contents Layers of ArcMap. There should only be one layer in each ArcMap document or .mxd that is saved
4	Have username and pass-word access to ArcGIS server	Either set up your spatial data server or log-in to your organization's account at ArcGIS.com
5	Connect to server from ArcMap	In ArcMap, click **File > Sign In** from the main menu and enter your username and password
6	Publish Feature Class Layers	Each layer of the application will be published from each map document individually. In ArcMap, click **File > Share As > Service** from the main menu. In the **Share as Service** window, select **Publish a Service** and click **Next**. In the **Publish a Service** window, click the drop-down box to select the server signed into in Step 5, give your service a name, then click **Continue**. In the **Service Editor** window, navigate from the left to **Capabilities** and select **Feature Access**; in **Feature Access** select the capabilities of each layer for the users of your application; in **Sharing** select **Everyone (public)**. Make any other selections desired then click **Publish** in the upper right of the window.
7	Login to ArcGIS.com	Using a browser, go to **arcgis.com** and login Click **My Content** from the top navigation bar, your feature service layers should be listed.
8	Create web map	Under **My Content**, select **Create Map**. Click **Add > Search for Layers**. Add all of the layers to be included in the application. Click the drop-down arrow next to the layer name in the **Contents** area to customize the name, pop-ups, table and more.

9	Export to Application	After finalizing the web map, click **Save** and then **Share**. In the **Share** window, select **Everyone (public)**, then click **Make a Web Application**. Select the template of preferred capabilities. Under the **Publish** drop-down, you can either select **Preview**; select **Download** for all the necessary files onto your desktop; or click **Publish > Save & Publish**, then configure your map options with the toolbar on the right and click **Save**.
10	Future Maintenance	Any changes to the application should be made to the web map listed in **My Content**. Change application configuration by selecting the application in **My Content** and then **Configure App.**

3.2.1 EPA Geo RSS

A third web application is included on the site with data provided by the Environmental Protection Agency (EPA) to inform current updates in air, land, water, and toxic substance conditions of Oakland Ca. This data is updated through a GeoRSS feed provided by the EPA and embedded in another map also set to the extent of Oakland, Ca. with an assessment summary displayed below the map. EPA “EnviroFacts Widgets” are also encoded to provide a search tool for users to type in a geographic location to obtain greenhouse gas emissions as reported by the Greenhouse Gas Reporting Program (GHGRP), hazardous waste, drinking water reports, locations of facilities manufacturing or importing toxic substances, and a multisystem search of environmental conditions in the specified area of interest. To customize an EPA map of envirofacts and obtain code to publish, visit http://www.epa.gov/emefdata/em4ef.home . Code for widgets can be found at: http://www.epa.gov/enviro/facts/widgets.html (EPA 2013b) .

CHAPTER FOUR: RESULTS

To this point, the motivation for this project has been offered along with an introduction to sustainability, urban planning, and a geographic vehicle to communicate customized indicators with the inclusion of participatory planning. Coverage of related work included an indicator method developed by SUD, web resources on urban sustainability indicators, including those hosted for Oakland, Ca., and other actual web GIS applications. To follow the study methods, indicator specifications and programming, the discussion of results for this section will begin with an overview of the site and demonstration of each indicator.

4.1 Site Overview

The site hosting this web GIS application is made-up of four html navigation pages: home, about, data, and contact. The "Home" page hosts the web GIS applications with a *Quick Start* of capabilities and layer descriptions. The "About" page provides a more detailed description of the indicators used in the application and an overview of sustainability. The "Data" page provides links and a description to the data used for this project and the "Contact" link simply provides information of my name, email and phone number. Initially visible upon opening the URL is the web GIS application of sustainability indicators with a Quick Start guide to the right of the map. Figure 18 below is the initial view displaying the first map application and navigation links at the top of the site. Each application contains the mapping functions to search, zoom, pan, and user location finder. Exposing legend and layers provides utility for data viewing with an additional level for attributes displayed as pop-ups.

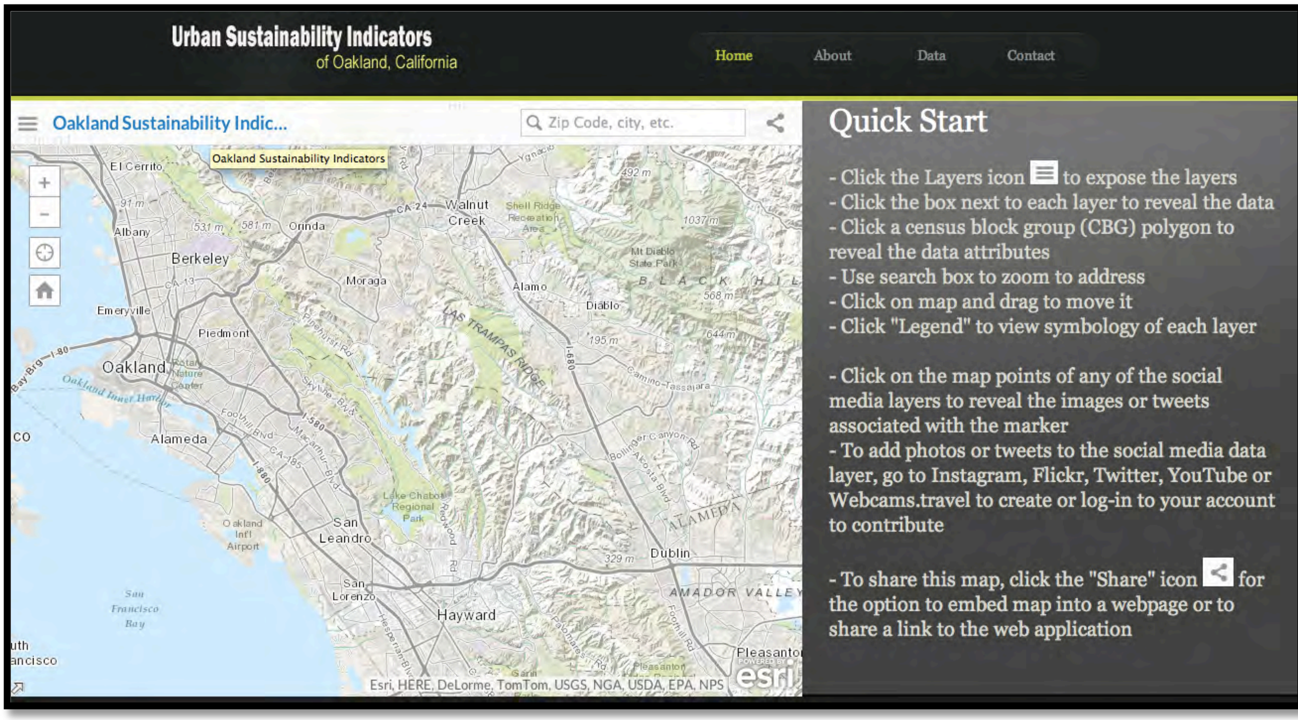

Figure 18. Urban Sustainability Indicators of Oakland, Ca. Web Page- Partial view of opening webpage showing the first application at the top
The hosting address is: http://www-scf.usc.edu/~gblackle/OaklandSustainability/index.html

Scrolling down the index page brings up the Culture and Community application. This is the PPGIS capable map and a quick guide with basic instructions on the right. The polygons on the map represent the landmark features that are the basis of the indicator. The panel on the left is used to perform the functionalities to edit existing features or to add new ones. Figure 19 below is a snapshot of the second PPGIS application.

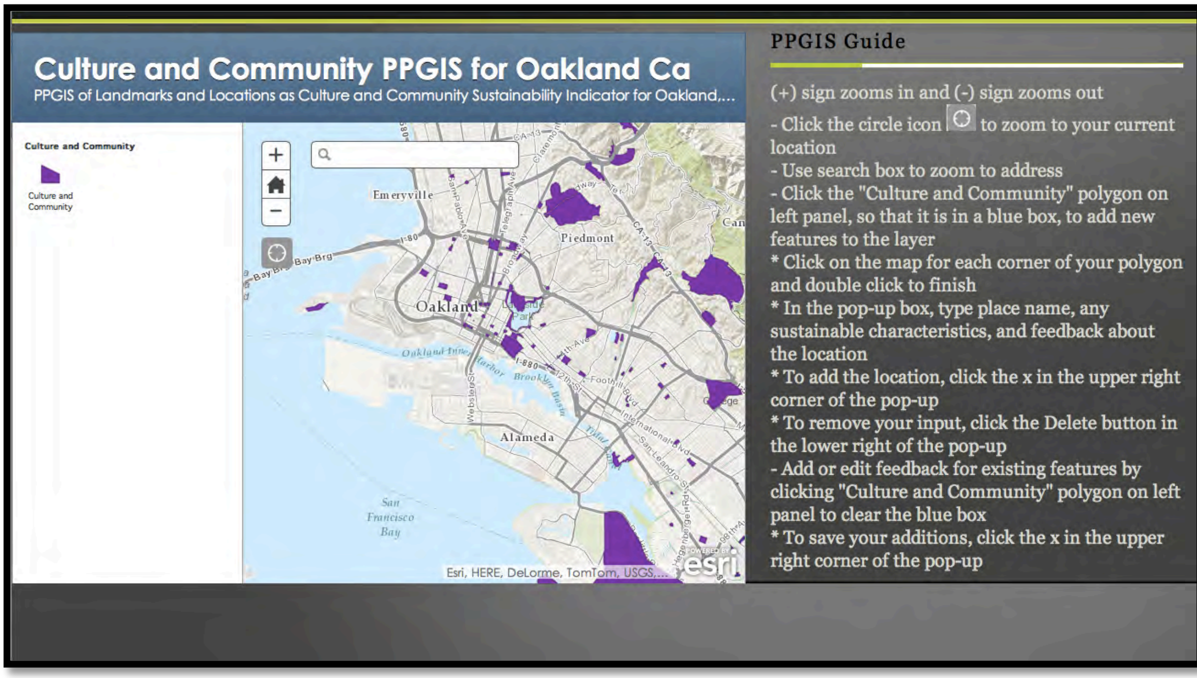

Figure 19. Culture and Community PPGIS for Oakland, Ca.- View scrolling down webpage showing the PPGIS application

Below the first two maps on the main web site is a map provided by the EPA for Oakland embedded with five widgets which query their database for specific environmental data: greenhouse gases, hazardous waste reports, drinking water safety, facilities importing toxic substances and a multisystem search-box tool. Following the EPA map are links concerning air quality, water quality and hazardous waste. Figure 20 below shows a partial view of the EPA GeoRSS feeds as displayed at the bottom of the page.

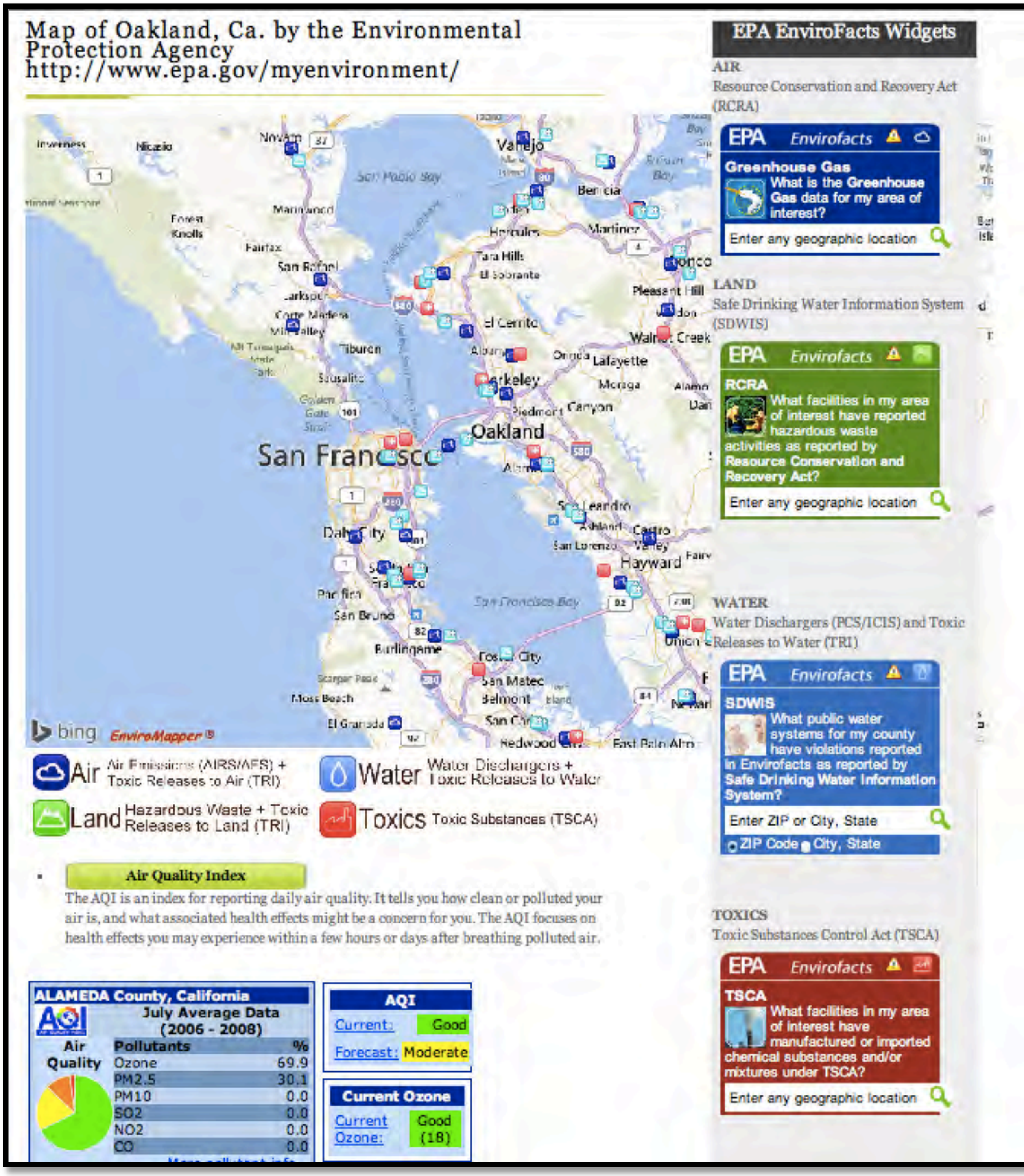

Figure 20. EPA GeoRss Feeds- View after scrolling to bottom of webpage showing the as a map, search widgets, and the partial updated listed and graphical data.

4.2 Demonstration of Climate Change Vulnerability Indicator

Building upon this work to measure Oakland's sustainability in relation to climate change is appropriate as the social vulnerability to such events is most likely what the public and planners will find of greatest interest in regard to climate change scenarios. This total feature class is categorized as a state indicator as the vulnerability rating from lowest to highest risk areas establishes an identification of conditions to aid in the targeting of future efforts. A planner or community member could click on any polygon to view the attributes used in the vulnerability score calculation. Figure 25 below, shows the climate vulnerability layer enabled with the analysis in red visible on the left. On the right, clicking on a high-risk vulnerability block group reveals the area to have a high percentage of people in poverty, foreign born, and of color. The actual vulnerability score is found scrolling to the bottom of the pop-up boxes.

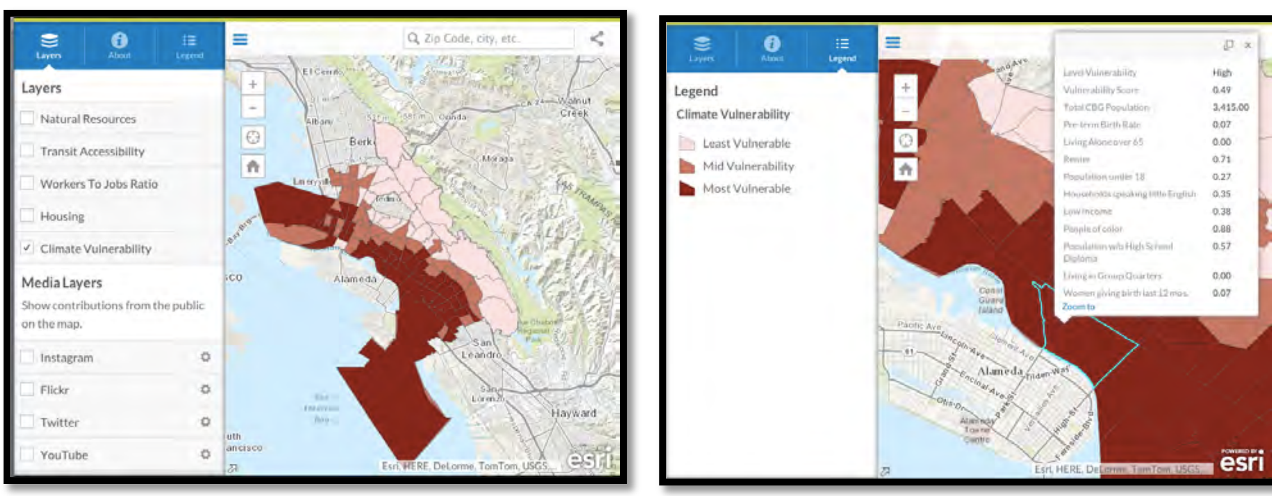

Figure 21: Climate Change Vulnerability Layer- On the left, Pacific Institute Analysis Indexed from High to Low Vulnerability to Climate Change, displayed in red, and Clipped to Extent of Oakland, Ca On the right, opening the Legend on the left displays the layer's symbology with display of pop-up attributes box clicked open.

4.3 Demonstration of Housing Indicator

The Housing indicator is displayed as three natural break categories with dark orange as the areas of most housing, orange as the middle range and light orange as the areas with least housing. As a current measurement of housing units, this is considered a state indicator. Users are able to select any CBG of interest by clicking that area. As done in figure 22 below, the left is the housing layer viewed alone. On the right, a section with a high number of housing units is selected, opening up the pop-up to reveal attributes relevant to understanding housing like the tract’s total population and total household units.

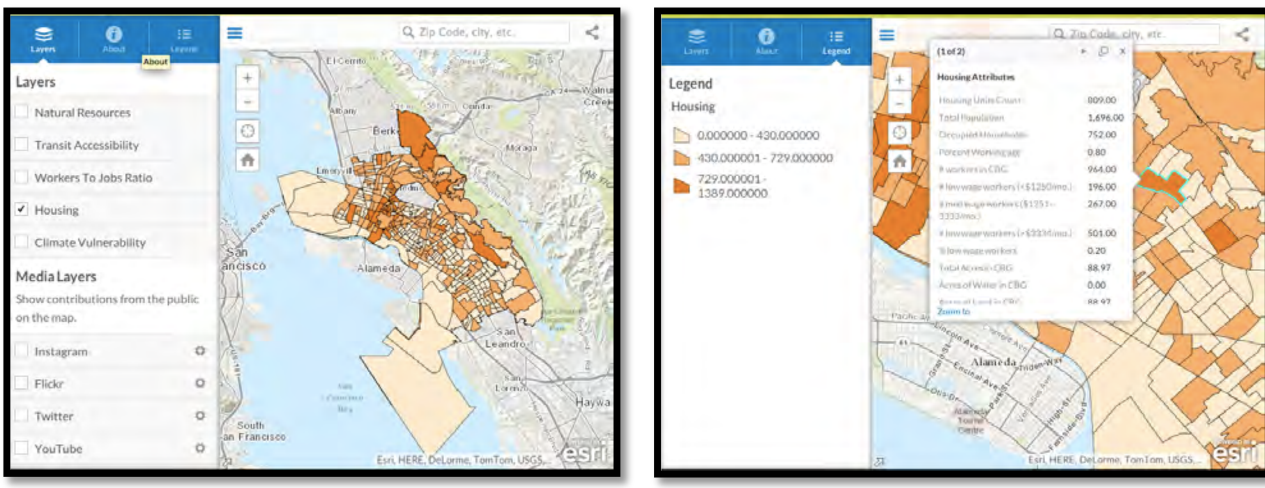

Figure 22: Housing Layer- On the left, Oakland Housing indicator is classified into low, mid and high natural breaks and displayed in a color range from light to dark orange.
On the right, a CBG with a high number of housing units is selected to reveal the pop-up.

4.4 Demonstration of Transit Accessibility Indicator

The transit accessibility indicator displays areas ¾, ½ and ¼ of a mile away from public transit service locations including the bus, Bart, Amtrak and Caltrans. From this analysis, each distance range is given a solid layer in a range of green representing the CBG’s accessibility to public transit. Dark green reveals the areas under ¾ of a mile from service locations, the green under ½ mile and light green for areas most accessible and under ¼ of a mile from public transit. This representation of current transit conditions acts as a state indicator for accessibility. In the demonstration figure below, an area of ¾ of a mile or more is clicked to display the pop-up attribute box with attributes such as number of pedestrian intersections per square miles and frequency of transit service per square mile available.

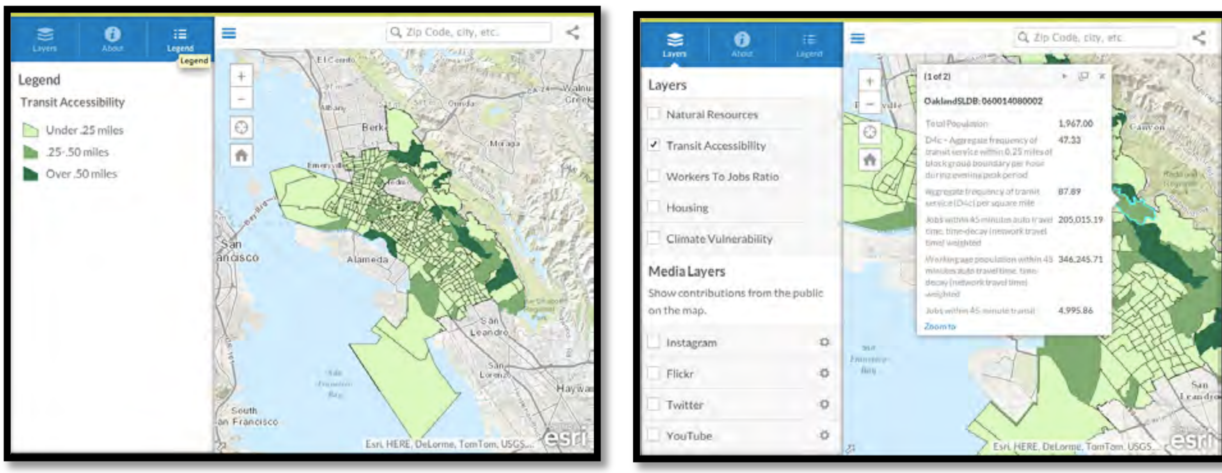

Figure 23: Transit Accessibility Layer- On the left, a preview of Transit Accessibility layers displayed as CBGs over ¾ mile, under ½ mile, and under ¼ mile in a range from dark to light green. On the right, a pop-up reveals attributes for a selected block group.

4.5 Demonstration of Economic Availability Indicator

The display of economic availability is represented as a high to low color range of light to dark blue. This is a state indicator as current conditions demonstrate the variation across CBGs. Figure 24 below has clicked on a block group categorized as a strong balance of worker to jobs ratio of selected CBG. The information in the resulting pop-up box reveal the correlating attributes, such as percent of population of working age, to income ranges and employment types. This could be of value to in-fill planning to determine where service, office, or retail employment would be of most benefit in increasing the balance of jobs and housing across the city.

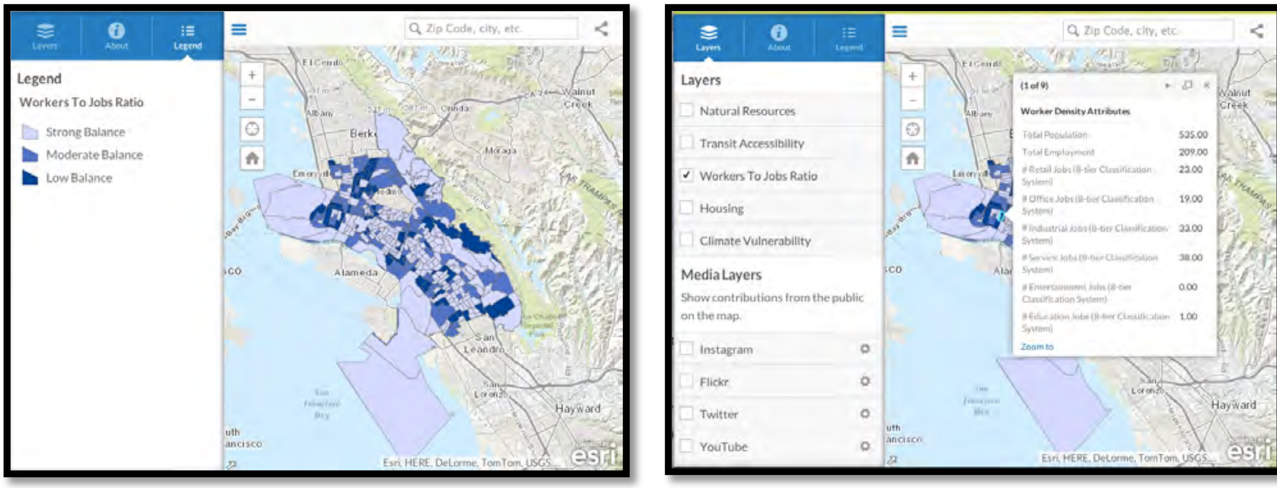

Figure 24: Workers to Jobs Ratio- On the left, Oakland Employment Availability based on worker to jobs ratio compared regionally and classified into three natural breaks
On the right, pop-up of attributes is displayed for a selected CBG.

4.6 Demonstration of Natural Resource Projects Inventory Indicator

Displaying progress towards this sustainability target in a web GIS would show the increase or decrease of preserved lands and biodiversity over time, which can be characterized in projects aimed at such objectives. Although only a current display of point locations hosting natural resource based projects is used in this web GIS application, over time, a rating of a color range scale could be introduced to indicate an increase or decrease in efforts to promote eco-system health and become a response indicator. The natural resource projects inventory is hosted by UC Davis at http://www.ice.ucdavis.edu/nrpi/home.aspx . This data layer acts as a state indicator, representing areas where conservation efforts have taken place. Figure 29 below shows the points of inventory projects and legend on the left. On the right, the selection of a point feature, displayed in yellow, reveals place name and project title displayed in attributes of the pop-up box.

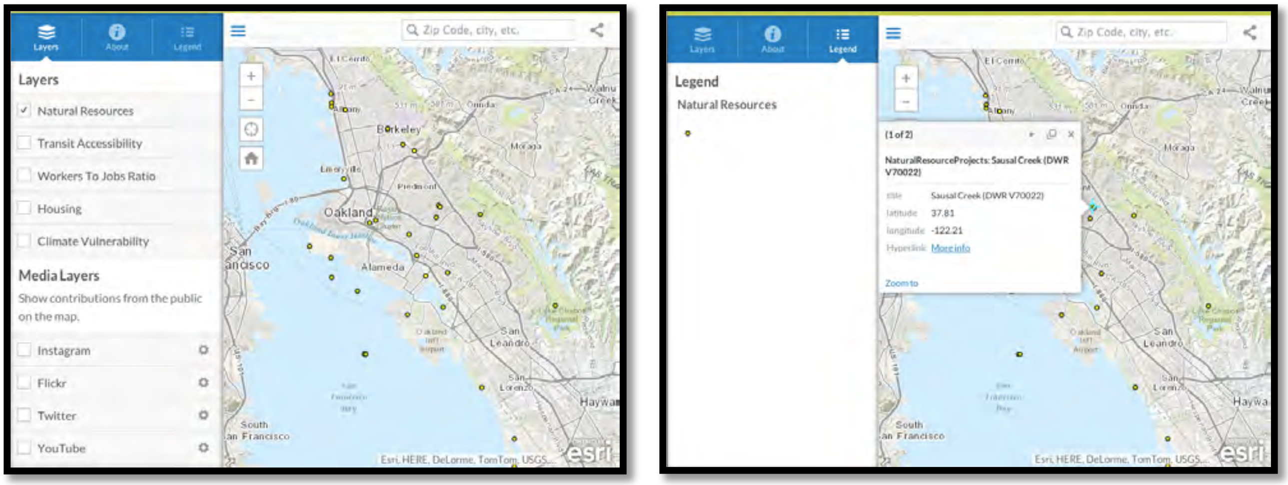

Figure 25: Natural Resources Layer- Preview of point locations in yellow, documented by the Natural Resource Project Inventory. On the right, a data point is selected revealing the pop-up dialog.

4.7 Demonstration of Culture and Community Indicator

The culture and community indicator is displayed as separate components in two of the applications on the same web page. The social media aspect displaying AGI data for the sites Flickr, Instagram, Twitter, Youtube, and webcam.travel, can be selected at the bottom of the first web app. Figure 26 below on the left, demonstrates the Instagram layer enabled and a photo marker selected for preview.

The editable element of the culture and community indicator can be found by scrolling below the top map of other indicators because of its VGI functionality. The polygons are displayed in purple with the option to add feedback to existing features or to add new features to the map. As a PPGIS application, the community is able to participate in determining where neighborhood assets are. Neighborhoods lacking in features of this indicator may provide the reasoning to evaluate whether it is necessary to intervene for the creation of strategies to build community. For the demonstration of this indicator in figure 26 below on the right, I added a polygon for the streets hosting the event for the Oakland Art Murmur along with the times on the first Fridays of the month that it occurs in the feedback text box.

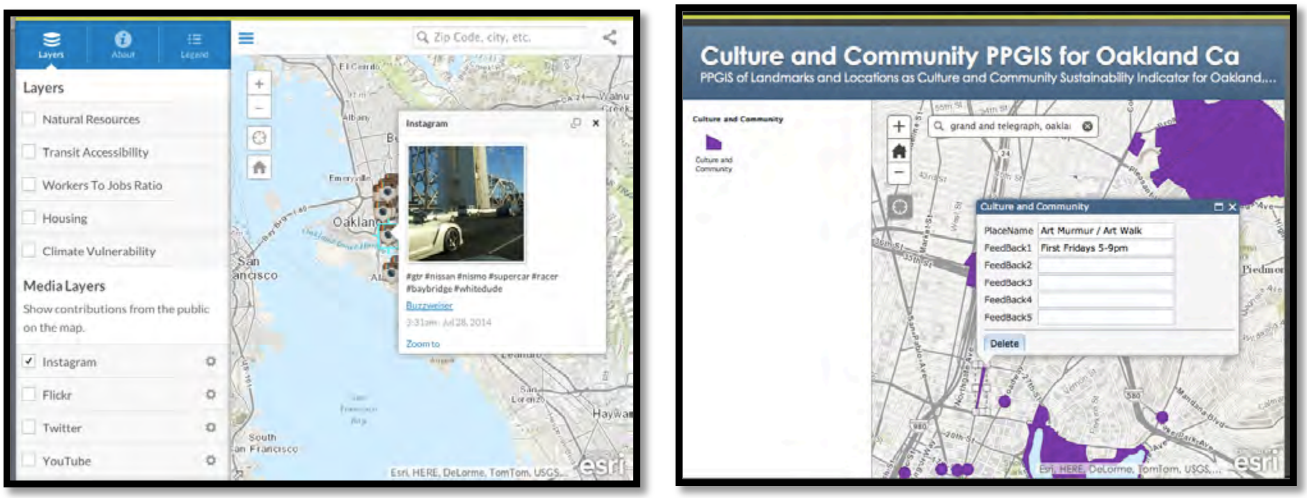

Figure 26: Social Media Layers- On the left, image pop-up selected in Instagram layer On the right, preview of adding feature to culture and community PPGIS application.

4.8 Integrated Application Demonstration

With the maps featuring sustainability all on one webpage, the information is easily viewable offering a tool for the community and planners. Perhaps a community of residents in Oakland, after searching and viewing the data for their census block, have come together to advocate for improvements to their neighborhood. They justify their demands by the low scoring of all indicators across the board. The increased pressure from the community has gained an allocation of a small budget for targeted development. A planner is now able to look at the census block in full detail with the applications.

With the first application, the ratings for climate change vulnerability ad transit accessibility rate moderately. However, the area is majority low income earners with a poor job to worker balance and low housing stock. There have been no natural resource projects in the area though with the Culture and Community PPGIS app, potential may exist from the Central Reservoir Recreation Area feature included. There is however no social media markers in the area, indicating that culture and community could potentially be included in the development plans. Further down, analyzing the block group through the EPA application, no pollution releases are indicated as a problem for the neighborhood. With limited funds for development of the site, planners determine that areas to concentrate efforts in seeking in-fill opportunities to introduce more jobs and housing to the neighborhood. The Central Reservoir Recreation Area also becomes apparent as potential for the planners to launch educational events and activities that engaged the public in community and conservation. The PPGIS application could also be used by these planners to work with the neighborhood in learning of other neighborhood assets by asking residents to document locations in their area that they would like to see preserved, restored or enhanced. This example demonstration is of course just one scenario of use for these applications.

CHAPTER FIVE: DISCUSSION / CONCLUSION

In concluding this work, it should be mentioned that as a demonstration web GIS urban indicator application, this work is not yet a part of Oakland's sustainability programs or efforts. Other than the presence of an existing sustainability indicator program, there was no special reason to select Oakland as the city to demonstrate this project sample. Work with the established sustainability program of any given city will reflect the unique conditions that each city will bring in local efforts to advocate or advance sustainability. This concluding chapter discusses limitations faced during this project and includes results from an informal survey to test the application. The most essential aspect in improving the quality of the map as a measure of sustainability indicators would be to update the data over time in order to visualize the progression of changes as they relate to the notion of sustainability for Oakland, Ca. Also, some consideration should be given to how the Web GIS tool demonstrated here might be integrated into the existing web page reporting for Oakland's SI program. Last, this chapter discusses implications of this project for future research on Web GIS for urban SI programs.

5.1 Limitations

Progress on this project inevitably met with a number of obstacles. One limitation was the constraints on available data with which to represent determined indicators. Other challenges over the development process were evident during the application programming, including limits on the integration of the maps and resulting in three separate map applications within the single webpage. Though the third EPA map is not directly linked to any designated indicators, it was included on the premise that real time air, land, water, and toxics data are important to planners and the public in regards to sustainability and may be a valuable inclusion to other programs attempting these methods. It is also important to note as a limitation, that user feedback was not collected as a scientific survey, but merely as a limited request for user experience.

5.2 Application Feedback

Fourteen residents of Oakland were asked to test and evaluate the web GIS application and to complete a survey. The initial feedback was provided by eight participants that responded within 2 weeks with a survey of five questions, asked to gauge user opinion and experience as described in the Table 3 below. The informal survey was conducted with interested stakeholders in Oakland's sustainability indicators. Survey respondents were not scientifically sampled and the survey itself is not a detailed user study. Overall, the web GIS application seemed to be acceptable to the initial users in communicating the information it was designed to convey.

Table 4. Survey Questions

Survey Questions	Answer Format
How would you rate how informative the first map was to understanding sustainability in Oakland, Ca?	1 not informative - 5 very informative
Did you input a feature location or feedback on an existing feature location on the 2nd map?	Open Ended (What was the input you added?)
How would you rate your experience adding input?	1 difficult - 5 easy
How would you rate your overall experience with the applications?	1 poor - 5 valuable
What is your overall feedback of the maps?	Open Ended (What you like or would improve?)

For the first question, ratings were quite positive for the information people perceived to gain from the maps. Six respondents posted a top score of five for very informative, while two gave a rating of four. The overall average for how informative users responded rated at 4.75.

For the second question, four respondents added a feature location into the Culture and Community indicator. These inputs were an open microphone venue called "Air", a performance theater called "the Flight Deck", a produce stand called "Phat Beets," and the Studio 1 art studio. One respondent added feedback to the existing Temescal Park feature, remarking about the availability of paved paths for stroller accessibility. Three respondents did not add new features, just remarking on the layers or data. In question number three, the five respondents that did add a feature or feedback, gave an average rating of 4 for overall experience in adding the input. Overall, they remarked on the ease of doing so, though one did reply that it was necessary to read the instructions.

The fourth question, asking for overall experience with the applications, rated an average of 4.63 from the eight participants. Comments included with this answer included adjectives like, "intuitive," "good," and "neat", with one remarking it is valuable to any resident of Oakland.

For the final more open-ended question for overall feedback, many of the comments were generally positive. While one commented specifically on appreciation for the transit data, three involved the social media photos. Of the suggestions offered, one critiqued the font face used, one pointed out typo mistakes, and two inquired whether and how they could add photos.

These feedback results were incorporated into the final map revisions, correcting the typos and text margin as well as including information on the map to instruct users on how to add photos of their own to be displayed with the social media layer.

5.3 Integration of Web GIS with Oakland Sustainability Reporting

The city of Oakland currently hosts a Sustainable Oakland webpage with a section for news and highlights, performance area achievements, photos, videos, links to the focus area indicators, awards, adopted policies, and to the Sustainable Oakland Reports. A web GIS on this initial webpage would work to complement the links to the focus areas by visualizing this information at a glance. The Oakland Sustainability Reports are available for the various years after it was first prepared in 1999. This tool could be customized to track the targets of Oakland by organizing the data to display the progress of each area over time. As new data becomes available, the tool could also be updated and compared with previous years. Another potential use for the city of Oakland to use this web GIS application might be to determine goals for each of the focus areas that could become a layer of its own in each indicator. The toggling of this goal layer with the actual indicator layers, could clearly demonstrate whether or not the specified goals were being met. These implementations into the city's program would increase the quality and value of these sustainability indicators by advancing them all from state to response indicators.

5.4 Future Considerations

An addition to this project may be to complete the remaining indicators from Oakland's Sustainability Report. From the combined elements in the "buildings, energy, and climate" indicator from Oakland's report, (though energy is inclusive in the RSS feed provided by the EPA and the "climate change vulnerability" layer covers climate) a future layer with data of Oakland's LEED certified or other sustainable standard of rating for building sustainability and efficiency would be more conclusive. From the "education, culture, and community" indicator from Oakland's report, a layer of education levels could be added from the census to visualize the geographic relationship to such attainment. The "health, safety and well-being" indicator is also unresolved with this application development. A future addition of this information could possibly come from the public health department and a map of type and number of crime occurrences. Also lacking in the customizations within this application, from the "housing, land use and transportation" indicator in Oakland's report, land use is not included. This could eventually be informed with data from the United States Geological Survey (USGS).

Other future contributions to this project would facilitate further public participation in defining and determining what and where neighborhood assets are, with the accessibility of a mobile device application. The use of cellphones and tablets to input these assets, would offer more ease to better inform an inventory of culture and community. Capabilities of a future mobile application would ultimately utilize the LocationService class to load to the user's location. This would enable the input of culture and community features while participants are actively involved or at the location of the feature they may wish to add. The future mobile application would also allow for captured photos and a rating option to be included with the geo-referenced feature locations that users find of value. Being able to add point or polygon features to the data could better demonstrate a collective view of where such places of value are.

Additionally, monitoring of the input features collected through the PPGIS application, would provide a level of quality assurance that the features added do exist or to circumvent graffiti or advertising from the PPGIS map. Adding a log-in feature with created user accounts could aid such efforts by adding a trace-back to connect the erroneous inputs with the users making such additions. Many of these additional capabilities are accessible through programming of web code, Android and Iphone developing environments, or from the

ArcGIS.com service features online.

Furthermore, as this project is simply a demonstration and not part of a municipal sustainability program, no long-term maintenance has been put into place. An urban sustainability program using such a tool, however, would need to consider a plan over time to keep the application relevant. At a minimum, GIS project teams would need to follow the data sources for the layers used in the map and create new GIS feature service layers in the ArcGIS desktop environment as additional data becomes available.

As mentioned, the most valuable improvement that would come from ongoing maintenance would be a progressive update over time of the established indicators. These could be added as new layers that are time stamped over multiple years, so that the user can toggle the visibility to compare the data layers from past to present. An additional layer could even be created that represented progress over time, with a color range from red to green for negative to positive activity between the given dates. Aside from data updates, continuing the application presence would otherwise only require continual web hosting.

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