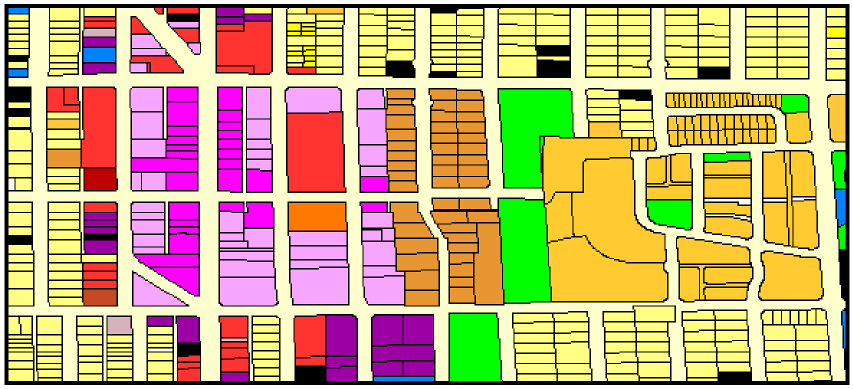
King County HealthScape
Community design for health and the environment

I-PLACE3S Health & Climate Enhancements and Their Application in King County



FINAL REPORT

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EXECUTIVE SUMMARY

Project Purpose

HealthScape is King County's effort to promote public and environmental health through community design. HealthScape builds upon the findings of the LUTAQH (Land Use, Transportation, Air Quality and Health)[1] study.

The purpose of this part of the HealthScape project was to create and test a tool that can evaluate potential transportation, health, air quality and climate change impacts of different development alternatives. The results of the LUTAQH research on the relationships between land use patterns, air quality, transportation and health, completed in 2005, provided the foundation for the tool. The original research results were updated, integrated into a modeling tool (I-PLACE3S), calibrated for application within all of King County, and tested on a case study site – SW 98th Street in White Center (unincorporated King County).

Methods

I-PLACE3S is a web-based modeling platform for scenario planning. It can evaluate how alternative development approaches or transportation investments may impact a number of indicators, including transportation patterns, energy usage, cost efficiency, and climate change. I-PLACE3S analysis is conducted through a web-based map display. This strong visual component and interactivity supports scenario development and testing by non-technical users in settings such as public workshops, as well as in more technical settings.

An updated analysis of built environment, transport, physical activity, and air pollution data in King County generated the statistical relationships that were programmed into I-PLACE3S, creating a version of I-PLACE3S that is calibrated especially for the County. To generate those equations, we measured land use patterns around each King County household location in the 2006 Puget Sound Regional Council (PSRC) household travel survey, and correlated these land use patterns to travel, air pollution (oxides of nitrogen, hydrocarbons, and carbon monoxide), carbon dioxide, physical activity and body mass index (BMI). Travel information came from the 2006 PSRC travel survey as well. Emissions estimates were developed from travel survey information using a detailed process that accounts for vehicle occupancy, travel speeds, and hot/cold starts – for each vehicle trip in the survey. Information on Body Mass Index and

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[1] Land Use, Transportation, Air Quality, and Health, developed by Lawrence Frank & Co., Inc. for King County, funded from a Federal Transit Authority Grant (For a full copy of the LUTAQH final report, see www.kingcounty.gov/transportation/healthscape)

Results also found in the following journal article: Frank L, Sallis JF, Conway T, Chapman J, Saelens B, Bachman W (2006). "Multiple Pathways from Land Use to Health: Walkability Associations With Active Transportation, Body Mass Index, and Air Quality." Journal of the American Planning Association Vol. 72 No. 1.

objectively measured physical activity was obtained from the NIH-funded Neighborhood Quality of Life Study (NQLS) project, led by Dr. James Sallis, which used King County as one of its study sites.[2]

Products

I-PLACE3S Health & Climate Modules
The HealthScape project created two new "modules" for I-PLACE3S: a Health module and a Climate/Air Pollution module. It is now possible for I-PLACE3S to assess the impacts of land use change on six new outcomes: carbon dioxide, oxides of nitrogen, carbon monoxide, hydrocarbons, physical activity and body weight.

In addition to these major new components, this project also resulted in other useful changes to I-PLACE3S that will benefit future analysis of decisions at the County. I-PLACE3S measures land use patterns in exactly the same way that the research was conducted, based on what is accessible within a 1 km walking distance on the actual street network. It can also now incorporate detailed demographic information (such as income, age and employment status) that is crucial to public health analysis. Demographics such as age and income typically play a large role in influencing health outcomes, so the ability to account for demographics within I-PLACE3S is critical. The third major enhancement to I-PLACE3S functionality is the ability to change relative transit service levels. As King County is a transit service provider, the ability to assess transit service changes alongside potential changes in land use is perhaps one of the model's most useful features.

White Center Case Study
I-PLACE3S was tested on a small case study area in White Center in unincorporated King County - the SW 98th Street corridor. White Center is one of the few remaining urban unincorporated areas in King County. Thus, there is a great deal of interest for the County in White Center and SW 98th Street. The County has made a number of investments in the area in recent years, and is very interested in connecting a recent Hope VI housing redevelopment called Greenbridge to the White Center business district via SW 98th street. The zoning regulations in the SW 98th Street corridor are being changed to increase allowable densities and allow/encourage mixed use development, and a pedestrian walkway connecting the Greenbridge public housing development to SW 98th Street is in the planning phase. Using I-PLACE3S, we tested how these potential changes might impact physical activity and obesity, and per capita CO2 and air pollution for residents of the area. The White Center case study was also a way to calibrate the new I-PLACE3S modules.

[2] More info on NQLS can be found at www.nqls.org.

Overall, the White Center case study was a successful test of the new I-PLACE3S modules, and produced informative results. We tested three scenarios:

- The Buildout Scenario, which assumed redevelopment of all the redevelopable parcels at the maximum zoned capacity
- The Interim Buildout Scenario assumed maximum buildout of some of the redevelopable parcels in the study area
- The TOD-only Scenario assumed redevelopment of a single parcel into a Transit-Oriented Development (TOD).

On the whole, the analysis indicates that if the changes the County made in development regulations can spur redevelopment of the SW 98th Street corridor, it will positively impact physical activity, Body Mass Index (BMI), air pollution and carbon dioxide emissions.

The Buildout Scenario was estimated to have the largest positive impact on the per-dwelling unit emissions, as it had the largest amounts of change in land use patterns – more pedestrian-friendly development, more proximate development (higher densities and land use mix), and a slight increase in intersection density / street network connectivity. However, the Buildout Scenario produced the highest *total* amount of vehicle trips/miles and emissions. This result highlights the challenge inherent in reducing total emissions as our population continues to grow - and also the potential for additional pollution exposure for an area's residents that exists when a place is developed more compactly. Although urban areas are more efficient in terms of transportation emissions – and thus are more beneficial when compared to fringe development – the residents and workers in those areas may very possibly be paying the price of those benefits in the additional exposure to pollution. Reducing *total* emissions (and air pollution exposure risks) will require more of a departure from business-as-usual - not just more dramatic changes in the built environment, but investments in faster, more convenient transit service to more destinations, and monetary disincentives to driving such as road and parking pricing or pay-as-you-drive insurance. It will also likely mean a switch to smaller, lighter and extremely low-emissions (e.g. electric) vehicles.

The largest amounts of relative change between the scenarios were seen for the physical activity outcome. For all four scenarios, the estimated total daily amount of physical activity (moderate and vigorous) is above the daily 30 minutes recommended by the U.S. Surgeon General. This is due largely to study area demographics, which favor more physical activity (more low-income households, with fewer cars than household members). However, it also reflects the fact that White Center is already relatively walkable, with a good mix of uses, an interconnected street grid, and a moderate to high level of transit service. Again, the Buildout scenario produced the largest physical activity and obesity benefit, increasing the total amount of physical activity by about 13 percent over the Existing Conditions scenario, and reducing average Body Mass Index by about 2.5 percent.

The other scenarios produced some positive results, but had very few changes from the baseline overall. This is due to the small amount of change assumed in these scenarios, particularly the TOD-only scenario. The TOD-Only Scenario, which tested the redevelopment of a single parcel into a mixed-use transit oriented development (TOD), was estimated to produce very little change in the outcomes of interest. This is to be expected; the redevelopment of a single, small parcel will rarely make much of an impact in the aggregate. However, the changes in development regulations recently adopted by the County along SW 98th Street can work in tandem with the TOD development.

The project team also conduted two supplemental scenarios in the 98th Street corridor – one that increases transit service, and another that adds more development on top of the 'Buildout' scenario. In the additional development scenario, per-dwelling unit emissions, car miles and BMI continue downward from 'Buildout,' and walking/bicycling and minutes of physical activity go up. The changes are not dramatic, but demonstrate that further departure from the prevailing land use pattern may be useful to examine. *Total* emissions, car miles, transit trips & miles, and walk / bike trips & miles continue to increase above the 'Buildout' scenario. The added transit service scenario produced even larger reductions in per-dwelling unit emissions. Total CO2 and emissions, while still a substantial increase over the Existing Conditions, were not as great as the 'Buildout' scenario – highlighting how transit investment can be used as a strategy to reduce the local emissions impacts of adding population and employment in an already-developed area.

Benefits

Geographically flexible, robust and versatile in application, the enhanced version of I-PLACE3S is a unique tool that has a great deal of potential to inform King County during a number of processes – including planning, zoning, development review, transit and other transportation investments, as well as Health Impact Assessment (HIA).

King County's leadership is apparent throughout this project in their commitment to a healthy, sustainable region; the recognition that transit-friendly, walkable communities have many converging benefits, and the desire to make decisions based on evidence. The evidence used to build this tool was not just any evidence, but relevant evidence – local data, that focused on the particular factors that the County can control, such as land use patterns and transit service. The County's leadership is reflected in its support of this unique project and the tool that came out of it – which is now generating interest around the country. With I-PLACE3S, King County has a significant opportunity to ensure that new development in King County supports active living and lower carbon footprints – putting policy into action.

"It is my belief that global warming is the defining issue for humankind in the 21st century."
Ron Sims, King County Executive

I. Background

About HealthScape

HealthScape is King County's effort to promote public and environmental health through community design. HealthScape builds upon the findings of the LUTAQH (Land Use, Transportation, Air Quality and Health)[3] study.

LUTAQH started in 2001 and examined how community design and transportation investment were connected to travel behavior, air quality, climate change and also to physical activity and obesity in King County. LUTAQH's results clearly show that compact, walkable land use patterns and good access to transit can help King County achieve its goals related to smart growth, land use, transit efficiency, and improved air quality and public health. Residents living in places that are compact, with well-connected street networks, a mix of homes, shops and services, and good access to transit, drive less, walk more, are less likely to be obese, and generate less air pollution and carbon dioxide per capita.

LUTAQH is just one of a number of studies that have documented the relationships between land use, transportation and physical activity, obesity, air pollution and climate change. Much of this work is an extension of ongoing investigations into how our development patterns impact travel choices. Transportation investments and land use patterns have been shown to influence travel behavior. Travel choices can affect physical activity levels and obesity through engagement in active or sedentary forms of transportation. Because driving generates greenhouse gases and air pollution, if land use patterns are connected to the amount of driving people do, they will also influence air pollution.

HealthScape, the project's second phase, helps to implement the LUTAQH findings. HealthScape's purpose is to develop evidence-based decision-making support tools for King County and its communities. Two tools were developed: a Nonmotorized Transportation Programming Tool that ranks nonmotorized transportation projects based on LUTAQH findings, and an Impact Assessment Tool, which predicts and compares the impacts of different development alternatives. This report discusses the development of the Impact Assessment Tool. Information on both tools can be found on the Healthscape website at www.kingcounty.gov/transportation/healthscape.

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[3] Land Use, Transportation, Air Quality, and Health, developed by Lawrence Frank & Co., Inc. for King County, funded from a Federal Transit Authority Grant (For a full copy of the LUTAQH final report, see www.kingcounty.gov/transportation/healthscape)

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Project Purpose and Overview

The purpose of this project is to create an impact assessment tool that can evaluate the potential transportation, health, air quality and climate change impacts of different development alternatives, based on changes in land use, transit, and street network characteristics.

The results of the LUTAQH research provided the foundation for the impact assessment tool. The research results were updated and integrated into a modeling tool (I-PLACE3S), calibrated for application within King County, and tested on a case study site – the SW 98th Street corridor in White Center (unincorporated King County). The SW 98th Street case study allowed us to test the functionality of the I-PLACE3S enhancements, troubleshoot and calibrate the model, and to evaluate the potential impacts of a real-world decision.

About This Report

This report summarizes how we enhanced I-PLACE3S so that it could evaluate health, air quality and climate impacts. A user guide and documentation of these new I-PLACE3S modules, *"Supplemental User Guide for I-PLACE3S Climate Change and Public Health Modules,"* and the *I-PLACE3S User Guide* is provided in conjunction with this report for those interested in the details of I-PLACE3S structure and application. Chapter 2 of this report summarizes how I-PLACE3S was selected as the model structure to work with, and gives an overview of the changes made to I-PLACE3S as part of the HealthScape project. Chapter 3 outlines the research, and how the research results were incorporated into I-PLACE3S, in greater detail. Chapter 4 discusses the White Center / SW 98th Street corridor case study and results. Chapter 5 concludes the report with a discussion of potential I-PLACE3S applications in King County, including activities such as station area planning, corridor planning, transit investment assessment, development or comprehensive plan assessment, and health impact assessment.

II. I-PLACE3S Overview

I-PLACE3S is a web-based modeling platform for scenario planning. It can evaluate how alternative development approaches or transportation investments may impact a number of indicators, including transportation patterns, energy usage, cost efficiency, and climate change. I-PLACE3S analysis is conducted through a web-based map display. This strong visual component and interactivity supports scenario development and testing by non-technical users in settings such as public workshops, as well as in more technical settings. I-PLACE3S was developed in the public sector by the California Energy Commission (CEC), the California Department of Transportation and the U.S. Department of Energy, and is currently managed by the Sacramento Council of Governments (SACOG). The current version I-PLACE3S is an overhaul of the PLACE3S model, which was initially developed in the early 1990s. I-PLACE3S is currently managed by the SACOG, and a private company provides programming, maintenance and web hosting.

I-PLACE3S has a number of key advantages as a modeling platform:

I-PLACE3S INDICATORS

- Employees
- Dwelling units
- Population
- Water consumption
- Jobs by sector
- Vehicle trips per household
- Vehicle miles traveled per household
- Transit ridership
- Pedestrian friendliness
- Pedestrian and bike trips
- Electricity / natural gas / gasoline demand
- Return on Investment

Indicators can be calculated at the region, city or neighborhood level, or any other defined geography or subarea.

1. INTERACTIVITY: I-PLACE3S supports interactive workshops to meaningfully involve stakeholders and quantitatively evaluate numerous, complex planning issues within a collaborative setting. From an administrative perspective, because I-PLACE3S is accessed through a server, there is only one dataset to maintain and update, and access can be secured to maintain quality control.

2. INTERNET-BASED USER INTERFACE: Because it is an internet-based system, no specialized hardware or software is required to operate I-PLACE3S. Particularly for public health staff, who may not be trained in or have access to a GIS platform, this feature will allow more in-depth participation and insights into the planning process.

3. ROBUST: I-PLACE3S is capable of working with detailed data at scales from neighborhood to multi-county regions, yet still provides results in real time. I-PLACE3S can easily perform analysis on extremely large datasets (over 750,000 records) within a several second time frame. I-PLACE3S can easily store and process terabytes of data, distinguishing it from other land use planning tools. PLACE3S can also incorporate data from regional travel models, and can feed back its own model outputs into the regional travel model, giving it the potential to illustrate regional transportation benefits of local-level land use change.

4. FLEXIBLE: I-PLACE3S is designed for flexibility; it can be expanded by adding new or updated modules and can be customized to meet the needs of individual organizations. Any new functionality added by any one agency is made available for use or customization for all users, thus enabling synergy and cost savings between the I-PLACE3S users. This flexibility has been crucial in expanding this tool for King County as part of the HealthScape project. I-PLACE3S has been able to incorporate a robust functionality that can take study area demographics into account (particularly important for any public health analysis) and can measure varying components of the built environment within the actual walking distance of each parcel in the study area.

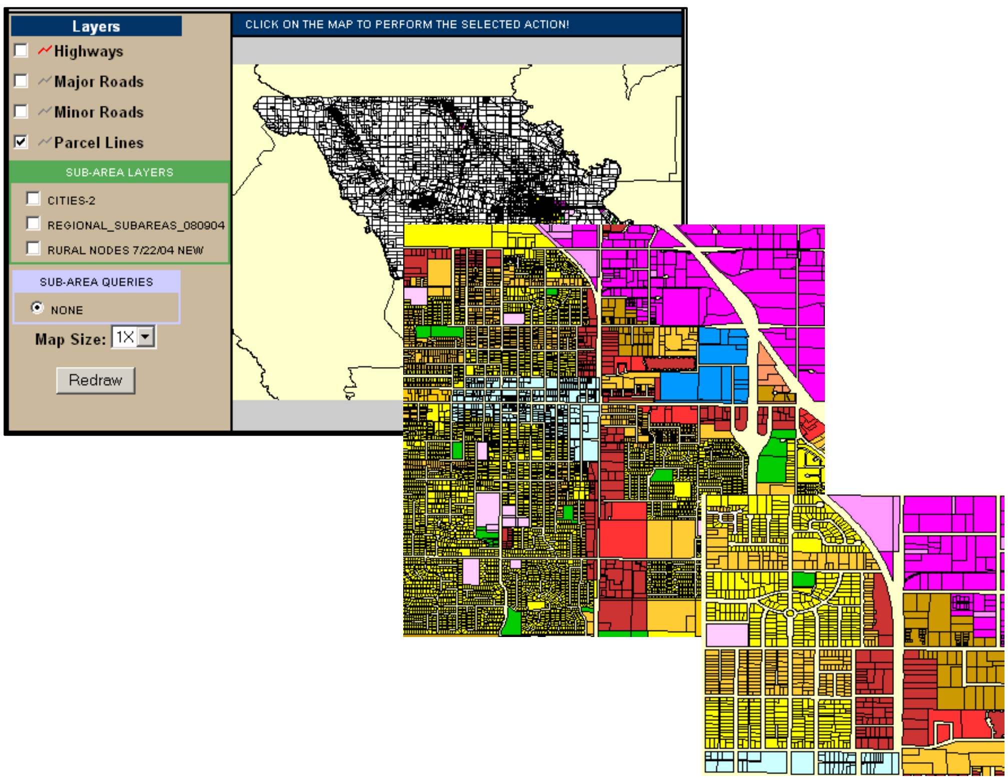

Figure 1. Sample I-PLACE3S Map Interface. I-PLACES uses parcel level land use data for integrated, rapid analysis at county, regional, or neighborhood scale.

Other Features

A number of other features make I-PLACE3S a particularly useful tool for King County. I-PLACE3S contains a Return on Investment (ROI) calculator, which examines whether the land use changes being considered will attract development. Users can define base ROI assumptions, such as rents, operating costs, and occupancy rates. I-PLACE3S allows the user to define constrained land where regulations exist that limit development in areas such as wetlands or steep slopes. I-PLACE3S can use, and export data to the regional travel model. This allows a 'feedback loop' to take place, where it is possible to examine the potential impact of land use decisions on travel patterns. I-PLACE3S also has several other new modules still under development - a rural land evaluation component, an infrastructure costs component, and a building energy usage module, which is currently in the beta testing phase.

Additionally, I-PLACE3S has a key methodological advantage: the ability to precisely replicate the methodology of the research upon which the health outcomes are based. Because it is parcel based, rather than grid cell based, I-PLACE3S can measure land use patterns in exactly the same way that the research team did, and can incorporate detailed demographic information (such as income, age and employment status) crucial to public health analysis.

There are also strategic advantages to building upon the I-PLACE3S model platform. In 2006, the California Legislature passed Assembly Bill 32 that requires the state to reduce greenhouse gas emissions. This was followed in 2008 by Senate Bill 375, which ties regional and local land use planning to those statewide goals. These requirements mean that the state will be heading toward standardization in regional modeling. Because it is the state of the art, because it was developed in California, and because it was part of the modeling work supporting the above legislation, I-PLACE3S is expected to become a standard for California's regions and local governments within about two to four years. This means that King County will be able to enjoy the support of a broadening user group and future I-PLACE3S upgrades in the years ahead.

As noted, the HealthScape project created two new modules for I-PLACE3S: a Health module and a Climate/Air Pollution module. An updated analysis of built environment, transport, physical activity, and air pollution data in King County generated the statistical relationships that were programmed into I-PLACE3S, creating a version of I-PLACE3S that is calibrated especially for the County. These linear regression models that are the basis of the Health and Climate modules express how much change can result in public health / air quality (dependent) variables, based on a change in built environment and demographic characteristics (independent variables). Therefore, equations from these models can be applied to alternatives analysis in order to estimate how different built environment scenarios might change public health and air quality.

For additional background on I-PLACE3S and the model selection process, see Appendix A. For a detailed explanation of the project's methodology, see Appendix B.

III. White Center / SW 98th Street Case Study Application

Study Area Description

I-PLACE3S was tested on a small case study area in White Center in unincorporated King County - the SW 98th Street corridor. Figure 6 is a context map of White Center, which is located just south of Seattle's city limits and north of Burien's city limits, between state highway 509 and Puget Sound. Figure 7 shows the SW 98th street study area boundaries, a two block wide corridor from 17th to 8th Avenue SW.

A number of potential sites were considered for case studies. In order to select a case study area, the consultant team and King County staff considered the following criteria:

- Is the site under King County authority (either owned by the County, or in an unincorporated area)?
- Is there potential for dense/mixed use/walkable development?
- Does it contain affordable housing, or is there the potential for affordable housing?
- Does the site have a strong community identity?
- Does the site have a mixture of demographic types, such as income and age?
- Does the site have redevelopment potential?
- Is there a potential public development project in the site, such as a TOD?
- Does the site contain a Park & Ride or Transit Center?

The SW 98th Street corridor in White Center met all of these criteria. The LUTAQH study, which used White Center as a case study, identified a number of assets in the area – a good deal of park space, including several large parks and open space areas; a culturally vibrant commercial district (16th Avenue SW) that is reasonably pedestrian friendly, a highly interconnected street network, and good transit service. However, much of the commercial core remains rather auto-oriented in nature, with a number of large parking lots and strip developments, and there are few people living within or adjacent to the commercial core.[4] White Center is one of the most diverse areas in the County, its affordable housing and low commercial rents serving as a gateway for new immigrants and small businesses.

As it is one of the few remaining urban unincorporated areas, King County has a great deal of interest in White Center and SW 98th Street. The County has made a number of investments in the area in recent years, including new sidewalks and storefront façade improvements along 16th Avenue SW, White Center's primary commercial corridor. The King County Housing Authority has

[4] Lawrence Frank and Company and Dr. Kathleen Kern. LUTAQH Case Study Report: Urban Design. Appendix V to the LUTAQH study final report, Dec. 2005. p. 40.

also utilized Federal assistance for the Greenbridge HOPE VI public housing redevelopment.

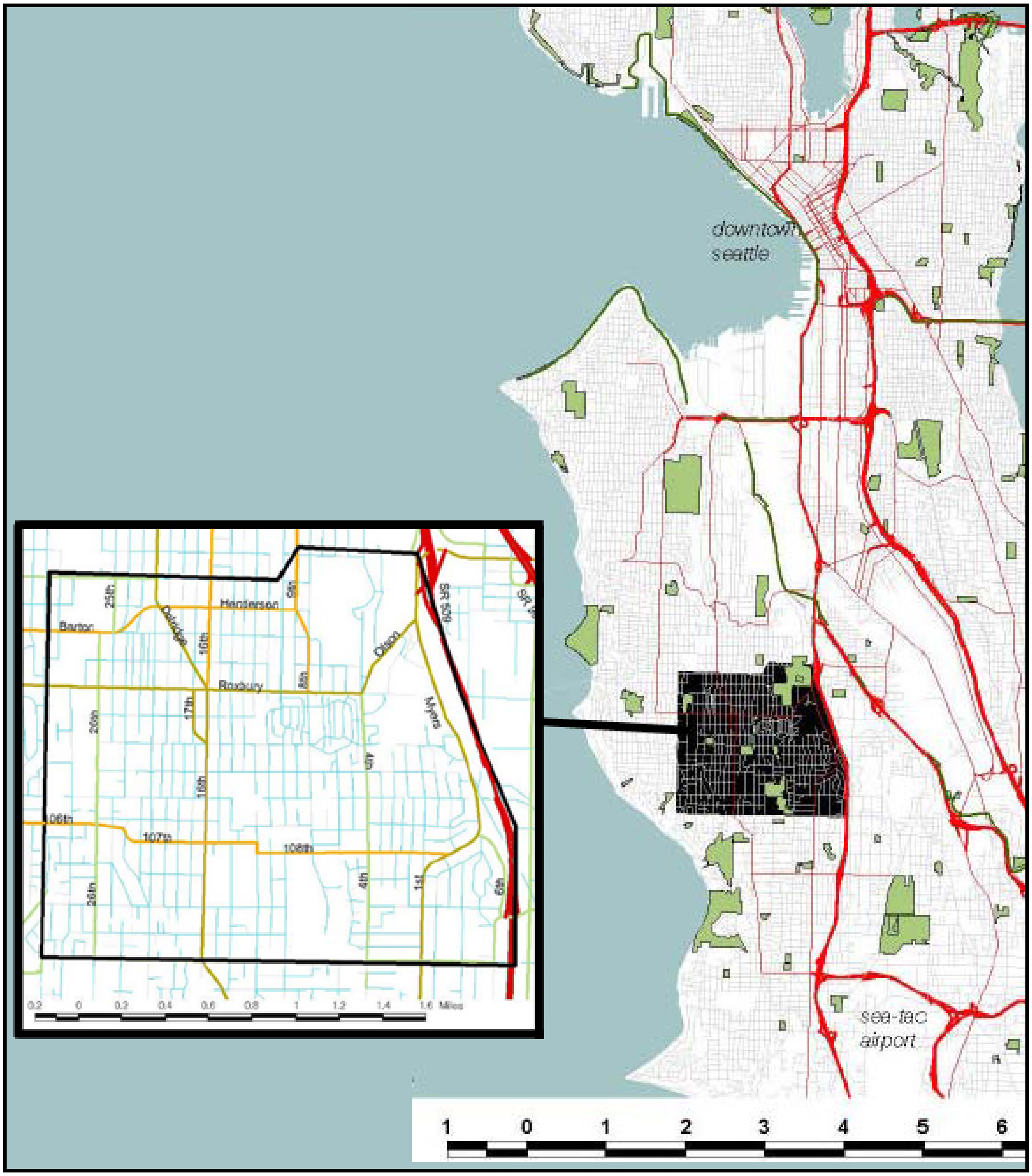

Figure 6. Context Map – White Center

A key strategy in making White Center a more pedestrian-friendly community is to connect Greenbridge to the White Center business district via SW 98th Street.

As part of the 2008 Comprehensive Plan update, King County updated the zoning regulations on the SW 98th Street corridor. Additionally, King County is working with a local business to explore the option of a transit oriented development (TOD) project. The SW 98th Street corridor has been the topic of a number of design charrettes and planning exercises sponsored by King County. With all these changes, King County determined that this would be a good case study for the Impact Assessment Tool.

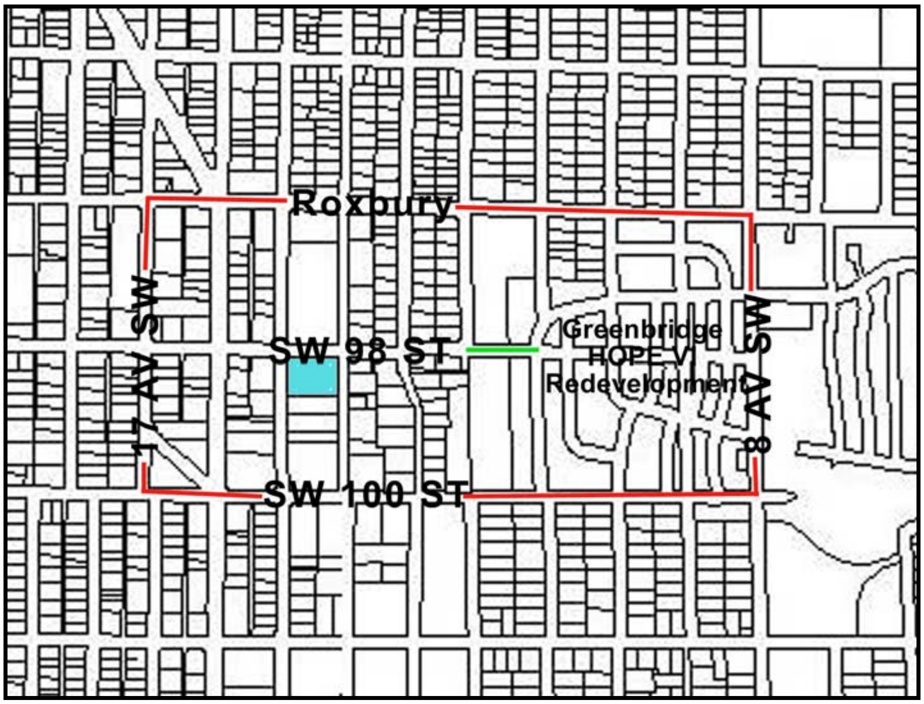

Figure 7. SW 98th Street Study Area.
Proposed pedestrian connection shown in green; the blue parcel is the potential TOD site tested in the 'TOD only' scenario.

As mentioned earlier, the zoning in the SW 98th Street corridor was recently changed to increase allowable densities and encourage mixed use development. With the exception of the parcels along the eastern edge of the study area (12th Avenue SW), the entire SW 98th Street study area is currently zoned CB (community business). An Economic Redevelopment Overlay Zone (King County Code 21A.38.090) is also applied on CB parcels directly adjacent to SW 98th Street. Office, retail and mixed use development is allowed under the current code, and the overlay zone waives some requirements in order to spur redevelopment of the corridor. For those parcels currently zoned CB, King County recently changed regulations increasing the allowable densities to a base density of 48 du/ac, with allowable densities up to 72 du/ac for mixed use development, and up to 96 du/ac under certain scenarios.

The pedestrian walkway connecting the Greenbridge public housing development to SW 98th Street is in the planning phase. Shown as a short green line on the study area map (Figure 7), the walkway would cut the travel distance on foot from Greenbridge to White Center's commercial district almost in half (from 0.6 miles to 0.37 miles). In addition, the County is exploring developing a transit-oriented development on SW 98th Street (Figure 7).

Using I-PLACE3S, we tested how these all of potential changes might impact physical activity and obesity, and per capita CO2 and air pollution. The White Center case study was also a way to calibrate the new I-PLACE3S modules.

Case Study Data Collection / Development

Base data development

The consultant team and King County staff collected the base data necessary for the SW 98th Street case study. In I-PLACE3S, each analysis is known as a 'project.' When beginning a project, the user prepares and uploads a GIS parcel shapefile into I-PLACE3S that contains the parcel-level attributes for the study area, such as employment yield, demographics, number of dwelling units, whether a parcel is developed or vacant, and the TAZ within which that parcel is located. This file represents the 'base case' scenario. Other scenarios can then be built from this foundation of parcel data:

Base data requirements

Zoning designations
Existing conditions: Dwelling units, land uses, employees
Growth forecast: Housing units, employees
Parcel data
Environmental Constraints, such as steep slopes or wetlands[5]
Subarea shapefiles for reporting and analysis

The most recent version of the King County parcel file was used for zoning designations, dwelling units, and land uses in White Center, as well as geospatial attributes such as parcel size. County staff indicated whether or not a parcel was developed. The number of employees on commercial parcels was estimated using commercially available data from INFO-USA. It was necessary for the consultant team to ground truth this data in order to properly match addresses in the parcel dataset to those provided by INFO-USA.

The parcel file included not only the parcels within the actual case study area (about 200 parcels), but all of the parcels within 1 km of the study area. These "contextual" parcels were necessary so that I-PLACE3S could measure land use patterns within a 1 km network buffer area around each study area parcel.

Data development for new modules

Because the new I-PLACE3S modules measures land use patterns within the 1 km buffer for each parcel in the study area, it was necessary to provide a relational data table telling I-PLACE3S which parcel was in the 1 km buffer, for every parcel in the study area. These tables were created in GIS for both the

[5] Because the case study was focused on testing the new I-PLACE3S modules, we did not enter information on environmental constraints or subareas.

"existing" road network and the "enhanced" network, which included the pedestrian connection from SW 98th Street to Greenbridge.

Demographics were applied using the same 2006 PSRC synthetic population that was used in the modeling. Population data was split out by housing type (single family, multi-family two to four units, multi-family five to 19 units, and multi-family 20 or more units) and applied at the TAZ level. Household characteristics included household income, number of workers, non-workers and children in the household, and whether or not a household had fewer cars than adults.

Defining Place Types

In I-PLACE3S, 'Place Types' are the land uses (e.g. high-rise office, medium-density single family, mid-rise mixed use) that are applied to each scenario. Place Types can be existing land uses, or land uses that do not yet exist or are not currently permitted by code. A list of Place Types is typically defined at the beginning of the project (but can be changed or added to at any time), and include assumptions such as mix of land uses, parking ratio, square footage of units, and setbacks. In the HealthScape case study, King County staff created a list of Place Types that matched current land use and new zoning designations to be tested. These Place Types were applied to parcels in I-PLACE3S to create the scenarios for SW 98th Street. For the "contextual" parcels (those surrounding the actual SW 98th Street study area), the Place Types were held consistent in all scenarios. Figure 8 shows the Place Types used in the case study.

Figure 8. SW 98th St Case Study Place Types (land use types).

PLACE TYPE NAME	MAX STORIES	DU / ACRE	EMP / ACRE	FAR
01 - (O). TOWNHOUSE (OWNER)	3	15.00	0.00	0.48
02 - (R). TOWNHOUSE (RENTAL)	3	15.00	0.00	0.41
03 - (O). LOW-RISE CONDOS (OWNER)	2	23.60	0.00	0.65
04 - (O). MID-RISE CONDOS (OWNER)	3	35.42	0.00	0.89
05 - (R). MID-RISE APARTMENTS (RENTALS)	3	35.28	0.00	0.77
06 - (O). HIGH-RISE CONDOS (OWNER)	6	69.02	0.00	1.58
07 - **MID-RISE HOUSING (OWN & RENT, R-24)	3	41.82	0.00	0.67
08 - **MID-RISE MIXED USE (CBSO)	3	34.16	64.06	1.10
09 - **MID-RISE MIXED USE PED CORRIDOR (CBSO)	4.5	81.68	65.63	1.88
10 - *BANK (CBSO)	2	0.00	41.88	0.38
11 - *CONV STORE W/GAS (CBSO)	1	0.00	31.21	0.50
12 - *DUPLEX (R-18, R-24)	2	13.61	0.00	0.38
13 - *INDOOR ACTIVITY CENTER	1	0.00	10.89	0.25
14 - *LOW-RISE APARTMENTS (RENT, LIVE/WORK, R-18)	1	21.51	21.07	0.56
15 - *LOW-RISE APARTMENTS (RENT, SMALLLOT, R-18)	2	33.22	0.00	0.76
16 - *LOW-RISE APARTMENTS (RENT, LARGELOT, R-18)	2	33.22	0.00	0.76
17 - *OFFICE BLDG (CBSO, LARGELOT)	1	0.00	44.55	0.41
18 - *OFFICE BLDG (CBSO, SMALLLOT)	1	0.00	44.55	0.41
19 - *PARK/OPEN SPACE (R-6, R-18)	0	0.00	0.00	0.00
20 - *PARKING LOT (CBSO)	0	0.00	0.00	1.00
21 - *RESTAURANT	1	0.00	35.00	0.56
22 - *RETAIL STORE (CBSO)	2	5.75	52.53	0.53
23 - *ROW/ROAD (R-18)	0	0.00	0.00	0.00
24 - *SINGLE FAMILY HOME (LARGELOT >5000SF; R-6, R-24)	2	5.73	0.00	0.26
25 - *SINGLE FAMILY HOME (SMALLLOT 5000SF OR LESS/R-18)	2	18.01	0.00	0.50
26 - *VACANT	0	0.00	0.00	0.00
27 - *WAREHOUSE/LIGHT INDUSTRIAL	1	0.00	30.04	0.48
28 - COMMUNITY/NEIGHBORHOOD RETAIL	1	0.00	47.39	0.27
29 - HOTEL	8	0.00	16.13	0.36
30 - INDUSTRIAL	1	0.00	25.02	0.30
31 - PUBLIC/CIVIC/EDUCATION	2	0.00	19.15	0.29
34 - TOD WHITE CENTER	5	60.01	37.61	2.30
35 - FAST FOOD		0.00	0.00	0.00

SW 98th Street Corridor Scenarios

Four development scenarios were created for the SW 98th Street corridor, the small area within the box in the map below. The surrounding parcels in White Center were also coded to their corresponding place types, in order to measure land use patterns within walking distance (1 km) of the SW 98th Street corridor.

Existing conditions / base case scenario (Figure 9): The existing conditions scenario assumed existing land use patterns and full buildout of Greenbridge public housing. A pedestrian connection from 12th Avenue SW in Greenbridge was NOT assumed to be present in this scenario.

This scenario was estimated to have almost 800 dwelling units and slightly over 800 employees. Because Greenbridge is still under construction, there was no existing count of actual study area population, however the I-PLACE3S estimate was consistent with Census data and population / employment projections from the PSRC. Additionally, because the scenarios were developed using actual data on dwelling units from Greenbridge, model results will likely be a close estimate for actual population.

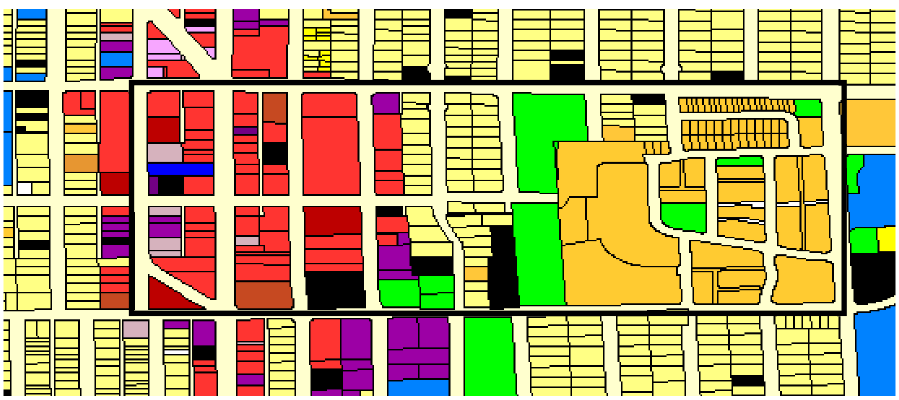

Figure 9. Existing conditions / base case scenario

Full buildout scenario (Figure 10): This scenario assumed buildout at maximum zoned density along SW 98th Street and 16th Avenue, full buildout of Greenbridge public housing and the pedestrian connection.

This meant the majority of the commercial development in the study area was converted to higher density, mixed use development - the 'mid rise mixed use' Place Type #8, with the 'mid rise mixed use pedestrian corridor' (Place Type #9) designation applied to parcels directly facing SW 98th Street or 16th Avenue. The only exception was the TOD development scenario. The residential parcels along 12th and 13th Avenues, currently single family development, were assumed to redevelop as mid-rise housing (Place Type #7).

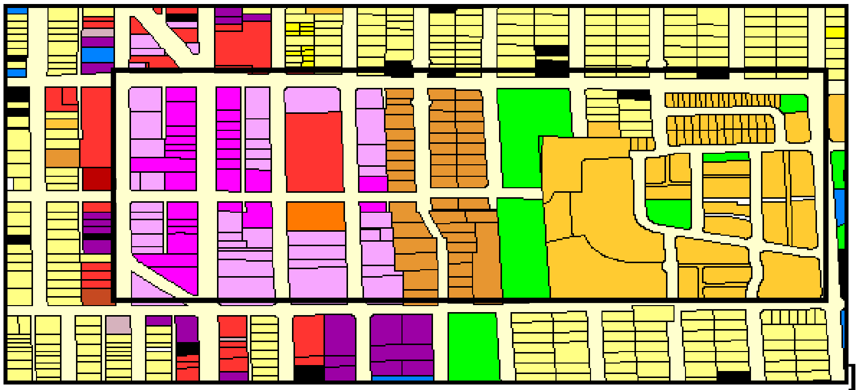

Figure 10. Full buildout scenario

Interim buildout scenario (Figure 11): The Interim Buildout scenario was created based on what a near-term (five to ten year), or less than maximum buildout might look like. This scenario assumed that only parcels directly facing SW 98th Street between 12th and 16th Avenues would redevelop in that time frame, but that those parcels would redevelop at maximum zoned density. Commercial parcels along SW 98th Street were changed to 'mid rise mixed use pedestrian corridor' Place Type (#9), while residential parcels were changed to mid-rise housing (Place Type #7). This scenario also assumed redevelopment of four single family residential parcels at the intersection of 100th Street SW and SW 13th Avenue, and of the currently vacant parcel just south of where 12th Avenue dead ends. These parcels were assigned Place Type #7, mid-rise housing.

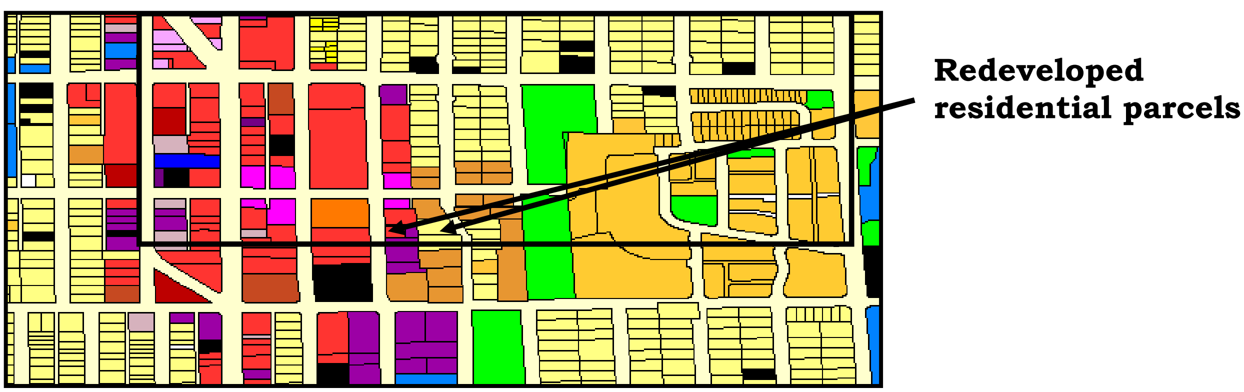

Figure 11. Interim Buildout Scenario

TOD-only scenario (Figure 12): This scenario tested how much of an effect the redevelopment of the TOD site would have on its own. It also assumed full buildout of Greenbridge public housing.

Figure 12. TOD-Only Scenario

Table 5 depicts the changes in study area population and employment from one scenario to the next. The Buildout scenario adds the most employees and residents, and consequently has the largest increase in population and employment density from the base case. The Interim scenario is estimated to increase the number of employees by 31, and adds about 450 dwelling units – for a total of about half of the 2,500 units expected for the Buildout scenario. The TOD-Only scenario was estimated to increase the employment by a very small amount, and adds about 50 dwelling units to the base case.

Table 5. Changes in Population and Employment

SUBAREA NAME	TOTAL EMPLOYEE CHANGE	TOTAL EMPLOYEES	EMPLOYEES PER ACRE	TOTAL DWELLING UNIT CHANGE	TOTAL DWELLING UNITS	DWELLING UNITS PER ACRE
EXISTING CONDITIONS	0	827	27.72	0	777	25.24
TOD-ONLY	+4	831	28.36	+53	830	26.49
INTERIM BUILDOUT	+31	858	33.32	+448	1,225	35.11
BUILDOUT	+1,017	1,844	101.25	+1,724	2,501	58.97

I-PLACE3S Testing and Calibration

After the SW 98th Street scenarios were set up and the basic program code in place, the results of the scenarios were used to test, troubleshoot and calibrate the new I-PLACE3S modules. We reviewed the results, paying attention to the following:

Is the I-PLACE3S programming correct? We confirmed that the correct parcels were being included in calculations and that the calculations / operations were correct and being conducted at the proper unit of analysis (for most outcomes, this was the household level, for BMI and physical activity it was for each adult). It was also necessary to confirm whether the urban form, demographic and accessibility values were being calculated correctly.

Is the study area population correct? We confirmed that the total population and employment calculated by I-PLACE3S in the base case approximated the actual population/employment of the study area. In some cases, this required adjustment to Place Type assumptions.

Do results match what is expected, based on the results of the statistical modeling? We looked for results that made sense when the scenarios were compared. For example, the Buildout scenario would be expected to have the lowest per household CO2 emissions out of all the scenarios, but the highest total CO2 (due to increased population in the study area). We compared the I-PLACE3S results to average values for the County and the study area in our study samples, as shown in Table 6 below, to confirm whether the I-PLACE3S results were reasonable.

In many cases, departures from the average values were expected and reasonable due to differences in demographics in the study area; e.g. car miles, and thus emissions, are about two-thirds the King County average.

Table 6. Average Values for Outcome Variables, King County

Physical Activity / BMI (per adult)	Mean (King County sample)	White Center Existing Conditions – I-PLACE3S estimate
Minutes moderate + vigorous activity	34.408	37.06
BMI	26.550	24.74
Trips and Emissions (per household)		
CO2 (g)	22827.34	14170
CO	860.53	580
NOX	70.97	47.62
HC	77.12	51.69
Vehicle miles	73.58	48.82
Vehicle trips	11.82	9.29
Transit miles	7.26	12.67
Transit trips	0.82	1.59
Walk/bike miles	2.14	3.13
Walk/bike trips	1.96	3.25

Interpretation of Results

Emissions, Vehicle Trips, Vehicle Miles

Generally, the Existing Conditions scenario resulted in the largest per dwelling unit emissions/car miles/car trips and smallest study area total emissions/car miles/car trips. Because there are fewer people and employees in the Existing Conditions scenario, when the emissions from study area residents and employees are added up, the total study area emissions are lowest – even though residents may be polluting more per dwelling unit. The Buildout scenario, on the other hand, produced the highest *total* amount of vehicle trips/miles, and emissions, but the smallest *per dwelling unit* amounts. This result is not unexpected, yet it highlights the challenge inherent in reducing total emissions as our population continues to grow. Although accommodating growth in already-developed areas such as White Center is better in terms of emissions than greenfield development on the fringe of the urban area, reducing *total* emissions will require more of a departure from business-as-usual. This will not only mean more dramatic changes in the built environment, but investments in faster, more convenient transit service to more destinations, and monetary disincentives to driving such as road and parking pricing or pay-as-you-drive insurance. It will also likely mean a switch to smaller, lighter and extremely low-emissions (e.g. electric) vehicles.

This phenomenon also highlights the potential for additional pollution exposure for an area's residents that exists when that place is developed more compactly. Although urban areas are more efficient in terms of transportation emissions – and thus are more beneficial when compared to fringe development – the residents and workers in those areas may very possibly be paying the price of those benefits in the additional exposure to pollution. In order to fully and fairly realize the benefits of growth management and infill development, these issues will need to be addressed to the greatest degree possible.

The TOD-Only scenario produced the smallest amount of change from the base case, as would be expected with only a small amount of change (just a single parcel) in urban form. The Interim Buildout scenario produced a moderate amount of total and per dwelling unit emissions, vehicle trips and miles. These estimates can be seen in Tables 7 and 8, below.

Table 7. Totals Per Dwelling Unit – Emissions, Car Trips & Miles

	CO2 (kg) / DU	NOX (grams) / DU	HC (grams) / DU	CO (grams) / DU	Car Vehicle Trips / DU	Car Vehicle Miles / DU
Existing Conditions	14.17	47.62	51.69	580	9.29	48.82
TOD Only	14.17	47.61	51.68	579.71	9.29	48.82
Interim Buildout	14.04	47.1	51.12	573.64	9.21	48.31
Buildout	13.94	46.7	50.61	569.82	9.08	47.85

Table 8. Whole Study Area Total – Emissions, Car Trips & Miles

	CO2 (kg)	NOX (grams)	HC (grams)	CO (grams)	Car Vehicle Trips	Car Vehicle Miles
Existing Conditions	10,652	35,792	38,851	435,976	6,984	36,695
TOD Only	11,400	38,287	41,562	466,238	7,470	39,263
Interim Buildout	16,104	54,008	58,616	657,815	10,562	55,397
Buildout	34,505	115,622	125,305	1,410,812	22,474	118,472

Transit Trips & Miles
There was very little overall difference in transit use between the four scenarios. The Buildout scenario had the highest *total* transit miles/trips, and the highest per dwelling unit transit miles. Transit trips per dwelling unit, however, go down slightly from the Base Case. The Interim Buildout scenario produced a total amount of transit trips and miles that was between the Buildout and TOD-Only scenarios. Per dwelling unit transit miles and trips, however, were the lowest of all scenarios for per household transit trips – about 2.5 percent less than the Existing Conditions. The TOD-Only scenario produced nearly as many transit person trips and miles as Existing Conditions. In the analysis presented in the previous chapter, transit use was closely connected to transit accessibility and less consistently associated with urban form. Because the White Center scenarios only tested changes in local land use, we did not expect any major changes in transit use. Future testing of transit service levels in I-PLACE3S will require a scenario that offers significant changes in travel time via transit. Therefore, a buildout scenario could be tested that offers increased utility (convenience and speed) for transit between the study area and major employment destinations. This could be done while maintaining a high level of local nonmotorized travel, which is synergistic with regional access on transit.

Table 9. Total and Per DU Transit Person Trips / Miles

	Transit Person Trips / DU	Transit Person Miles / DU	Total Transit Person Trips	Total Transit Person Miles
Existing Conditions	1.59	12.67	1,194	9,526
TOD Buildout	1.58	12.64	1,271	10,168
Interim Buildout	1.55	12.47	1,782	14,297
Buildout	1.57	12.99	3,881	32,156

Walk/Bike Trips & Miles
There was a small difference in walk/bike trips between the Existing Conditions and the other scenarios. The Buildout Scenario had the highest total and per dwelling unit walk/bike trips, but the lowest per dwelling unit walk / bike miles. This is likely due to the increased proximity of homes to destinations (better land use mix) and the new street connection in the study area, which shortens walking distances between Greenbridge and the SW 98th Street commercial corridor. This same phenomenon resulted in per-dwelling unit walk/bike distances for the Interim Buildout and TOD-Only scenarios that were in-between Existing Conditions and Buildout. The Interim Buildout and TOD-Only scenarios had an equal amount of per dwelling unit walk / bike trips, slightly lower than the Existing Conditions.

Table 10. Total and Per DU Walk / Bike Trips and Miles				
	Walk Bike Trips / DU	Walk Bike Miles / DU	Total Walk / Bike Trips	Total Walk / Bike Miles
Existing Conditions	3.25	3.13	2,445	2,356
TOD-Only	3.23	3.08	2,602	2,475
Interim Buildout	3.23	2.97	3,699	3,410
Buildout	3.37	2.73	8,340	6,769

Physical Activity / Body Mass Index

The largest amounts of relative change between the scenarios were seen for the physical activity outcome. For all four scenarios, the estimated daily amount of physical activity (moderate and vigorous) is above the daily 30 minutes recommended by the U.S. Surgeon General. This is due largely to study area demographics, which favor more physical activity (more low-income households, with fewer cars than household members). However, it also reflects the fact that White Center is already relatively walkable, with a good mix of uses, an interconnected street grid, and a moderate to high level of transit service.

The Existing Conditions scenario was estimated to have the smallest daily amount of physical activity, followed by the TOD-Only scenario. The Buildout Scenario was estimated to generate the most daily physical activity per adult in the study area – over 40 minutes a day and about 13 percent more than the Existing Conditions scenario.

The estimated average adult BMIs approached, but did not surpass, overweight status (generally a BMI of 25 to 30) for all scenarios. The Existing Conditions Scenario was estimated to have the highest estimated BMI of the four scenarios. The Buildout Scenario was estimated to result in the lowest average BMI, about 2.5 percent less than Existing Conditions, with the other two scenarios falling in between, as expected.

Table 11. BMI and Physical Activity		
	BMI / Adult	Minutes of Physical Activity / Adult
Existing Conditions	24.74	37.06
TOD-Only	24.72	37.11
Interim Buildout	24.5	38.24
Buildout	24.1	41.94

Summary of Results and Lessons Learned

Overall, the White Center case study was an informative test of the new I-PLACE3S modules, but further testing and refinement of the scenarios is recommended. Generally, the Buildout Scenario was estimated to have the largest positive impact on the per-dwelling unit outcomes, as it had the largest amounts of change in land use patterns – more pedestrian-friendly development (higher retail FARs), more proximate development (higher densities and land use mix), and a slight increase in intersection density / street network connectivity. This indicates that if the changes the County made in development regulations can spur redevelopment of the SW 98th Street corridor, it will positively impact physical activity, Body Mass Index, and per capita air pollution and carbon dioxide emissions.

The TOD-Only and Interim Buildout Scenarios in particular produced little change in the outcomes from the Existing Conditions. This is to be expected; although redevelopment of a parcel may change the behavior of the people who live or work in that building, the redevelopment of a single, small parcel or a small area will rarely make much of an impact in the aggregate. Although the Greenbridge Hope VI redevelopment made up nearly half the study area, it was left constant in all the scenarios. This was useful in terms of isolating (and accurately reflecting) the impact of potential zoning changes in the other half of the corridor, but also probably contributed to the lack of differences in the results from one scenario to the next.

The small amounts of change tested created results that offer little difference from the existing conditions, and were in some instances counterintuitive. I-PLACE3S is designed to create a testing and scenario building process by providing feedback to users. It is therefore an iterative rather than static process. The reasonable yet perhaps somewhat modest changes in urban form within a small area as shown in this study, without regional accessibility changes via transportation network improvements yielded very little changes in emissions.

The scenarios tested here should be seen as a jumping-off point. Additional scenarios should be created and tested, with an attempt to create larger amounts of change between the scenarios. To be the most policy-instructive, different 'focal points' of urban form change could be tested – for example, creating one scenario that is focused on increasing study area employment, another that is focused on mixed-use development, and another that is focused on increasing residential density. In the case of the transit outcomes, the County may also want to consider further I-PLACE3S testing to measure the impact of transit level of service changes in addition to the land use changes.

Because the study area is influenced by redevelopment within 1 km walking distance of each parcel, it may also be useful to also test some amount of redevelopment outside the SW 98th Street corridor. Additional experimentation and testing what is likely / possible in the area may yield more optimal scenarios than those tested for the course of this project.

Addendum: Testing Supplemental Scenarios

Due to the County's interest in further testing of the I-PLACE3S tool, the project team assembled two additional SW 98th Street scenarios. The first, 'Buildout + Transit,' increased transit service levels throughout the study area on top of the 'Buildout' land use and pedestrian network scenario assumptions. The second, 'Buildout + More Growth,' placed more residents and employees in the study area (with no changes to transit service).

Results are presented in the tables that follow. For reference, results are presented alongside Existing Conditions and Buildout scenarios.

Buildout + Transit Scenario
The Buildout + Transit scenario increased transit service assumptions to a level of 100 (peak) and 90 (off-peak) for all the TAZs in the study area. A service level of 100 represents an increase to equal the best service that currently exists in the County – i.e. Downtown Seattle. An off-peak service level of 90 corresponds to existing average peak period transit service in White Center.

This change produced even larger reductions in per-dwelling unit emissions and car vehicle miles, and increased per-dwelling unit transit trips (both number of trips and miles). Number of per-dwelling unit walk / bike trips also went up slightly, while walk / bike miles stayed about the same as 'Buildout' with only a very slight increase. Number of car vehicle trips per dwelling unit increased from 'Buildout' to a level close to what was found in 'Existing Conditions.' The analysis upon which the I-PLACE3S modules are based found a positive relationship between transit level of service and number of vehicle trips – when one increases, so does the other. Car trips in centrally located, more walkable places tend to generate more, yet shorter trips.

Body mass index dropped slightly, and minutes of physical activity stayed virtually the same as in 'Buildout,' with a minimal increase. Total CO2 and emissions, while still a substantial increase over 'Existing Conditions,' were not as great as the Buildout Scenario – highlighting how transit investment can be used as a strategy to reduce the traffic impact that will otherwise occur with adding population and employment in an already-developed area.

Buildout + More Growth Scenario
The 'Buildout + More Growth' Scenario added about 200 dwelling units and 400 employees to 'Buildout' across the SW 98th Street study area. This increased the population density (from 10.27 to 10.54 du/ac) and the employment density (from 16.92 – 17.96) slightly, as well as the overall jobs / housing balance and mix of land uses in the study area.

In this scenario, per-dwelling unit emissions, car miles and BMI continue downward from 'Buildout,' and walking/bicycling and minutes of physical activity go up. The changes are not dramatic, but demonstrate that further departure from the prevailing land use pattern may be useful to examine. *Total* emissions, car miles, transit trips & miles, and walk / bike trips & miles continue to increase above the 'Buildout' Scenario.

Table 12. Per-Dwelling Unit Results – Transit / Growth Scenarios

	CO2 (kg) / DU	NOX grams / DU	HC grams / DU	CO grams / DU	Car Vehicle Trips / DU	Car Vehicle Miles / DU	Transit Person Trips / DU	Transit Person Miles / DU	Walk / Bike Trips / DU	Walk / Bike Miles / DU	BMI / Adult	Minutes of Physical Activity / Adult
Existing Conditions	14.17	47.62	51.69	580.00	9.29	48.82	1.59	12.67	3.25	3.13	24.74	37.06
Buildout	13.95	46.74	50.65	570.24	9.08	47.90	1.57	12.99	3.36	2.73	24.11	41.93
Buildout + Transit	12.90	43.70	47.54	532.20	9.22	44.67	1.63	13.65	3.37	2.73	23.96	41.94
Buildout + More Growth	13.74	46.14	49.99	563.11	9.08	47.48	1.54	12.64	3.42	2.78	24.01	43.11

Table 13. Total Study Area Results – Transit / Growth Scenarios

	CO2 (kg)	NOX (grams)	HC (grams)	CO (grams)	Car Vehicle Trips	Car Vehicle Miles	Transit Person Trips	Transit Person Miles	Walk / Bike Trips	Walk / Bike Miles
Existing Conditions	10,652	35,792	38,851	435,976	6,984	36,695	1,194	9,526	2,445	2,356
Buildout	34,539	115,722	125,415	1,411,846	22,480	118,590	3,879	32,174	8,325	6,753
Buildout + Transit	31,938	108,198	117,703	1,317,670	22,839	110,607	4,026	33,798	8,340	6,769
Buildout + More Growth	36,675	123,170	133,455	1,503,380	24,234	126,763	4,104	33,737	9,120	7,425

The results of these two supplemental scenarios demonstrate the synergy between transit investment and infill development. Infill development will produce the most benefits – and the fewest impacts - when accompanied by increases in transit service. The improvements in transit service tested here are aggressive but not impossible within the context of what currently exists in White Center, and could be accomplished by adding routes to more destinations, reducing headways, and reducing travel times on existing routes (potentially considering strategies such as bus rapid transit or dedicated transit lanes). Again, further testing of additional permutations of better transit service and more residential / employment growth will generate ideas and insight as to the types of changes that will lead to the greatest benefits and lowest impacts.

IV. Conclusions: Other Potential Uses of I-PLACE3S in King County, and Next Steps

Geographically flexible and versatile in application, I-PLACE3S has a great deal of potential to inform King County during a number of processes. In its current state, I-PLACE3S can inform planning, zoning, development review, and transportation investments, as well as Health Impact Assessment (HIA).

Development review. Although, as the SW 98th Street case study illustrates, small increments of change are unlikely to make a large difference in the outcomes (such as physical activity or per capita CO2), I-PLACE3S can be used much like a GIS system to simply measure whether a new development is having a net positive impact on the surrounding urban form. For key parcels where the County wants to spur reinvestment or redevelopment, I-PLACE3S' has a separate Return on Investment module that can be a useful tool to test changes in development regulations. The module is for larger developments (greenfield development, or larger-scale redevelopment) that include a number of buildings or parcels that I-PLACE3S will be particularly useful, as it can identify likely health and climate impacts in addition to potential mitigation actions.

TOD planning. The development of the transit accessibility factor gives the County the ability to simultaneously test transit service level and land use changes to arrive at optimal levels of both for its TOD planning.
The scale of analysis cautions discussed in the previous chapter will be relevant here, but it may be possible to expand the analysis beyond a single TOD parcel to include the surrounding neighborhood or parcels. In some cases, TOD development takes place in conjunction with other redevelopment activities, changes in development regulations designed to spur redevelopment, or a station area planning process. The scale and scope of such an analysis would be very similar to the White Center / SW 98th Street Corridor case study. Further testing of transit service levels in the White Center case study would help the County to determine the sensitivity of the model to changes in transit service coupled with changes in urban form.

Zoning changes, comprehensive planning, or unincorporated areas planning. I-PLACE3S is an excellent tool for comprehensive planning or changes in development regulations at the neighborhood scale and above. For larger-scale analysis (for instance, county or corridor level) or analysis of land use – transportation interactions, the County may want to consider running I-PLACE3S in conjunction with a four-step travel model.

Comprehensive Planning. I-PLACE3S can be a key tool to assess the potential climate, air pollution and public health impacts of the County's comprehensive plan. I-PLACE3S can be used to measure impacts of specific land use elements of the plan might have on health and environmental outcomes – and whether/how transit service can be used to leverage further change. Local jurisdictions within the County can also use I-PLACE3S in their comprehensive planning process. King County's most recent comprehensive plan update sets greenhouse gas reduction targets for the County (an 80 percent reduction from 2007 levels by 2050). I-PLACE3S modeling can help the County understand how its plans (and those of the jurisdictions within it) can help to achieve this goal, in tandem with changes or investments in transit service. I-PLACE3S analysis can be used at the regional level for comprehensive planning - it was actually designed for this exact purpose at SACOG. At the larger scales of analysis, such as the entire county or region, I-PLACE3S results could be used in conjunction with the regional transportation model in order to capture the full interaction between land use and transportation investments under consideration.

Transit investment planning. Because transit service is a key role for King County, the enhancements to I-PLACE3S allow the user to change transit accessibility assumptions from one scenario to the next, in order to assess the impact of transit investments. Although a full-fledged travel model is still the most robust approach to evaluating potential transit investment, I-PLACE3S can be used to examine the *interaction* between transit investment and land use change. It is also faster to use and less technical than a travel model.

Other Transportation Investments. I-PLACE3S can also be used in conjunction with a four-step travel model to evaluate the impact of other transportation investments in combination with land use changes, or to understand how land use changes might impact regional travel patterns.

Health Impact Assessment (HIA). I-PLACE3S can be used in HIA to assess impacts of land use, transit or transportation facility changes on walking and bicycling trips, physical activity and BMI. In some cases this may entail running I-PLACE3S in conjunction with a travel model. Although I-PLACE3S cannot estimate air pollution exposure, I-PLACE3S provides total and per capita NOx, CO, HC and VOC emissions which may serve as a limited indicator of exposure. Now that I-PLACE3S has the ability to use buffer-based measurement, it may be possible to build a spatial assessment of exposure into I-PLACE3S in the future. This would use buffers to create an 'high exposure zone' around facilities such as highways and ports that are associated with lower air quality, in order to identify conflicts with sensitive land uses, such as schools and hospitals.

As for next steps, County staff should continue working with and learning I-PLACE3S; it may be helpful to schedule a training session to ensure that key staff are fully knowledgeable about I-PLACE3S setup and operation. Seattle/King County Public Health staff, in particular, should be engaged in dialogue and training surrounding I-PLACE3S. It is possible for staff to experiment with the existing case study with little to no training; continued testing of the White Center / SW 98th Street. scenarios would increase staff familiarity of I-PLACE3S and yield additional information about what might generate more health and climate benefits to the study area.

In thinking about additions or further refinements to I-PLACE3S, incorporating the ability to evaluate road network characteristics (speeds, traffic volumes, number of lanes, street widths) would allow the development of a traffic safety module, if crash data is made available in the future. Additionally, although I-PLACE3S can estimate the amount of air pollution generated, it cannot estimate exposure to air pollution. Being able to evaluate who is potentially being harmed by air pollution is a logical next step in expanding the I-PLACE3S public health module. However, it is expected that such an improvement would be a complex undertaking. Drawing in additional data from other regions of the United States will also broaden I-PLACE3S' geographic applicability.

With a projected population increase of nearly half a million additional residents by 2030 (about a quarter of the current population), there is significant opportunity to ensure that new development in King County supports active living and lower carbon footprints. Furthermore, the choice to guide those decisions via not only evidence, but local evidence, will make a clear connection between research and what is happening on the ground, creating the strongest argument for a built form that supports an active, healthy and sustainable King County.

APPENDIX A. I-PLACE3S BACKGROUND

The Rationale for Choosing I-PLACE3S

In the early stages of this project, LFC, Inc. and King County assessed the County's needs for an evidence-based modeling tool. There were four major requirements:

1. Ability to evaluate land development alternatives
2. Ability to evaluate at a relatively small scale (roughly a neighborhood)
3. Flexibility to incorporate outcomes and land use measures based on results of prior research in King County / Puget Sound region
4. Ability to evaluate both health and climate change outcomes of land development proposals

We reviewed several sketch planning tools to determine which was best for the purposes of this project. I-PLACE3S, a web-based model developed in the public domain, and INDEX and CommunityViz, both of which are proprietary ArcMap-based platforms, met all of the criteria above. We reviewed available literature and documentation for all three models, and discussed our project with model developers. We concluded that I-PLACES provided the best modeling structure for the County. The public nature, web-based structure, and flexibility of I-PLACE3S made it a superior choice. Table A1 summarizes the three model platforms.

INDEX is a proprietary GIS-based add-on developed by Criterion, Inc. – an ArcMap extension that works with ArcView, ArcEditor, or ArcInfo. It is designed for land-use and transportation scenario creation, evaluation, and ranking. PlanBuilder can be used in public workshop settings, contains a comprehensive set of indicators, integrated multi-modal travel networks, and can rank multiple scenarios.

CommunityViz is also a proprietary ArcGIS extension that can calculate the economic, environmental and social impacts of geographic decisions in real time, and communicate the results of those impacts to decisionmakers. CommunityViz can create 3D scenes, maps and reports, charts, graphs, and interactive scenarios. CommunityViz was originally developed by the nonprofit Orton Family Foundation and is now owned and administrated by a private company, Placeways LLC.

I-PLACE3S is a web-based modeling platform for scenario planning. It can evaluate how alternative development approaches or transportation investments may impact a number of indicators, including transportation patterns, energy usage, cost efficiency, and climate change. I-PLACE3S analysis is conducted through a web-based map display. This strong visual component and interactivity supports scenario development and testing by non-technical users in settings such as public workshops, as well as in more technical settings.

Table A1. Model Comparison

	I-PLACE3S	INDEX	CommunityViz	Comments
Ownership	Public	Private	Private \ Non profit	
Software requirements for use	Web browser (internet based)	ESRI ArcMap 9.2	ESRI ArcMap 9.2	GIS skills required to set up base data & scenarios in I-PLACE3S
Costs to user	Software is free. Must purchase server access (cost depends on database size & usage requirements)	Must purchase software (standard version $1900)	Must purchase software (basic “pro” software package + support $750)	
Data resolution	Parcel	Grid cell	Grid cell	
Public Workshop Capability	Can adjust scenarios & get results in “real time”	Can build scenarios in real time but can not output results as readily		
Scale of analysis	Neighborhood to region	Neighborhood to region	Neighborhood to region	
Data quality / administration	One dataset on remote server creates data consistency; internet-based structure automatically saves all scenarios created	User dependent. Personal PC based data storage and use of software.	User dependent. Personal PC based data storage and use of software.	
Potential for Customization / Flexibility	Designed to be modular - can add indicators, land use measures, interface components, functionality.	Some ability to customize – can add indicators, some land use measures	Some ability to customize – can add indicators	Because I-PLACE3S is web-based, all programming is made available to all users (no update fees or downloads).
Demographics	Parcel level household demographics	Raw population and employment totals only	Raw population and employment totals only	
Other features	Has an embedded travel model for use in areas that may not have access to travel modeling experts.	Able to interface with regional travel model	Able to interface with regional travel model	

I-PLACE3S was developed in the public sector by the California Energy Commission (CEC), the California Department of Transportation and the U.S. Department of Energy, and is currently managed by the Sacramento Council of Governments (SACOG). The current version I-PLACE3S is an overhaul of the PLACE3S model, which was initially developed in the early 1990s. I-PLACE3S is currently managed by the SACOG, and a private company provides programming, maintenance and web hosting.

Operating I-PLACE3S

This section will provide a general overview of how I-PLACE3S works, how to set up and run an I-PLACE3S project, and will also give some guidance about skills and time needed in each step. For more detail on I-PLACE3S technical requirements, refer to the I-PLACE3S User Guide and the supplemental User Guide / documentation for the new I-PLACE3S modules for King County, both of which have been provided along with this final report. An online tutorial of the basic I-PLACE3S functions is also available at www.places.energy.ca.gov/places (click link for online demo/tutorial; no login necessary).

In general, staff can be trained to use I-PLACE3S in a couple of days, depending on their level of technical expertise. The very basic I-PLACE3S functions (comparing outcomes, applying Place Types) can be performed with little to no training, and no specialized skills are needed.

In I-PLACE3S, each analysis is known as a 'project.' Creating scenarios for a project and running I-PLACE3S involves the following steps, each of which is discussed further in the sections that follow:

- Data preparation
- Define Place Types
- Define a project and alternative scenarios
- Apply Place Types to scenarios
- Compare outcomes

1. Data Preparation

When beginning a project, the user prepares and uploads a GIS parcel shapefile into I-PLACE3S that contains the parcel-level attributes for the study area, such as employment yield, demographics, number of dwelling units, whether a parcel is developed or vacant, and the TAZ (traffic analysis zone) within which that parcel is located. This file represents the 'base case' scenario. Other scenarios can then be built from this foundation of parcel data.

- Zoning designations
- Existing conditions: Dwelling units, land uses, employees
- Growth forecast: Housing units, employees
- Vacant / developed parcels
- Parcel data
- Demographic data
- Environmental Constraints (optional)
- Subarea shapefiles for reporting and analysis (optional)

Parcel data. Typically, a parcel file is used for zoning designations, dwelling units, and land uses, as well as geospatial attributes such as parcel size and boundaries. Sometimes parcel information will indicate whether or not a parcel is developed; it may be necessary to check this information for accuracy, and in the case of small study areas, confirm that vacancy information matches the reality on the ground. The number of employees on commercial parcels can be estimated using a number of sources: commercially available data, parcel data, regional estimates, or other local data. Each of these data sources has their own drawbacks, and it will be necessary for to determine which data source best matches the needs of the particular project. Environmental constraints and subarea shapefiles are optional, but can provide utility for planning studies. Both of those will entail uploading new data layers or adding data fields to the parcel data.

In some cases, King County may want to use I-PLACE3S to evaluate potential greenfield development. These locations will have relatively little existing employment, and housing unit and demographic data will likely not exist (or may only contain very small numbers) for the area in question. Therefore, comparisons between a development proposal or plan, and actual existing conditions on a greenfield site could show an extremely large amount of change, especially if the base population data has a very low population. Because of this it will be more useful to create the 'base case' scenario based on the dwelling unit / employee targets in the Comprehensive Plan, or the official population projections for that area.

Demographic Data. Demographics will also need to be included in the parcel file. In the case of demographics, it will also be necessary to determine which source of demographic data to use. The demographics available and the scale at which they are applied will depend on the data sources available and the scale of analysis (i.e. person, household, census zone, or traffic done).

Buffers. The parcel file will need to include not only the parcels within the actual case study area, but all of the parcels within a chosen threshold (e.g. one kilometer) of the study area. These "contextual" neighboring parcels are necessary so that I-PLACE3S can measure land use patterns within a specified buffered area around each study area parcel, matching the research methods used in the analysis (see the section "Other Changes to I-PLACE3S" for further description of this process).

Because the new I-PLACE3S module measures land use patterns within the 1 km buffer for each parcel in the study area, it is also necessary to provide a relational data table telling I-PLACE3S which parcel is in the 1 km buffer, for every parcel in the study area. This can be generated in GIS, and is discussed in more detail in the supplemental User Guide.

Skills / Time Needed. It is best to have someone familiar with GIS analysis and the data sources listed above to complete the I-PLACE3S data preparation and setup. This will make the process go much faster, and a planner or GIS technician will have a better idea of which data sources to draw from. If analysis of numerous small study areas is desired (as would be the case for TOD, station area, or unincorporated areas planning), the most efficient way to do this may be to prepare a base parcel file for the whole region. Subsets of this master file can then be pulled into I-PLACE3S for testing when it is needed.

2. Define Place Types

In I-PLACE3S, 'Place Types' are the land uses (e.g. high-rise office, medium-density single family, mid-rise mixed use) that are applied to each scenario. Place Types can be existing land uses, or land uses that do not yet exist or are not currently permitted by code. A list of Place Types is typically defined at the beginning of the project (but can be changed or added to at any time), and include assumptions such as mix of land uses, parking ratio, square footage of units, and setbacks. These Place Type assumptions are the foundation of many of the I-PLACE3S calculations, and can be created to work at the general (area) or specific (building) level. It will be possible to define the Place Type assumptions based on 1) the information in the land use code and 2) the information contained in a development proposal. New Place Types can be added at any point in a project, and can be added by simply copying and tweaking existing Place Types. Changing a Place Type will change it for all scenarios in which it is used, so if in doubt it is better to create a new one.

Skills / Time Needed. It is also preferable to have someone who is familiar with land development and zoning in the area to develop, assist or review the list of Place Types; otherwise correctly filling in the assumptions can be a time-consuming process to find "from scratch." Because Place Types can be copied from one project to another, again, it may be worth creating a single exhaustive set of Place Types which can then be used or tweaked for multiple projects.

3. Define a Project and Alternative Scenarios

Before starting the project, think about the scope of the analysis and the number of scenarios to be analyzed. Two scenarios will be necessary to start: the "base case" (existing conditions, or the Comprehensive Plan targets/land uses) and the proposed development / plan. However, in I-PLACE3S, new scenarios can be easily created (any of the existing scenarios can be copied and tweaked), and scenarios can be changed, at any point in the analysis.

It will also be important to confirm that the land uses in the proposal line up with the list of existing Place Types (typically, the input needed for Place Type assumptions synchs up with the standard information provided in a development application). If there is not a match between what is being proposed/planned and existing Place Types, it will be necessary to create new ones.

Skills/Time Needed. In the beginning of a project, it may help for project staff to coordinate to make sure they understand what is being proposed and to make sure the scenarios are being defined correctly. In cases where public participation is part of the process, the stakeholders will help to define (or refine) the scenarios to be tested.

4. Apply Place Types
Place Types will need to be applied to parcels in I-PLACE3S to create the base case and alternative scenarios. This can be done by using the I-PLACE3S map interface, the query function, or the initial parcel file (more detail on how these functions work can be found in the I-PLACE3S tutorial / User Guide). Place Types will need to be applied to both the study area parcels and the "contextual" parcels (the buffers around the actual study area).

Skills/Time Needed. Provided that the user is familiar with the Place Types and the basic I-PLACE3S functions, this part of the process requires no specialized skills and can be done with very little training. The time that it takes to apply the Place Types will depend on the size of the study area and the method used to apply them. For a small study area, it may only take an hour or two.

5. Compare Indicators
Scenario comparisons are simple and fast in I-PLACE3S. I-PLACE3S has a standard set of planning indicators, such as population, density and employment. For HealthScape, a separate Climate and Health Indicators menu was added. For either menu, the comparison involves selecting which scenarios to compare, and which indicators to compare. Results will show up after a short delay. Upon reviewing the results, it is possible to go back and tweak existing scenarios or create additional scenarios to optimize the results, then run them again.

Case Study: SACOG's Sacramento Region Blueprint Project

In 2003, the Sacramento Area Council of Governments (SACOG) launched a region wide growth analysis called Blueprint. The award-winning Blueprint project has been a resounding success in helping planners and citizens in the six county Sacramento region make informed land use choices for future growth.

I-PLACE3S was used to determine how different regional growth alternatives would affect the transportation system, air quality, housing, natural resource protection, and many other issues. The Blueprint project required a high-performance, robust, planning analysis tool capable of integrated planning analysis. I-PLACE3S was also successful in helping SACOG work effectively with the cities and counties of the region, elected officials, and the public. The real value of I-PLACE3S is that all the participants were working off a single common data set and all participants gained immediate feedback to easily view the ramifications of their own ideas for improving each regional, county, city or neighborhood level growth scenario. I-PLACE3S analysis helped avoid "dumbing down" the data to summary aggregations, while still providing results in real time.

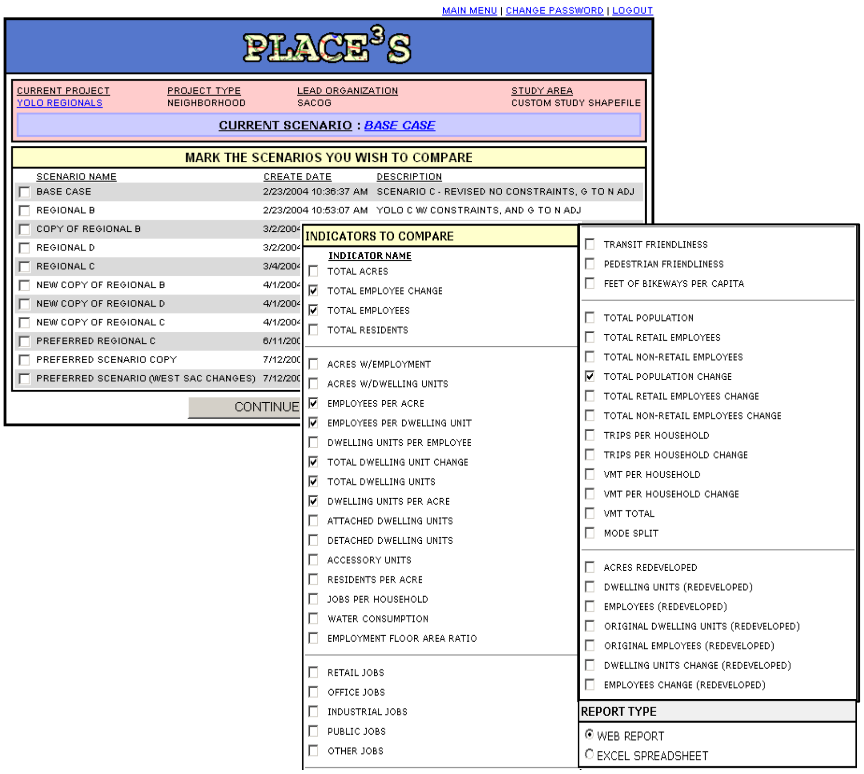

Figure A1. I-PLACE3S Indicators/Scenario Comparison

Based on the I-PLACE3S scenario analysis, the SACOG Board of Directors adopted a regional vision for 2050 that "promotes compact, mixed-use development and more transit choices as an alternative to low density development." Since the adoption of the Blueprint vision, a number of the region's counties and jurisdictions have been implementing the principles of the vision in their planning and development processes.

APPENDIX B. METHODOLOGY

Data Sources

The regression modeling upon which the I-PLACE3S enhancements were based relied on travel, emissions and land use data from King County and the Puget Sound Regional Council. Four primary data sources formed the basis of the analysis:

- The Puget Sound Regional Council's 2006 Household Travel Survey provided the trip, person and household level socio-demographic data. This survey was a two-day travel diary of 4,746 households in the four county region. 2,699 King County households, and the more than 45,000 trips associated with those households, were used for the analysis.

  The resarchers initially planned to use results from the original LUTAQH analysis, which used PSRC's 1999 travel survey data matched to parcel data from that same time period. The PSRC, however, had its 2006 travel survey available, which created an opportunity to use this more recent dataset in combination with 2006 land use data.

- King County parcel-level land use data was the source of the urban form measures in the analysis. Parcel databases from the King County Tax Assessor were used in combination with the County's GIS (Geographic Information System) parcel level land use database. Data from 2006 was used to match the travel survey time period.

- To estimate emissions, PSRC also supplied zone to zone estimates of distance, travel time, CO2 and emissions for all traffic analysis zones[6] (TAZs) related to travel survey trips in the 2006 travel survey. Multiple adjustments to this data were necessary to estimate CO2 emissions at the finest level of detail possible.

- Physical activity and body weight data was used from the NIH-funded Neighborhood Quality of Life (NQLS) study led by Dr. James Sallis. Approximately 75 persons in each of 16 King County communities were surveyed for a full week at two separate intervals to objectively assess physical activity with an accelerometer.

- The NQLS physical activity surveys were completed in 2001-2002 and thus temporally mis-matched to the 2006 land use data. Instead, we used a 2002 version of the King County parcel database for the BMI and physical activity analysis.

[6] Traffic analysis zones divide the region into polygons and are used by PSRC as part of their regional travel demand modeling process.

To generate the required equations, we measured land use patterns around each King County household location in the PSRC household travel survey. We then correlated land use patterns with reported travel, air pollution and CO2, and objectively measured physical activity and body mass index (BMI). We adjusted for demographics in the analysis, and also tested for regional accessibility impacts on travel. Three separate sets of models were developed:

- One for the transportation outcomes: miles and number of auto, transit, and nonmotorized trips;
- One for health outcomes: BMI and minutes of physical activity;
- One for per capita air pollution outcomes: total and per capita oxides of nitrogen (NOx) hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO2).

Independent Variables

We measured neighborhood urban form (land use patterns) using a combination of data including census information, road network data, and 2006 King County parcel level land use data. The urban form measures used are similar in nature to those previously identified in other King County and Puget Sound region research as being related to travel and CO2 and other emissions.[7] However, the set of independent variables that could be modeled was constrained by the land use classifications and characteristics that I-PLACE3S could measure.

These land use variables were calculated for network buffers around each King County household location in the travel survey at a one kilometer (km) buffer distance. The buffer includes the area that can be traveled to from the household, in all directions along the street network. Unlike “crow-fly” or straightline distance based buffer, these network buffers establish the area people can actually access around their homes. The street network used to create the buffers was modified so that it includes only those streets on which pedestrians are allowed to travel (for example, limited access highways and their on-ramps are not included).

In Figure B1 below, a 1 km network buffer is shown around a hypothetical activity location in two contrasting land uses. It also shows the difference between radial (crow-fly) and network buffer areas around these two locations.

[7] Lawrence Frank and Company, Inc., Dr. James Sallis, Dr. Brian Saelens, McCann Consulting, GeoStats LLC, and Kevin Washbrook (2005). A Study of Land Use, Transportation, Air Quality and Health in King County, WA. Prepared for King County Office of Regional Transportation Planning.
Lawrence Frank and Company, Inc., Mark Bradley, and Keith Lawton Associates (2005). Travel Behavior, Emissions, & Land Use Correlation Analysis in the Central Puget Sound. Prepared for Washington State Department of Transportation Report no. WA-RD 625.1.

The size of the network buffer for each location varies based on the connectivity of the road network - more intersections allow a greater area to be covered on the ground.

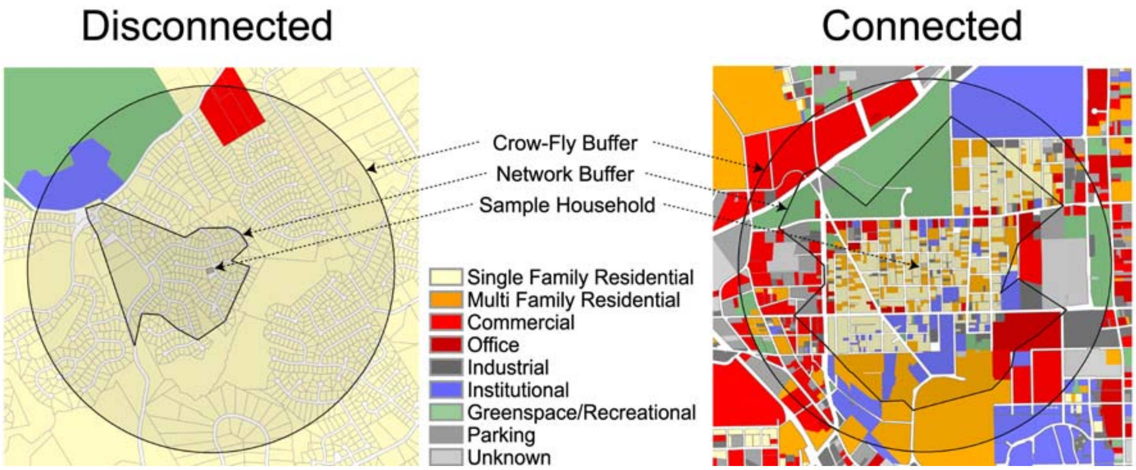

Figure B1: Measuring Land Use Patterns Using Network Buffers

Three types of independent variables were measured:

1. Land use variables
Land use variables were calculated using a buffer-based approach and 2006 parcel level land use data from King County. In the modeling, we experimented with different sized buffers, ranging from 0.25 km to 2.5 km. In a few cases, the 2.5 km buffer measures had slightly higher predictive power than the 1 km buffer measures. However, because using a 2.5 km buffer would increase the number of calculations that would need to be done in I-PLACE3S by about six times that of the 1 km buffer, we decided that the small amount of additional predictive power was not worth the massive increase in model run time that would result.

Net residential density is a measure of residential compactness. Concentrations of residential areas are important to put a critical mass of people close to shops, services, jobs and transit. Several density-related variables were calculated:

- Net residential density for single family land uses within 1 km buffer: total number of single family dwelling units in buffer / area within buffer in single family residential use. This variable was only applied if there were no multi-family parcels within the buffer.
- Net residential density for mixed unit types within 1 km buffer: total number of single and multi family dwelling units in buffer / area within buffer in residential use. This variable was applied in cases where there was multi-family residential development within the buffer.
- Single family only in buffer: A dummy (yes / no) variable indicating that, out of the following five land uses - single family residential, multifamily

residential, office, retail/restaurant, and entertainment/recreation - single family residential is the only land use present.

Retail Floor Area Ratio (FAR) is a proxy for pedestrian oriented site design because FAR measures the proportion of the building as it relates to the lot. Typically, auto-oriented retail buildings that are surrounded with huge parking lots will have low FARs – below 0.3 – while multi-story buildings with no dedicated parking, small parking lots, or underground parking will have FARs above one.

- Retail Floor Area Ratio: The ratio of the building square footage to parcel square footage, for all retail and restaurant parcels within the buffer.

Intersection density measures street network connectivity. Fine-grained street networks (typically gridiron patterns as opposed to cul-de-sac layouts) will make travel to nearby destinations more direct. This is especially important for walking. Because walking is a slower travel mode, having a more direct route matters more.

- Intersection density: number of intersections in buffer / buffer area

Land use mix measures whether different land use types, such as homes, shops and employment uses, are in close proximity to one another. This proximity is important for walking trips, and also for transit trips. This particular measure of land use mix measures the evenness of distribution of square footage for five different land use groups: single and multi-family residential, retail, office, civic & education, and entertainment. The result is a value between 0 and 1, with 1 being a perfectly even distribution of the five land uses.

- Land use mix: Land Use Mix = ((F1/TF * LN(F1/TF) + F2/TF * LN(F2/TF) + F3/TF * LN(F3/TF) + F4/TF * LN(F4/TF) + F5/TF * LN(F5/TF)) / -LN(5.0)
  F1 = square feet SF residential parcels
  F2 = square feet MF residential parcels
  F3 = office parcels
  F4 = retail/restaurant parcels
  F5 = entertainment/recreation parcels
  TF = F1+F2+F3+F4+F5

Access to parks, retail/fast food, and transit: these variables measured the distance to particular land uses, found in past analyses to be predictors of travel, CO2, air pollution or physical activity/BMI.

- Park/recreation available within buffer: dichotomous (1=yes/2=no) variable indicating whether or not a park or recreational parcel is located within the buffer.

- Number of retail/fast food parcels within buffer

- Distance to Nearest Bus Stop: measured as the network distance from the King County travel survey household locations to the closest bus stop. Although this variable does not capture transit service frequency or number of routes available, it was found to be a significant predictor of travel outcomes in previous studies in the region.[8]

2. Accessibility variables
Accessibility scores for auto and transit which were calculated at the Traffic Analysis Zone (TAZ) level using outputs from the PSRC regional travel model. These variables, which are based on transit and auto travel times from the origin to all the destination TAZs with employment or, in the case of off-peak accessibility, retail employment (which serves as an indicator of retail development). Accessibility variables were calculated as follows:

- **Auto peak accessibility** = LN(1+Sum from the zone to all destination zones with employment in the destination zone * EXP(-2*(AM peak O-to-D drive alone travel time + PM peak D-to-O drive alone travel time)/30))
- **Auto off-peak peak accessibility** = LN(1+Sum from the zone to all destination zones with retail employment in the destination zone * EXP(-2* (Midday O-to-D drive alone travel time + Evening D-to-O drive alone travel time)/20))

- **Transit peak accessibility** = LN(1+Sum from the zone to all destination zones connected by transit of Total employment in the destination zone * EXP(-2*(AM peak O-D weighted transit travel time)/60))
- **Transit off-peak peak accessibility** = LN(1+Sum from the zone to all destination zones connected by transit of Retail employment in the destination zone * EXP(-2*(Midday O-to-D weighted transit travel time)/30)), where weighted transit travel time is the in-vehicle time plus 2.5 times (wait time plus transfer time plus boarding time).

For the physical activity models, the transit peak accessibility value was used for workers and the off-peak value was used for non-workers. For the emissions and travel models, a weighted average was used: # working adults * peak value + # non-working adults * off-peak value) / total # adults in HH.

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[8] Lawrence Frank and Company, Inc., Dr. James Sallis, Dr. Brian Saelens, McCann Consulting, GeoStats LLC, and Kevin Washbrook (2005). A Study of Land Use, Transportation, Air Quality and Health in King County, WA. Prepared for King County Office of Regional Transportation Planning.
Lawrence Frank and Company, Inc., Mark Bradley, and Keith Lawton Associates (2005). Travel Behavior, Emissions, & Land Use Correlation Analysis in the Central Puget Sound. Prepared for Washington State Department of Transportation Report no. WA-RD 625.1.

Both accessibility factors were re-scaled to a range between one and 100 for purposes of legibility in the I-PLACE3S application.

3. Household demographic variables
Demographic variables were created using a 2006 full synthetic population generated by UrbanAnalytics for the PSRC, using the UrbanSim model. Households were divided into 54 types based on the number of workers, non-workers and children; income classification, and whether or not a household contained fewer cars than adults.

- Number of working adults in household (0/1/2+)
- Non-working adults in HH (0/1/2+)
- Children in HH (0/1/2+)
- HH income under $50K (1=yes/0=no)
- HH income over $100K (1=yes/0=no)
- HH fewer cars than adults (1=yes/0=no)

Dependent Variables

The independent variables were correlated to a number of outcomes: Transportation, Climate and Air Quality outcomes were calculated based on the PSRC's 2006 household travel survey, and Body Mass Index (BMI) and Physical Activity outcomes were based on accelerometer data from the Neighborhood Quality of Life Study, funded by the National Institutes of Health.

Transportation Outcomes

- Number of Vehicle Trips
- Vehicle Miles Traveled
- Number of Transit Person Trips
- Transit Person Miles Traveled
- Number of Bike/Walk Trips
- Bike/Walk Miles Traveled

Transportation characteristics were calculated based on King County households in the PSRC's 2006 household travel survey. Trip totals were taken directly from the survey. Distances were generated as part of the CO_2 and air quality variables estimation, discussed in detail in Appendix A.

Climate and Air Quality Outcomes

- Carbon Dioxide (CO_2, kg)
- Oxides of Nitrogen (NO_x, g)
- Hydrocarbons (HC, g)
- Carbon Monoxide (CO, g)

The methods used to estimate CO_2 and air pollution emissions are based on methodologies developed in earlier research (Frank and Stone, 1998; Frank et al., 2000). We used information about each vehicle trip taken by King County households in the 2006 PSRC travel survey, supplemented by information from the PSRC travel demand model. Each reported trip was assigned to PSRC's modeled road network assuming a shortest time path based on the congested flows for that mode and time of day. Trips were then broken into multiple road segments, or “links” according to facility type. For each link of each vehicle trip, emissions levels were assessed based upon a vehicle’s travel distance and speed. The travel speed on any given segment was determined by PSRC using its regional travel model, which takes into account road facility type (arterial, freeway, etc), road capacity and estimated traffic volume based on the time of day.

The PSRC travel survey includes 45,606 trips from King County households. Of that total, 39,297 trips were made by a mode for which emissions were estimated. Appendix A discusses the emissions estimation process in detail.

Physical Activity and BMI Variables

- Total Minutes of Vigorous + Moderate Physical Activity Per Day (VMPA)
- Body Mass Index (BMI)

Physical activity and BMI variables were taken from King County data collected as part of the Neighborhood Quality of Life Study (NQLS). Approximately 75 persons in each of 16 King County communities (1,200 persons total) were surveyed for a full week at two separate intervals to objectively assess physical activity with an accelerometer. The 16 NQLS communities were selected based on their level of walkability and income as shown in Figure B2 - four communities were selected within each of four walkability and income quadrants. Height and weight data was collected using self-reported survey data from the same sample. Both of these variables were log-transformed to ensure normal distribution of the sample.

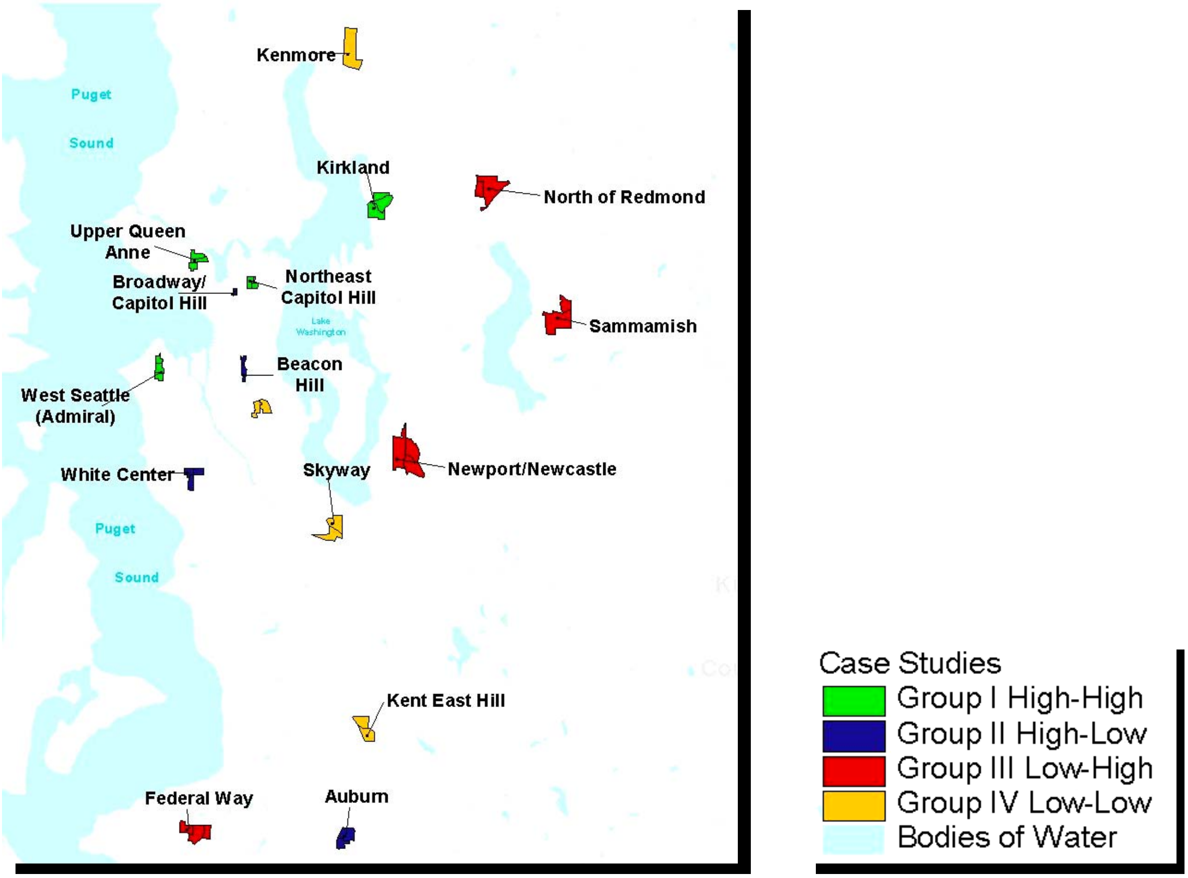

Figure B2. NQLS King County Communities

Model Results Application to Health / Climate Modules

A set of linear regression analyses of built environment, transport, and physical activity generated the statistical relationships that form the basis of a health module in I-PLACE3S. The set of independent variables that can be modeled was, to a small degree, constrained by the need to match the land use classifications and characteristics used in I-PLACE3S. This is only the case when calculating land use mix, which requires aggregating total square footage of different land use types. Tables B1 through B3 on the following pages present the final sets of model variables incorporated into I-PLACE3S. All variables that attained the level of statistical significance), were retained in the final models. In some cases, land use variables of interest were left in the models despite not attaining the threshold of significance – if the variable was logically signed and contributed to the model.

Physical Activity (PA) and Body Mass Index (BMI) Model Results

Demographic variables are strongly correlated with Physical Activity (PA), with total PA increasing with the number of children and employed adults in the household. PA also increases slightly for those with high (over $100K) incomes, but decreases more for those with lower incomes (under $50K). PA also, as expected, increases in cases where households have fewer cars than adults. Intersection density, residential density, retail FAR, and whether or not a park is located within the 1 km buffer were all positively correlated with PA.

Those households in the lowest income category (under $50K) were correlated with slightly higher BMIs, and those with incomes over $100K had slightly lower BMIs. Intersection density, presence of a park, transit accessibility and residential density were all associated with lower BMIs, while presence of fast food and presence of other food or retail outlets within walking distance were associated with a slight increase in BMI. Amount of physical activity has a relatively strong negative association with BMI – as would be expected, as total amount of physical activity increases, BMI goes down.

While the significance levels of key urban form variables met or exceeded the 95 percent confidence level, these R-squared values for PA and BMI are low and quite typical to what has been found in similar research. This is because there are many factors that impact physical activity levels and body weight that extend well beyond the scope of the current study. Health outcomes are distal outcomes – more steps removed from the urban form variables, and a number of other factors not accounted for in this analysis (diet and genetics, particularly) – play a much larger role than urban form. In this case, it is more important to focus on the variables within the model rather than its overall explanatory power (R-squared). The urban form variables within this analysis are modifiable by public policy, as opposed to a variable such as genetics, which is not. For this project, the individual, *modifiable* variables are the focus. Although a number of these variables were identified in the original LUTAQH study, we tested additional variables that measured similar concepts in order to select those with the highest predictive power.

Table B1. Final Model for Physical Activity and BMI Outcomes[9]

Model Type	Regression		Regression	
Dependent variable	Total Daily Minutes of Moderate & Vigorous Physical Activity LN(VMPA)*		Body Mass Index LN(BMI)*	
	Coeff.	T-stat	Coeff.	T-stat
Adults in HH (0/1/2+)	-0.0783	-2.9	--	--
Children in HH (0/1/2+)	0.0505	2.6	--	--
Adult is employed (0/1)	0.2088	5.4	--	--
HH fewer cars than adults (0/1)	0.1458	3.4	--	--
HH income under $50K (0/1)	-0.1716	-4.6	0.0241	2.7
HH income over $100K (0/1)	0.0918	2.4	-0.0205	-2.1
Intersection density	0.0011	1.1	-0.0008	-3.2
Park/recreation available in buffer	0.0893	2.1	-0.0259	-2.5
NRD - Single family units only in buffer	0.1307	2.7	-0.0149	-1.2
NRD - Mixed unit types in buffer	0.0217	4.4	-0.0051	-3.4
Retail FAR	0.4586	2.9	--	--
# Fast food parcels	--	--	0.0063	2.6
# Other retail/food parcels	--	--	0.0005	3.1
Transit accessibility measure	--	--	-0.0013	-1.6
LN(VMPA)	--	--	-0.0681	-13.0
Constant	2.9622	33.3	3.6555	55.1
R-squared (adj)	0.075		0.111	

Climate and Air Quality Model Results

In the case of the climate and air quality models presented in Table B2, where approximately 40 percent of the variation in each of the emissions is explained by the variables in the models presented. The set of variables, and the direction of the relationships (positive or negative) is the same for each outcome in this set of models. In all cases, the nature of the relationships are as expected.

Larger households and higher incomes are associated with more per household emissions, while fewer cars and lower incomes are associated with lower emissions. Higher transit accessibility is associated with lower emissions, and as distance to transit increases, emissions increase. Single-family only development is associated with higher emissions, while higher levels of land use mix and higher intersection densities are associated with lower emissions.

[9] Blank cells in the table indicate the variable was not retained in the final model. In the tables, the T-statistic increases with the level of statistical significance - a T-statistic with an absolute value of 1.9 corresponds to approximately a 95% confidence interval. The R-squared value, at the bottom of each table, is the percentage of total variation in the outcome that is explained by the model.

Table B2. Final Model for Climate and Air Quality Outcomes[10]

Dependent variable (all regression models)	CO2 (grams) Coeff.	T-stat	NOX (grams) Coeff.	T-stat	HC (grams) Coeff.	T-stat	CO (grams) Coeff.	T-stat
Working adults in HH (0/1/2+)	15227.95	21.9	44.87	22.3	48.17	22.9	547.97	21.4
Non-working adults in HH (0/1/2+)	7934.93	11.4	24.76	12.3	27.00	12.8	292.70	11.4
Children in HH (0/1/2+)	611.55	1.3	9.07	6.8	10.84	7.8	98.15	5.8
HH income under $50K (0/1)	-1776.43	-2.2	-6.02	-2.6	-6.36	-2.6	-78.71	-2.6
HH income over $100K (0/1)	2289.47	2.8	5.02	2.1	5.07	2.1	73.92	2.5
HH fewer cars than adults (0/1)	-10654.63	-11.9	-25.37	-9.8	-27.08	-10.0	-312.70	-9.5
Transit weighted accessibility	-230.39	-5.9	-0.67	-5.9	-0.68	-5.8	-8.36	-5.8
Miles to nearest bus stop squared	959.19	6.3	2.27	5.2	2.12	4.6	34.09	6.1
Single family only in buffer	4535.21	3.8	15.36	4.4	17.27	4.7	171.69	3.9
Land Use Mix	-3317.90	-1.9	-8.40	-1.7	-10.28	-2.0	-85.40	-1.4
Intersection density	-48.22	-3.3	-0.14	-3.3	-0.16	-3.5	-1.47	-2.7
Constant	25801.77	7.5	73.72	7.4	77.31	7.5	901.34	7.1
R-squared (adj)	0.381		0.404		0.421		0.384	

Transportation Model Results

As would be expected, the transportation models differed substantially depending on the specific outcome – the travel mode and whether the outcome was total distance or number of trips per household. The demographic variables were significant predictors of nearly all of the transportation related outcomes. The number and distance of trips for all travel modes increases with number of working adults in the household. More non-working adults in a household tended to increase the number and distance auto and walking / bicycling trips, but decrease the number and distance of transit trips. This finding may indicate a greater reliance on transit for commuting trips, as opposed to non-work trips. More children in a household were associated positively with all of the transportation outcomes, with the exception of transit miles, for which the association was negative. Higher incomes were associated with increased car and walk / bike miles and trips, and transit person miles. Transit trips went down for those with higher incomes. It is somewhat unexpected that those in the lower income category are associated with slightly

[10] Blank cells in the table indicate the variable was not retained in the final model. In the tables, the T-statistic increases with the level of statistical significance - a T-statistic with an absolute value of 1.9 corresponds to approximately a 95% confidence interval. The R-squared value, at the bottom of each table, is the percentage of total variation in the outcome that is explained by the model.

less walk / bike travel, but the total effect is small and it is likely that lower income households take fewer trips overall compared to mid or high income groups.

Households with fewer cars than adults were associated with less driving and more transit and walking. Transit accessibility was associated with a small increase in the number of vehicle trips, and a decrease in vehicle miles – which may be due to driving to park and ride lots – and an increase in transit travel. Transit accessibility and distance to bus stop did not significantly impact walk and bike trips. Likewise, as distance to transit increased, car trips actually decreased slightly, car miles increased, and both number and distance of transit trips went down. Auto accessibility only appeared to impact transit travel, with a significant negative association with transit trips and miles.

Out of the urban form variables, single family-only development was only positively associated with car travel, and had no significant relationship with transit or walk / bike modes. Retail FAR, on the other hand, was only significantly (positively) related to nonmotorized travel. Land use mix had a negative association with car trips and miles, and with walk/bike miles – which is to be expected; as proximity to a variety destinations increases, the total distances one needs to walk go down. Land use mix was positively associated with transit person miles, which could be due to the fact that places with a healthy mix of residents, shops and services attract transit trips, because people can accomplish multiple errands on a single transit trip. Intersection density was negatively associated with driving, positively associated with walking, and associated with more transit trips but fewer transit miles. The number of retail or food-related parcels in a buffer increased the number of nonmotorized trips, but decreased the number of miles, which is, again, a proximity issue. Having a park within the buffer was associated with more transit person trips and miles, an indication that parks may be an important regional – as well as local – destination.

Table B3. Final Model for Transportation Outcomes[11]

Dependent variable (all regression models)	Car vehicle trips		Car vehicle miles		Transit person trips		Transit person miles		Walk/bike trips		Walk/bike miles	
	Coeff.	T-stat	Coeff.	T-stat	Coeff.	T-stat	Coeff.	T-stat	Coeff.	T-stat	Coeff.	T-stat
Working adults in HH (0/1/2+)	6.505	22.4	47.766	21.1	0.296	3.8	4.293	4.7	0.726	4.9	1.044	4.1
Non-working adults in HH (0/1/2+)	5.923	20.4	31.280	13.8	-0.276	-3.1	-4.603	-4.6	0.340	2.3	0.398	1.6
Children in HH (0/1/2+)	4.537	23.7	13.724	9.2	0.025	0.5	-0.471	-0.9	1.178	12.1	1.235	7.3
HH income under $50K (0/1)	-0.823	-2.4	-7.290	-2.8	0.156	1.9	0.032	0.0	-0.085	-0.5	-0.102	-0.3
HH income over $100K (0/1)	0.356	1.0	3.653	1.4	-0.006	-0.1	0.032	0.0	0.107	0.6	0.365	1.2
HH fewer cars than adults (0/1)	-4.568	-12.2	-29.352	-10.1	1.635	17.7	9.290	8.8	1.099	5.7	1.516	4.6
Transit weighted accessibility	0.033	2.0	-0.706	-5.5	0.013	2.5	0.147	2.5	--	--	--	--
Auto weighted accessibility	--	--	--	--	-0.127	-2.2	-3.703	-5.5	--	--	--	--
Miles to nearest bus stop squared	-0.099	-1.6	2.939	6.0	-0.014	-0.9	-0.354	-2.0	--	--	--	--
Single family only in buffer	0.708	1.4	16.534	4.2	--	--	--	--	--	--	--	--
Retail FAR	--	--	--	--	--	--	--	--	1.876	3.0	2.888	2.7
Land Use Mix	-0.803	-1.1	-5.301	-1.0	--	--	2.153	1.1	0.307	0.9	-0.181	-0.3
Intersection density	-0.009	-1.5	-0.166	-3.5	0.002	1.5	-0.025	-1.4	0.022	5.4	0.023	3.3
# Retail/food parcels	--	--	--	--	--	--	--	--	0.005	2.7	-0.005	-1.4
Park/recreation available	--	--	--	--	0.172	2.4	0.674	0.8	--	--	--	--
Constant	-1.878	-1.3	72.033	6.5	0.174	0.4	27.577	5.6	-1.678	-5.1	-1.839	-3.2
R-squared (adj)	0.466		0.398		0.147		0.050		0.163		0.068	

Application of Model Results to I-PLACE3S

The regression equations that result from the analysis express how much change results in each outcome, based on a change in built environment and demographic characteristics (the independent variables). The basic form of the

[11] Blank cells in the table indicate the variable was not retained in the final model. In the tables, the T-statistic increases/decreases with the level of statistical significance - a T-statistic with an absolute value of 1.9 corresponds to approximately a 95% confidence interval. The R-squared value, at the bottom of each table, is the percentage of total variation in the outcome that is explained by the model.

equation used is shown below. Each outcome has a slightly different regression equation programmed into I-PLACE3S, with unique values for 'a' (the constant) and for each of the 'b's (the coefficients for each independent variable). In cases where an independent variable does not have statistically significant predictive value for a particular outcome, it was held at 0.

$$= a + (b11 * SF\text{-}NRD) + (b21 * MF\text{-}NRD) + (b31 * LUMix) + (b41 * RetFAR) + (b51 * IntDens) + (b61 * TransitDis) + (b71 * ffood) + (b81 * otherfood) + (b91 * park) + (b101 * TransitAcc) + (b111 * AutoAcc) + (b121 * HHinc_1) + (b131 * HHinc_2) + (b141 * HHwrk) + (b151 * HHnwrk) + (b161 * HHkids) + (b171 * HHage_1) + (b172 * HHage_2) + (b173 * HHage_3) + (b174 * HHage_4) + (b175 * HHage_5) + (b181 * HHcar)$$

Figure B3. Base Regression Equation -
format of all I-PLACE3S Climate/Health Module formulas

The regression equations are applied within the I-PLACE3S program in order to estimate how different built environment scenarios might change public health. For each parcel in a study area, I-PLACE3S calculates a value for each independent variable (land use mix, residential density, number of parks, etc.), in each scenario being evaluated. Those values are inserted in the formula above, multiplied by the coefficients and summed along with a constant to generate an estimate for the outcome variable of interest.

Other Changes to I-PLACE3S

In addition to the new Public Health and Climate Change / Air Quality modules, some key changes were made to I-PLACE3S' functionality. To precisely match the methodology used in the analysis, I-PLACE3S programmers added the ability to measure land use patterns within a 1 km network buffer around every parcel in a scenario. The I-PLACE3S user uploads a data file that, for each parcel in the analysis, contains a list of all the parcels within that parcel's buffer. The user then applies Place Types to each scenario as necessary. When the results are viewed, I-PLACE3S calculates each of the buffer-based urban form measures "on the fly" based on Place Type specifications – for every parcel in the analysis. This contextual, buffer-based approach is a more fine-grained and rigorous approach than I-PLACE3S has used in the past, and explicitly links land use to transportation-related outcomes.

The ability to incorporate detailed demographics into I-PLACE3S is another key improvement. For public health analysis, demographics such as age and income typically play a large role in influencing the outcome, so the ability to account for demographics is crucially important. In the case of King County, it is possible to apply demographics at the household level, due to synthetic population information from the PSRC.

The third major enhancement to I-PLACE3S functionality is the ability to change relative transit service levels. For each parcel, there are three accessibility variables:

- Distance to the nearest transit stop
- Peak transit accessibility
- Off-peak transit accessibility

Distance to the nearest transit stop will need to be calculated in GIS, and merged into the parcel database. Transit accessibility variables can be changed from one scenario to the next in I-PLACE3S using a drop-down menu.

APPENDIX C: CREATING CO2, NOx, HC and CO EMISSIONS ESTIMATES

The emissions estimation process used the following basic steps, each of which is discussed in further detail in the sections that follow:

1. Determine travel modes for which emissions estimates will be created, and assign a primary travel mode to each trip.

2. Determine travel path, speed and distance.

3. Calculate emissions for all modes, and adjust for cold starts and vehicle occupancy.

1. Determining Travel Mode. PSRC travel survey participants were able to report up to five different modes used to complete their trip. For example, a person could report they went from home to work by driving their car to the ferry terminal, riding the ferry, walking from the ferry terminal to a bus stop and after arriving near their destination by bus walking the rest of the way to their work location. Of the 45,605 trips in the analysis set (trips made by King County households), 96.4% of them reported using a single mode, 2.5% of trips used two modes, 1% of trips used three modes, and 0.1% of trips used four modes. No trips listed five or more types of transportation.

Many trips, such as going from home to work, are accomplished using several modes of travel in a sequence (for example, walk, bus, walk). A primary mode was determined for each trip, and emissions were estimated for this primary mode. The primary mode variable (mode1) provided by PSRC in the travel survey data was used to assign a single mode to each trip. For trips reporting more than one mode, the following rules were used to determine which mode was the 'primary' mode for each trip:

- If a trip used a public bus for any segment of a trip (regardless of other modes used) that trip was categorized as having public bus as its primary mode.

- If a trip used a school bus for any segment of a trip (regardless of other modes used) that trip was categorized as having school bus as its primary mode.

- If a trip used a car/van/truck for any segment of a trip (regardless of other modes used, unless a public bus or school bus is used) that trip was categorized as having car/van/truck as its primary mode.

- If a trip used a taxi/shuttle for any segment of a trip (regardless of other modes used) that trip was categorized as having taxi/shuttle as its primary mode.[12]

[12] Only one taxi trip used another mode (bicycle).

2. Determining Travel Path, Speed and Distance. The actual trip path followed for each travel survey trip was not recorded in the PSRC travel survey. In order to estimate the trip path, PSRC, using its modeled road network and travel demand model's equilibrium assignment process, modeled a path between the centroid (centerpoint) of every traffic analysis zone (TAZ) to every other one in the region.

Traffic volume and flow (congestion levels) used in determining the shortest time path (from a loaded assignment at equilibrium) varies by the time of day. PSRC provided five matrices (one for each time period used in the modeling process) showing the estimated emissions between TAZs. The time periods are:

AM: AM Peak Period (6-9 am)

MD: Mid-Day Period (9 am to 3 pm)

PM: PM Peak Period (3-6 pm)

EV: EVening Period (6-10 pm)

NI: NIght Period (10 pm to 6 am)

Trip ends were assigned to the TAZ which contained them. For each pair of TAZs associated with a trip (one for the origin and one for the destination) the estimated emissions from the PSRC matrix was determined and merged to the trip record. The reported trip start time for the trip determined which time period matrix to use.

For intra-TAZ trips, the TAZ to TAZ centroid distance method was not used, as it would result in a trip distance of zero. Instead, the PSRC model estimates an average intrazonal trip length based on the area of the TAZ.[13] For the distances associated with intra-zonal trips, we assumed the travel speed was 20 mph for their entire length, and applied the corresponding emission value for that speed.

Distance Adjustments. The TAZ-based estimates used in this analysis for vehicle trips provided by PSRC do not account for the distance between the actual trip end point and the TAZ centroid. Most trips do not start or end at the TAZ centroid, but at some other location within the TAZ. However, the centroid is a central location, and where the major roadway network is located. Therefore, it is designated by the PSRC as the surrogate geographic terminus for trips within a zone because it its ability to provide an "average" approximation of origins and destinations within that zone. Figure C1 conveys

[13] http://wwwpsrc.org/data/tdmodel/model_doc(final).pdf (pg. 147: Average-intrazonal-trip-length (in miles) = 0.75 * SQRT (area (in sqmi)). "For a square TAZ, the square root of the area gives the length of one side. For a non-square TAZ, the square root of the area is the side of an equivalent square. The average length of a straight line with both ends randomly chosen in the unit square is 0.52665 if the distance is Pythagorean, 0.67333 if the distance is rectilinear. The coefficient of 0.75 is a higher than it would be for a unit square, but is a reasonable number to use for the wide mix of TAZ shapes."

the origin (O) and destination (D) of a hypothetical trip in relation to the TAZ centroid. It is important to also note that TAZ-based estimates for bus trips (both school and public buses) are unlikely to accurately represent the actual path (route) of the bus.

We attempted to adjust the PSRC-provided trip distances estimates in order to account for distance between the actual trip end point and the TAZ centroid. Using X/Y coordinates of the TAZ centroids and actual trip end locations, we were able to calculate the crow-fly (straight line) distance between the trip end point and TAZ centroid. This adjustment added, on average, just over a half-mile to the beginning and end of each trip (about 1.1 miles per trip, on average). However, this approach would only have *added* the distance between the TAZ centroid and the trip end, regardless of the direction of the trip.

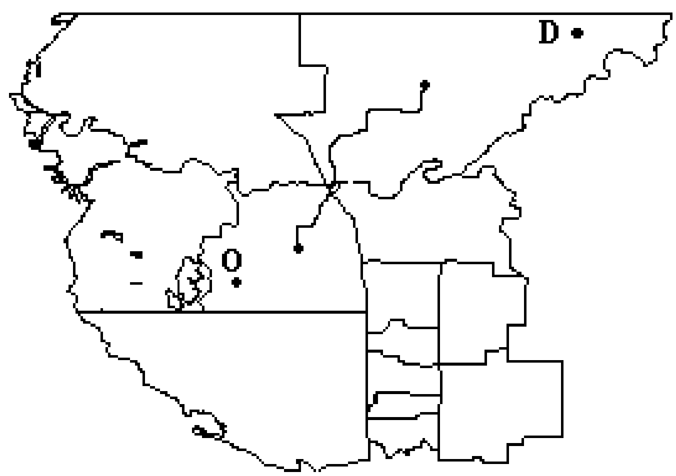

Figure C1. TAZ Centroids and Actual Trip Ends

The hypothetical trip shown in Figure 1 (between points O and D) is longer than the distance between TAZ centroids. However, it is important to note that the opposite circumstance also exists, where the distance between points O and D is actually shorter than the distance between the TAZ centroids. Therefore, while adding the calculated distances from the actual trip origins to the centroid would work in the case shown in Figure 1, it would artificially bias the results by always increasing distances and not accounting for the opposite condition, where trip ends are closer than centroids. Therefore, we chose to use the centroids and not add in the additional distances between trip ends and centroids. This issue can be addressed by using the closest location of the modeled road network to the actual trip end rather than the centroid, an approach that has been used in past research.

The centroid based distance estimates are not anticipated to create much of a difference in the results, due to the averaging that will come from trips that are actually longer or shorter than the centroid. A distinct advantage of the approach used in this analysis is that it is consistent with the methods employed by the PSRC for travel demand modeling -- and it is an acceptable industry standard.

Concurrent with this process of determining speeds and distances, PSRC applied speed-based CO2 emissions rates provided by the California Air Resources Board (CARB) to determine a CO2 emissions amount for each link of each trip based on the estimated travel speed and distance. For the other emissions (NOx, CO, and VOCs) PSRC applied rates from MOBILE6, the EPA's vehicle emissions model. The amount of emissions from all links in the modeled path were then summed to give a trip total between TAZ centroids.

3. Calculating Emissions. Table C1, below, shows all the travel modes reported by King County households in the PSRC travel survey. Emissions were not estimated for all modes. Nonmotorized modes, highlighted in green, were assigned zero emissions. Modes highlighted in yellow are those for which emission estimates were created using speed sensitive emission data from the California Air Resource Board (CARB) and MOBILE. Those in red are also motorized modes, but generating emissions estimates for these modes was not possible. PSRC was only able to provide emission estimates for a single mode combination (to reflect the regional fleet – 55.4% auto and 44.6% light duty truck).

In the case of motorcycle and school bus trips, there was no ability to use a common emission factor ratio (across all speeds) to adjust the auto/truck emissions provided by PSRC. For public bus modes (highlighted in blue), CO2 estimates were created based on fuel efficiency rates and CO2 production estimates per gallon of diesel. Emission estimates for these modes are not speed sensitive. For auto-bus combination trips it was not possible to proportion the trip distance between the different modes given available survey data.

The following sections of this document provide more detail into the specific methodology used to generate emissions for those modes. The remainder of the modes listed (in white) generated emissions, but had very small trip totals and no clear methodology to estimate emissions.

Emissions factors provided by CARB were used to generate CO2 emissions, and MOBILE6 factors were used for NOx, HC and CO. These factors account for vehicle acceleration and deceleration, a refinement over those used in the past. For each time period, the emissions per mile for each link of each trip were calculated and aggregated up to total per-vehicle, per-trip emissions.

Table C1. Travel Modes Used in PSRC Travel Survey (number of King County trips with valid data for emissions)

Car, Van, Truck (36,327)
Motorcycle/Moped (134)
Bicycle (648)
Walk (4,880)
School Bus (5)
Taxi/Shuttle (83)
Dial-A-Ride (15)

Train (14)
Public Bus (1,902)
Ferry auto access (72)
Private Bus (4)
Boat/Kayak (6)
Skateboard/Scooter (10)
Golf Cart (6)
Wheel Chair/Power Chair (9)
Jogging/Running (14)
Flexcar (3)
Picked up/Got a ride (unspec.) (7)
Ferry walk access (34)
Auto-Bus combination (250)
All other miscellaneous responses (2)

Bus Emissions. Bus emissions were estimated based on the trip distance provided by PSRC in the travel survey data, fuel mileage, and the US Environmental Protection Agency's (EPA) ratio of pounds of CO2 emissions per gallon of diesel fuel (22.2)[14]. This single conversion factor does not account for speed or acceleration.

Hot/Cold Start Adjustment. The PSRC generated base emissions estimates assumed 100% of the trips were 'hot start' trips. The travel survey information was then used to determine the percentage of each trip that was "cold start." The emissions were based on CARB and MOBILE factors for autos and light duty trucks. For CO2, these factors do not change with temperature. Taxis/shuttles, public buses and school bus were assumed to have no cold starts.

Table C2 shows the cold start adjustment factors for CO2 provided by CARB. The 'minutes' column is the amount of time elapsing between trips, which can be calculated using travel survey information. Interim minute values were determined using simple weighted proportions between the two end values. The last column shows the final values used, based on the regional fleet distribution of 55.4% auto and 44.6% light duty trucks, as provided by the PSRC – regardless of the vehicle type actually used for the trip. The PSRC would not provide emission estimates that were sensitive to vehicle model year and type. Although this approach has the benefit of eliminating vehicle type as a confounding factor in the analysis, creating estimates that account for vehicle type is nevertheless an important next step.

[14] http://www.epa.gov/otaq////////////climate/420f05001.htm

Table C2: CO2 Cold Start Adjustment Factors (Source: California Air Resources Board)

Time									55.4%	44.6%		
min	LDA	LDT	MDT	HDT	UBUS	MCY	ALL		LDA	LDT		
												Both
5	11.106	13.536	16.212	15.571	3.510	28.559	13.151	5	11.106	13.536		12.190
10	13.976	16.751	21.910	19.474	5.609	31.263	16.678	10	13.976	16.751		15.214
20	19.976	23.532	33.603	27.168	9.767	36.525	23.997	20	19.976	23.532		21.562
30	26.324	30.782	45.691	34.715	13.870	41.590	31.672	30	26.324	30.782		28.312
40	33.018	38.502	58.177	42.113	17.920	46.458	39.702	40	33.018	38.502		35.464
50	40.059	46.691	71.058	49.363	21.915	51.131	48.087	50	40.059	46.691		43.017
60	47.447	55.349	84.336	56.464	25.856	55.606	56.828	60	47.447	55.349		50.971
120	93.738	111.562	160.041	87.870	42.995	76.458	109.986	120	93.738	111.562		101.688
180	107.406	127.658	184.818	98.069	50.105	77.589	125.966	180	107.406	127.658		116.438
240	120.679	143.344	208.656	107.668	56.796	78.656	141.443	240	120.679	143.344		130.788
300	133.555	158.617	231.555	116.666	63.067	79.660	156.414	300	133.555	158.617		144.733
360	146.036	173.480	253.516	125.064	68.919	80.600	170.881	360	146.036	173.48		158.276
420	158.121	187.930	274.537	132.862	74.351	81.477	184.844	420	159.121	187.93		171.970
480	169.810	201.970	294.619	140.059	79.364	82.291	198.302	480	169.81	201.97		184.153
540	181.104	215.597	313.762	146.655	83.957	83.041	211.255	540	181.104	215.597		196.488
600	192.001	228.813	331.966	152.651	88.131	83.727	223.703	600	192.001	228.813		208.419
660	202.503	241.618	349.231	158.046	91.886	84.350	235.647	660	202.503	241.618		219.948
720	212.609	254.011	365.557	162.841	95.221	84.910	247.087	720	212.609	254.011		231.074

Vehicle Occupancy. Emissions and distance were divided among vehicle occupants to create a per-person, per-trip total. For auto/truck we used the vehicle occupancy reported by travel survey participants. The maximum number of people a survey participant could indicate were in the vehicle with them is “6 or more.” When this amount is indicated the number of people in addition to the survey participant that are assumed to be in the car is 6. Ridership data provided by King County Metro Transit was used to apply average weekday ridership assumptions of 11.29 passengers for off peak (midday, night and evening) periods, and 12.59 passengers for peak periods (AM and PM).

For school buses we assumed an occupancy of 35, and in the case of taxis vehicle occupancy was assumed to be 1 for the purpose of allocating emissions. Although taxis will have at least 2 people in them, but as in the case of driving alone, the sole reason the trip is occurring is due to a single person, and therefore all the emissions generated were assigned to that person.