URBAN FOOTPRINT

Technical Summary

Model Version 1.0

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URBAN DESIGNERS, PLANNERS, ARCHITECTS

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Team Credits

UrbanFootprint was developed with funding and support from :

California High Speed Rail Authority

California Strategic Growth Council

Additional technical and data support was provided by :

Urban Land Use and Transportation Center
at the University of California at Davis

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Introduction

The UrbanFootprint model is a powerful land use planning, modeling, and data organization framework designed to facilitate more informed planning by practitioners, public agencies, and other stakeholders. Built on fully open-source software platforms and tools, UrbanFootprint requires no proprietary software of any kind. Its development is led by Calthorpe Associates, a planning and urban design firm based in Berkeley, California.

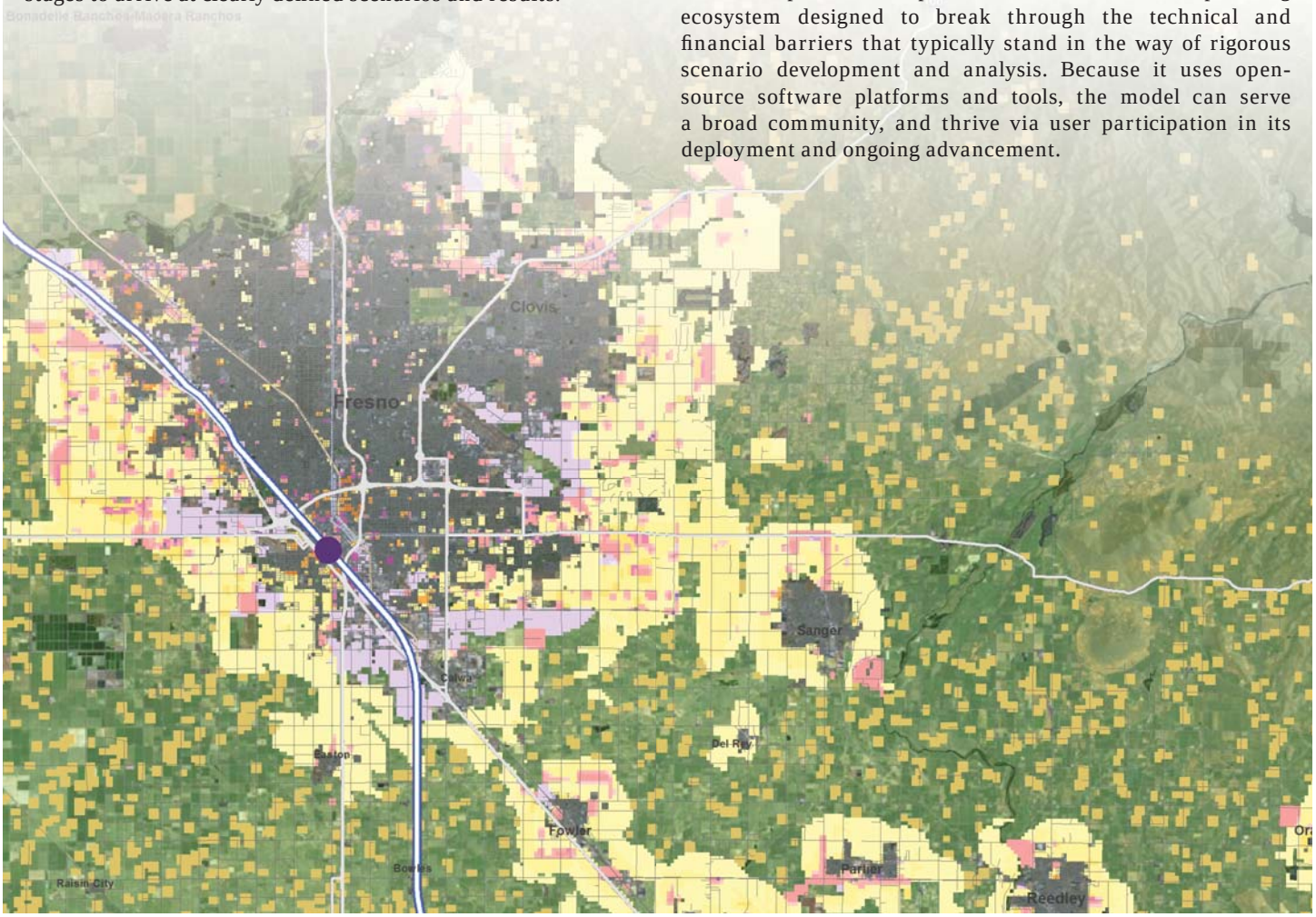
UrbanFootprint comprises a suite of tools and analytical engines that vastly decrease the time and resources required to get up and running with scenario development, while significantly increasing the technical capacity of state, regional, and local users to analyze the fiscal, environmental, transportation, and public health impacts of plans and policies. Moreover, it provides a common data framework within which planning efforts at various scales can be integrated and synced.

Scenario-based planning with UrbanFootprint involves four stages: data organization, the translation of existing plans, scenario development, and scenario analysis. This guide describes how UrbanFootprint works through each of these stages to arrive at clearly defined scenarios and results.

The model currently includes analytical engines that produce results for the following metrics (with more to come as the model is advanced through deployment and research-based activities):

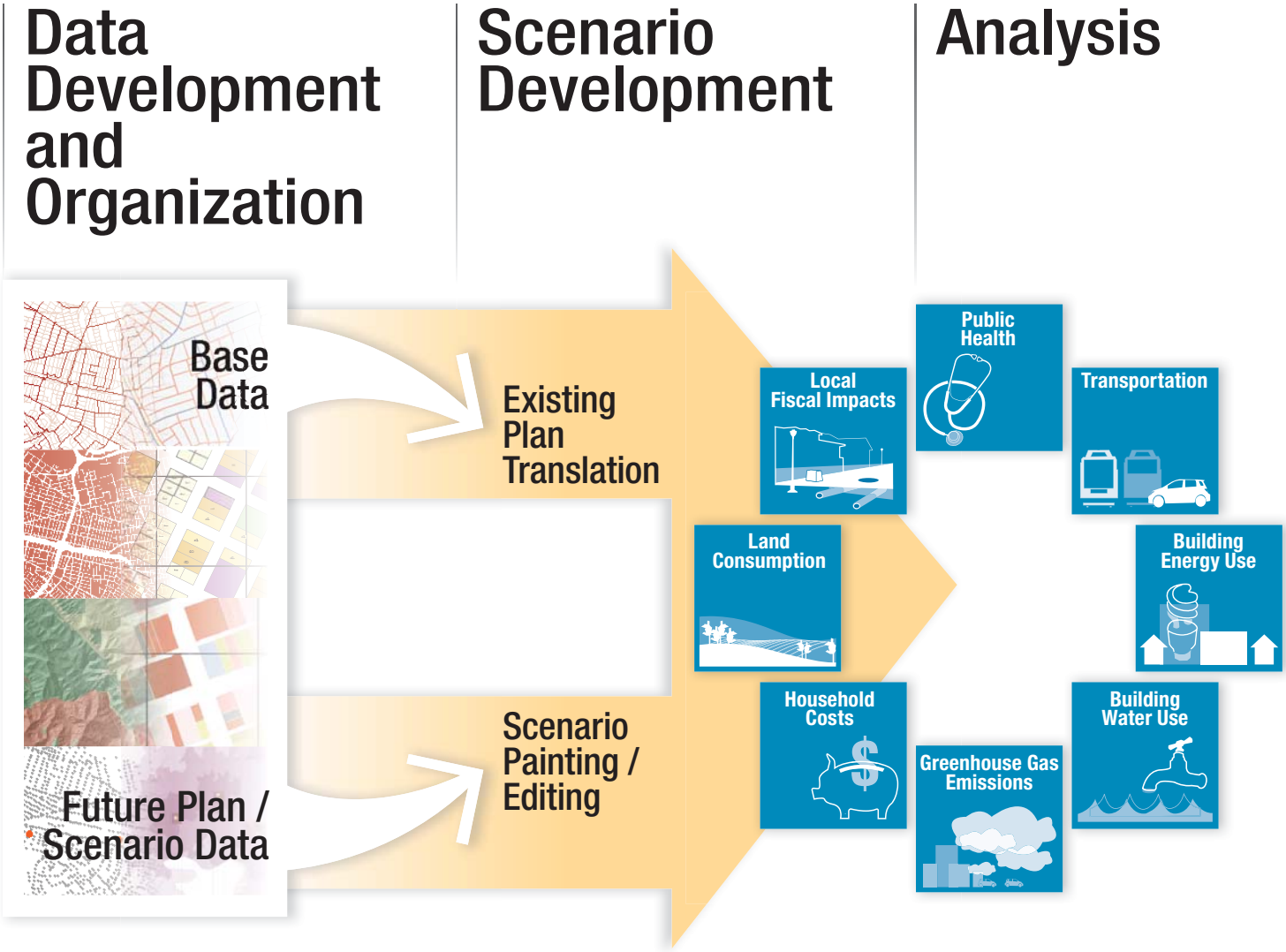
- Land consumption
- Vehicle miles traveled (VMT), travel mode, and fuel consumption
- Transportation greenhouse gas (GHG) and air pollutant emissions
- Building energy and water consumption, costs, and related GHG emissions
- Household costs for housing, transportation and utilities
- Public health impacts and costs (physical activity/weight-relayed, pollutant/respiratory-related, and pedestrian-safety)
- Local fiscal impacts (capital infrastructure and operations and maintenance costs, and tax/fee revenues)

UrbanFootprint is a comprehensive data and scenario planning ecosystem designed to break through the technical and financial barriers that typically stand in the way of rigorous scenario development and analysis. Because it uses open-source software platforms and tools, the model can serve a broad community, and thrive via user participation in its deployment and ongoing advancement.

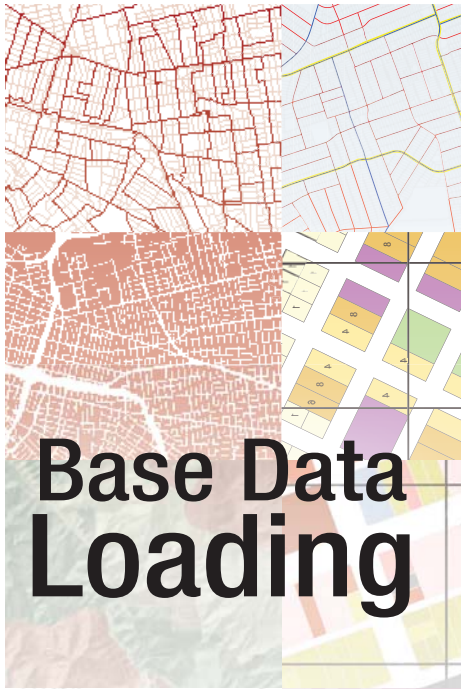


UrbanFootprint as an Ecosystem

The UrbanFootprint modeling framework functions as a data and scenario planning ecosystem. It includes *data development and organization tools* that streamline the creation, updating, and storage of detailed existing conditions data, existing city, regional, or other plans and policies, and future scenarios. It also includes novel *translation tools* that transform city, county, and regional plans into a common language of building and place types, and a web-based *scenario painter* that facilitates scenario creation and editing. Finally, UrbanFootprint includes analytical engines that measure the fiscal, environmental, transportation, public health, and community impacts of future scenarios.



UrbanFootprint Model Components



Base Data Loading

A dataset of existing conditions is required by the model's scenario development tools and analytical engines. The model streamlines the development of this base environment dataset through scripts and processes that draw from diverse sources. Deploying the model in any jurisdiction or region within the United States requires only minor modification; processes are also being developed to facilitate use of the model outside of the United States.

Existing Plan Translation

The translation engine analyzes existing local and regional plans and integrates them into the model for subsequent analysis or modification. "Translating" plans into the schema of UrbanFootprint Place Types facilitates the ongoing compilation or "stitching" of local plans and policies into a common regional or statewide fabric of land use and transportation plans.

Place Type and Building Type Library

A complete library of place and building types is used to represent existing land use plans and build new scenarios. These scenario "building blocks" represent the full range of existing and future land development patterns, from mixed-use urban centers, to employment zones, to standard suburban residential areas. The default set of 35+ place types and 90+ building types can be customized for specific model deployments.

The UrbanFootprint web-based painting tool facilitates scenario creation or editing. The current version of the model uses the 5.5-acre grid cell as the unit of painting and analysis; the model will be built to deploy at the parcel level as well the grid in the near future.

Scenario Painting / Editing

Land Consumption

New Land Consumed
Agricultural, Sensitive Lands Consumed

Local Fiscal Impacts

Capital Costs for Local Infrastructure
Operations and Maintenance Costs
Local Tax and Fee Revenues

Transportation

Vehicle Miles Traveled (VMT)
Travel Mode (walk/bike/auto/transit)
Congestion
Greenhouse Gas and Criteria Pollutant Emissions

Building Energy Use

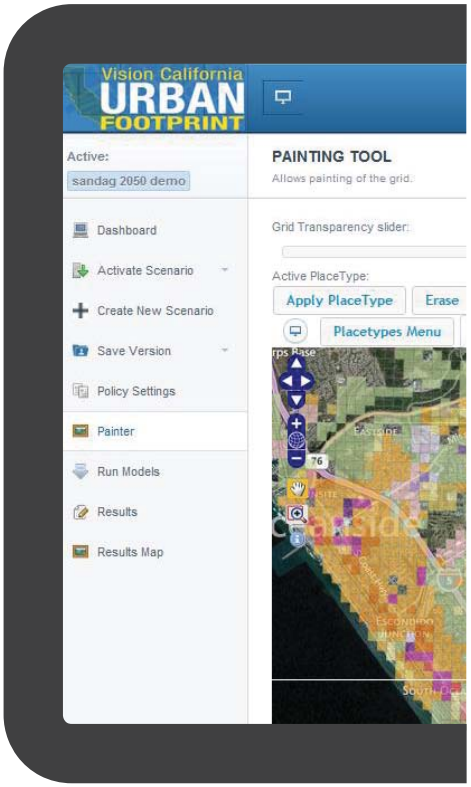
Residential Energy Use
Commercial Energy Use
Building-related CO_2e Emissions

Building Water Use

Indoor and Outdoor Water Use
Water-Related Electricity Use
Water-Related Electricity CO_2e Emissions

Graphical User Interface (GUI)

UrbanFootprint features a web-based, platform-neutral GUI that operates in any web browser, on any operating system, and on most hardware (desktop, laptop, or tablet computer). The GUI can be used to control scenario setup, load Place Types, paint scenarios, run primary scenario and analysis engines, and report results. Scripts are used to perform other model functions. In time, all primary model functions, including public engagement functionality, will be integrated into the web-based interface.



Scenarios >

Analysis

Analytical engines estimate travel impacts; greenhouse gas (GHG) and air pollutant emissions; building energy and water use; fiscal impacts (capital and operations and maintenance costs for local infrastructure); public health impacts; and land consumption.

Greenhouse Gas Emissions

Transportation (Liquid Fuel and Electricity) Emissions
Building Energy Emissions

Public Health

Physical Activity/Weight Related Disease Incidence and Costs
Respiratory/Pollution-Related Disease Incidence and Costs
Pedestrian-Auto Collisions and Associated Costs

Household Costs

Transportation (Driving and Related) Costs
Residential Energy and Water Costs

Open Source Tools

UrbanFootprint is built on a suite of open source software platforms and tools, and requires no proprietary software of any kind. Ubuntu Linux-based server or desktop hardware hosts major model databases and analytical engines, which are accessed or controlled via a 'thin' web browser client and other tools from any hardware or operating system (i.e. Windows, Mac OS, Linux, iOS, Android).

Major software components of UrbanFootprint v1.0 include:

DATABASE

PostgreSQL 9.1 – an industry standard, high volume, high performance relational database.

SERVER OPERATING ENVIRONMENT

Ubuntu Linux 12.04 LTS was chosen for its stability, speed and efficiency, allowing UrbanFootprint to have true, scalable 64-bit computing, including multi-threading capabilities.

GEOSPATIAL ANALYSIS

PostGIS 1.5 - PostGIS integrates with the PostgreSQL database to provide maximum performance Geographic Information Systems (GIS) functionality within UrbanFootprint's 64-bit multi-core, multi-threaded computing environment.

CROSS-ENVIRONMENT DATA TRANSFER

ogr2ogr,part of GDAL, an evolving open-source toolset used to transfer vector geodata in and out of UrbanFootprint's PostgreSQL environment; GDAL developers have published plug-in drivers for more than one hundred industry standard vector data formats, notably including the ESRI GIS Geodatabase and ESRI Shapefiles.

DISTRIBUTED PROCESSING and QUEUING

Django, Celery, Redis. UrbanFootprint version 1.0 includes an advanced task queue to manage processes running on servers and report status and results back to the user interface for long running analysis.

OTHER PROGRAMMING LANGUAGES

PGSQL, Python, Apache, Django. SQLis used to write queries to the Postgres database; PostgreSQL programming via pl-sql and pl-R; Python is used to 'wrap' native SQL queries and make them available to the rest of the model; Python, Apache and Django are used for the GUI.

SPATIAL DATA VISUALIZATION

Geoserver serves geographic data layers to the user interface via the web. Advanced users can access data in almost every industry standard format in use today, with options for granular security, custom data and performance enhancements.

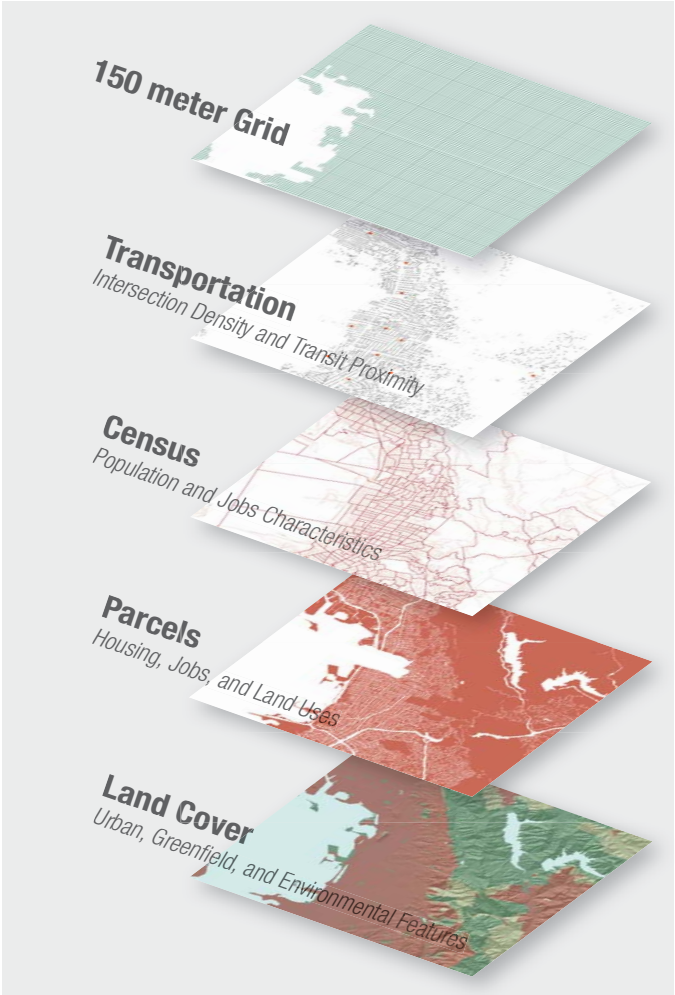
DISPLAY / REPORTING

OpenLayers web maps, JQuery and Highcharts. OpenLayers serves base data from multiple sources, such as OpenStreetMap, Bing, or Google Maps; Highcharts allows results to be displayed using a wide selection of high-performance interactive charts and graphs.

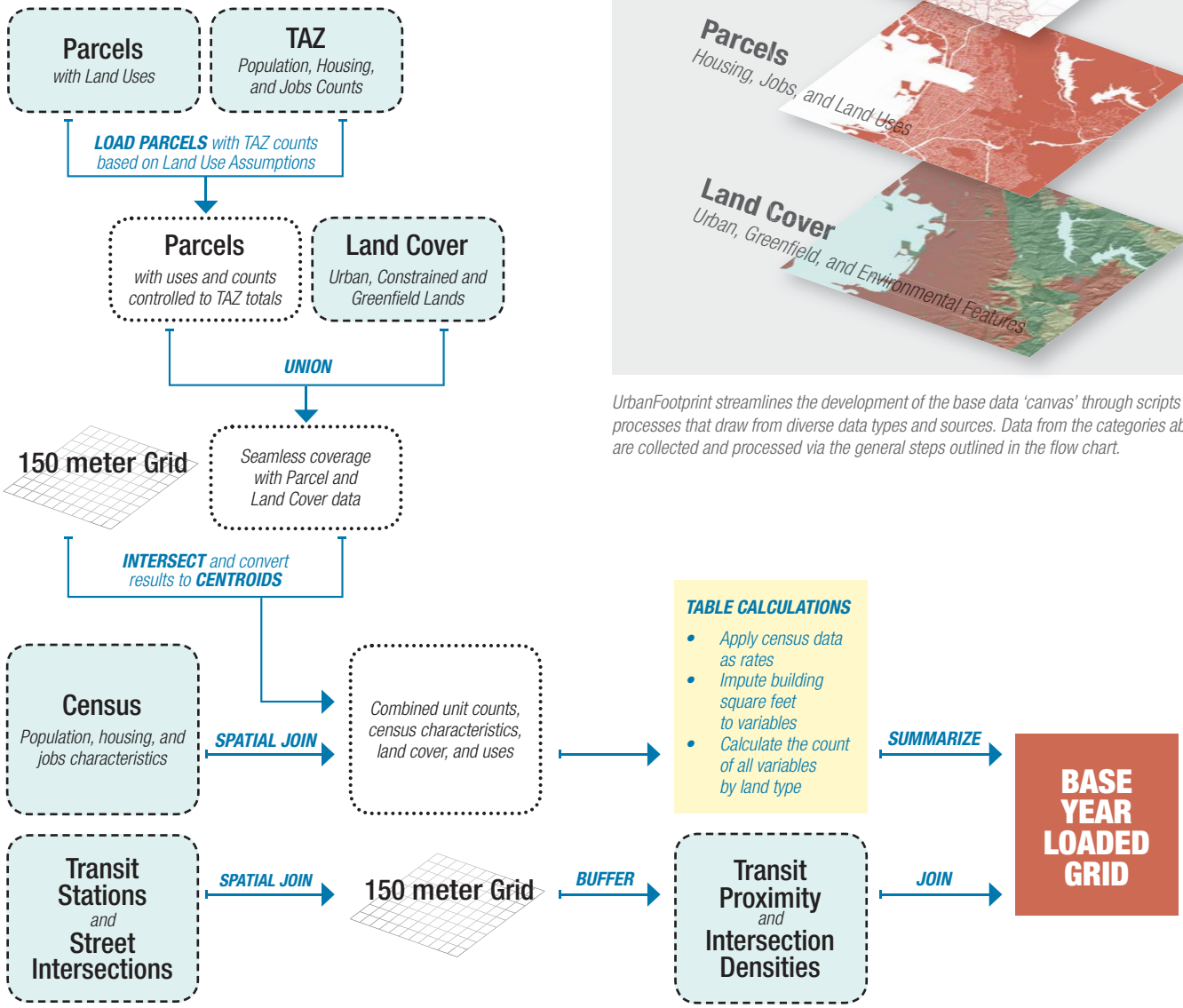
Base Data Loading

Scenarios are built upon a base-year grid that describes the existing environment. This highly detailed "canvas" of data constitutes a baseline assessment of land use, demographic characteristics, and other conditions, providing the context for scenario painting and the foundation for analysis by the various model engines.

UrbanFootprint uses a series of scripts to normalize data of varying quality, type, and scale from a wide range of sources and import them into the model analysis grid. As described in the graphics below, the base loading process brings a range of data types together into the model's 5.5 acre (150 meter x 150 meter) grid, including: land cover and environmental features data; parcel-based data on housing, employment, and population; Census population, housing, and jobs characteristics; control total data from MPOs or other agencies, generally at the traffic analysis zone (TAZ) resolution; and roadway and transit data. The following pages describe the loading process for each of these data categories in more detail.



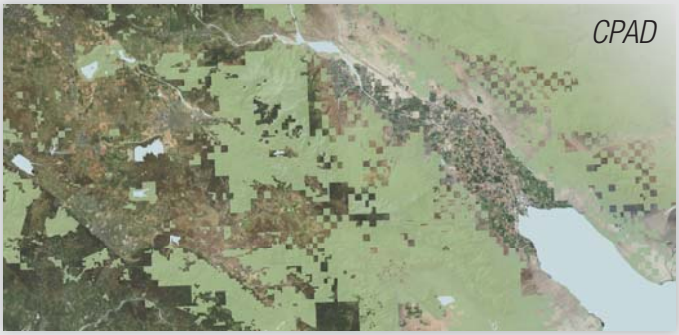
UrbanFootprint streamlines the development of the base data 'canvas' through scripts and processes that draw from diverse data types and sources. Data from the categories above are collected and processed via the general steps outlined in the flow chart.



Base Data Loading

Land Cover and Environmental Data

UrbanFootprint classifies the landscape into three broad land type categories: urban, greenfield or constrained. Urban land includes lands that have already been urbanized. Constrained land includes water and lands legally protected from development. Greenfield land includes all other non-urban developable areas. In California, the primary dataset used to classify land as either urban or greenfield is the California Farmland Mapping and Monitoring Program (FMMP) dataset; greenfield data is further classified by the sub-categories in the FMMP dataset. Constrained lands include protected areas defined by the California Protected Areas Database (CPAD) dataset, as well as water bodies as defined by a combination of: the California Spatial Information Library (CASIL) 'Polygon Hydrologic Features' dataset; the water features contained in the FMMP dataset; and the Tele-Atlas North America (TANA) 'U.S. and Canada Water Polygons' dataset.



The California Farmland Mapping and Monitoring Program (FMMP) dataset is used to identify urban and greenfield lands, as well as specific categories of agricultural land. Other sources, such as the California Protected Areas Database (CPAD) dataset, are used to identify environmentally constrained land.

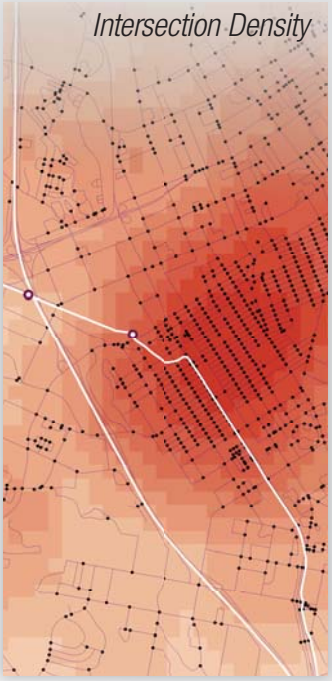
Parcel Data

Assessor's tax parcel data (cadastral data) is used as the finest grain of geographical resolution to which data is assigned in UrbanFootprint's base data loading process. The existing land use attribute of each parcel is used as the basis for allocating dwelling units and employees, as well as assessing lot coverage for the purposes of energy use, water consumption, and other analyses.

Parcel data is collected from state, regional, and local sources, including county assessor and commercial parcel databases. In this example, demographics and control totals are processed from traffic analysis zones (TAZs), attributed to appropriate land uses, and then distributed onto the landscape into parcels.

Transportation Features

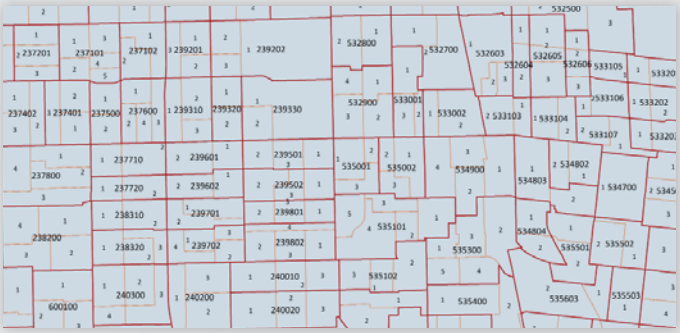
Every grid cell is assigned a distance to the nearest passenger rail or other fixed-guideway transit stop. This information is used by many of UrbanFootprint's engines, including travel and public health. A dataset of street intersections, which is critical for Place Type translation, travel, public health and other UrbanFootprint functions, was produced using street centerline data from Census Topologically Integrated Geographic Encoding and Referencing (TIGER) data.

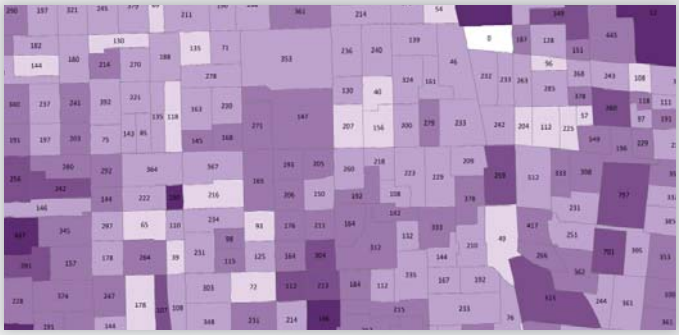


Intersection density and transit proximity are two critical components of the base environment in UrbanFootprint.

Census and Related Data

UrbanFootprint generates raw counts of population, dwelling units, jobs and other demographic variables at the parcel and grid level using a Census rate file. This rate file is generated from a combination of: Census Summary File 1 (SF1: blocks, from the short form); Summary File 3 (SF3:block groups, from the long form); Census Transportation Planning Package (CTPP2: block groups); Longitudinal Employer-Household Dynamics (LEHD: blocks); American Community Survey (ACS) and other data products, which in the State of California include job estimates and counts from the California Employment Development Department (EDD) and population counts and estimates from the California Department Of Finance (DOF).





UrbanFootprint derives critical demographic information from a variety of US Census and state data sources.

Place Types and Building Types

UrbanFootprint includes a library of more than 35 Place Types and 50 building types that make up the palette of development options used to translate or "paint" scenarios. Place Types – each composed of a mix of Building Types (based on studies of over 300 real-world buildings) – are the land use building blocks of future scenarios, and represent the complete range of potential development types and patterns that make up a scenario. They include a range of mixed-use centers, residential areas of varying densities and types, employment and industrial areas, and other land use types that make up existing and future urban land uses.

Study Areas

UrbanFootprint's Place and Building Types are calibrated based on studies of exemplary places across California and the US, as well as detailed studies of a complete range of building types across California and the West. The UrbanFootprint Place Type library can be utilized by cities, regions, or MPOs as they develop their own plans – either as an "off the shelf" library or customized for their specific needs.

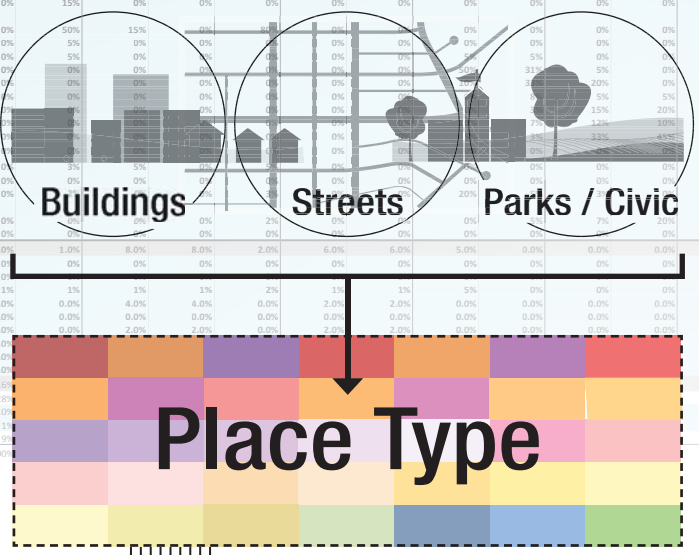
Place Type Studies

Building Type Studies

UrbanFootprint's Place Types represent a full range of existing and future land development patterns, from mixed-use urban centers, to employment zones, to standard suburban residential areas. The default set of 35+ Place Types and 90+ Building Types includes detailed density, mix, demographic, and other characteristics

Mixed Use Centers and Corridors	1	Urban Mixed Use
	2	Urban Residential
	3	Urban Commercial
	4	City Mixed Use
	5	City Residential
	6	City Commercial
	7	Town Mixed Use
	8	Town Residential
	9	Town Commercial
	10	Village Mixed Use
	11	Village Residential
	12	Village Commercial
	13	Neighborhood Residential
	14	Neighborhood Low
Employment Areas	15	Office Focus
	16	Mixed Office and R&D
	17	Office / Industrial
	18	Industrial Focus
	19	Low-Density Employment Park
Suburban Commercial / Mixed Use	20	High Intensity Activity Center
	21	Mid Intensity Activity Center
	22	Low Intensity Retail Centered Neighborhood
	23	Retail: Strip Mall / Big Box
	24	Industrial / Office / Residential Mixed High
	25	Industrial / Office / Residential Mixed Low
Suburban Residential Single Use	26	Suburban Multifamily
	27	Suburban Mixed Residential
	28	Residential Subdivision
	29	Large Lot Residential Area
Rural	30	Rural Residential
	31	Rural Ranchettes
	32	Rural Employment
Institutional	33	Campus / University
	34	Institutional
	35	Parks and Open Space

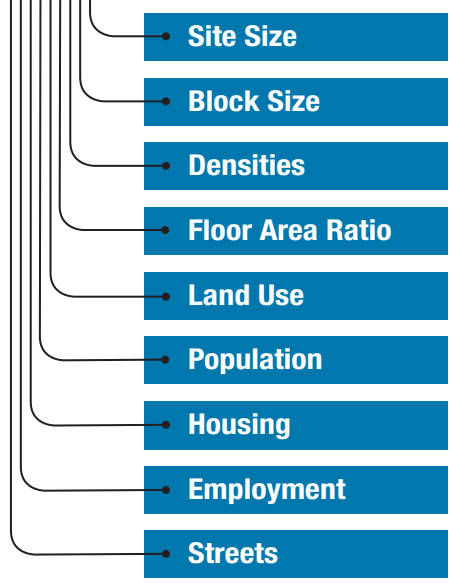
	Meta-Place Types ®	Mixed Use Centers & Corridors														Employment Areas				
		Urban (Super Regional Center)			City (Regional Center)			Town (Subregional Center)			Village (Small Mixed-Use Center)			Neighborhood		Hi/Mid Intensity		Low Intensity		
	Place Types ®	Urban Mixed Use	Urban Residential	Urban Commercial	City Mixed Use	City Residential	City Commercial	Town Mixed Use	Town Residential	Town Commercial	Village Mixed Use	Village Residential	Village Commercial	Neighborhood Residential	Neighborhood Low	Office Focus	Mixed Office and R&D	Office/Industrial	Industrial Focus	Low-Density Employment Park
	Buliding Types ~	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Calibrated to Study Areas?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	BUILDING % CHECK	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	MIXED USE	57.0%	15.0%	12.0%	44.0%	14.0%	5.0%	38.0%	12.5%	20.0%	20.0%	0.0%	10.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	Skyscraper Mixed Use	7%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2	High-Rise Mixed Use	15%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	Mid-Rise Mixed Use	17%	3%	2%	10%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
4	Low-Rise Mixed Use	12%	3%	3%	9%	4%	1%	10%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5	Parking Structure/Mixed Use	0%	2%	0%	5%	1%	1%	5%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6	Main Street Commercial/MU High (3-5 Floors)	3%	5%	5%	15%	5%	1%	13%	0%	5%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
7	Main Street Commercial/MU Low (1-2 Floors)	3%	0%	0%	5%	2%	1%	10%	13%	10%	15%	0%	10%	2%	0%	0%	0%	0%	0%	0%
	RESIDENTIAL	23.0%	80.0%	0.0%	35.0%	81.0%	0.0%	35.0%	87.5%	0.0%	60.0%	100.0%	0.0%	98.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	Skyscraper Residential	5%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
9	High-Rise Residential	7%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10	Urban Mid-Rise Residential	8%	34%	0%	10%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11	Urban Podium Multi-Family	3%	14%	0%	10%	26%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12	Standard Podium Multi-Family	0%	5%	0%	5%	10%	0%	5%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13	Suburban Multifamily Apt/Condo	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14	Urban Townhome/Live-Work	0%	0%	0%	10%	20%	0%	20%	45%	0%	30%	55%	0%	0%	0%	0%	0%	0%	0%	0%
15	Standard Townhome	0%	0%	0%	0%	5%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
16	Garden Apartment	0%	0%	0%	0%	0%	0%	0%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
17	Very Small Lot 3000	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	35%	0%	68%	0%	0%	0%	0%	0%	0%
18	Small Lot 4000	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	10%	0%	25%	30%	0%	0%	0%	0%	0%
19	Medium Lot 5500	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	20%	0%	0%	0%	0%	0%
20	Large Lot 7500	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%	0%
21	Estate Lot	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22	Rural Residential	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
23	Rural Ranchette	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	COMMERCIAL/INDUSTRIAL	20.0%	5.0%	88.0%	21.0%	5.0%	95.0%	27.0%	0.0%	80.0%	20.0%	0.0%	90.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
24	Skyscraper Office	0%	0%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25	High-Rise Office	5%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26	Mid-Rise Office	0%	0%	13%	2%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
27	Low-Rise Office	0%	0%	39%	3%	0%	42%	19%	0%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28	Main Street Commercial (Retail + Office/Medical)	5%	0%	8%	5%	0%	31%	5%	0%	50%	15%	0%	80%	0%	0%	0%	0%	0%	0%	0%
29	Parking Structure+Ground-Floor Retail	5%	0%	5%	3%	0%	5%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30	Parking Structure	0%	0%	0%	3%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%
31	Office Park High	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	31%	5%	0%	0%
32	Office Park Low	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	31%	20%	0%	5%
33	Industrial High	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	5%	0%
34	Industrial Low	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	15%	20%	20%
35	Warehouse High	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	12%	10%	0%
36	Warehouse Low	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	31%	33%	45%	70%
37	Hotel High	5%	5%	5%	3%	3%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
38	Hotel Low	0%	0%	0%	2%	2%	2%	3%	0%	3%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
39	Regional Mall	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
40	Medium Intensity Strip Commercial	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%
41	Low Intensity Strip Commercial (weighted avg)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	0%	0%	0%	0%	0%	10%	5%
42	Rural Employment	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	INSTITUTIONAL (Itemized Civic)	5.0%	5.0%	1.0%	5.0%	5.0%	1.0%	8.0%	8.0%	1.0%	8.0%	8.0%	2.0%	6.0%	6.0%	5.0%	0.0%	0.0%	0.0%	0.0%
43	Campus/College High	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
44	Campus/College Low	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
45	Hospital/Civic/Other Institutional	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	5%	0%	0%	0%	0%
46	Urban Elementary School	2.0%	2.0%	0.0%	2.0%	2.0%	0.0%	4.0%	4.0%	0.0%	4.0%	4.0%	0.0%	2.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%
47	Non-Urban Elementary School	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
48	Urban Middle School	1.0%	1.0%	0.0%	1.0%	1.0%	0.0%	2.0%	2.0%	0.0%	2.0%	2.0%	0.0%	2.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%
49	Non-Urban Middle School	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
50	Urban High School	1.0%	1.0%	0.0%	1.0%	1.0%	0.0%	1.0%	1.0%	0.0%	1.0%	1.0%	0.0%	1.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
51	Non-Urban High School	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	STREETS/PARKS/OTHER CIVIC	44.6%	44.6%	44.6%	44.0%	44.0%	44.0%	44.0%	35.6%	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%
	Streets	37%	37%	37%	36%	36%	36%	36%	28%	36%	36%	36%	36%	36%	36%	35%	35%	35%	35%	35%
	Park	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%	4.0%	4.0%	4.0%	4.0%	4.0%
	Detention/Utilities	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	5%	5%	5%	5%	5%
	Total Civic	6%	6%	2%	6%	6%	2%	9%	9%	6%	6%	6%	2%	9%	9%	5%	5%	5%	5%	5%
	TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%



Place Types, and the buildings within them, are "loaded" with a unique set of assumptions that facilitate scenario modeling and testing at a variety of scales. Some assumptions are related to the individual buildings in a Place Type (i.e. commercial mid-rise, single family home, townhome), including:

- Building energy and water consumption
- Building-related greenhouse gas emissions
- Infrastructure cost/burden (including operations and maintenance costs)
- Household costs and tax burden for utilities

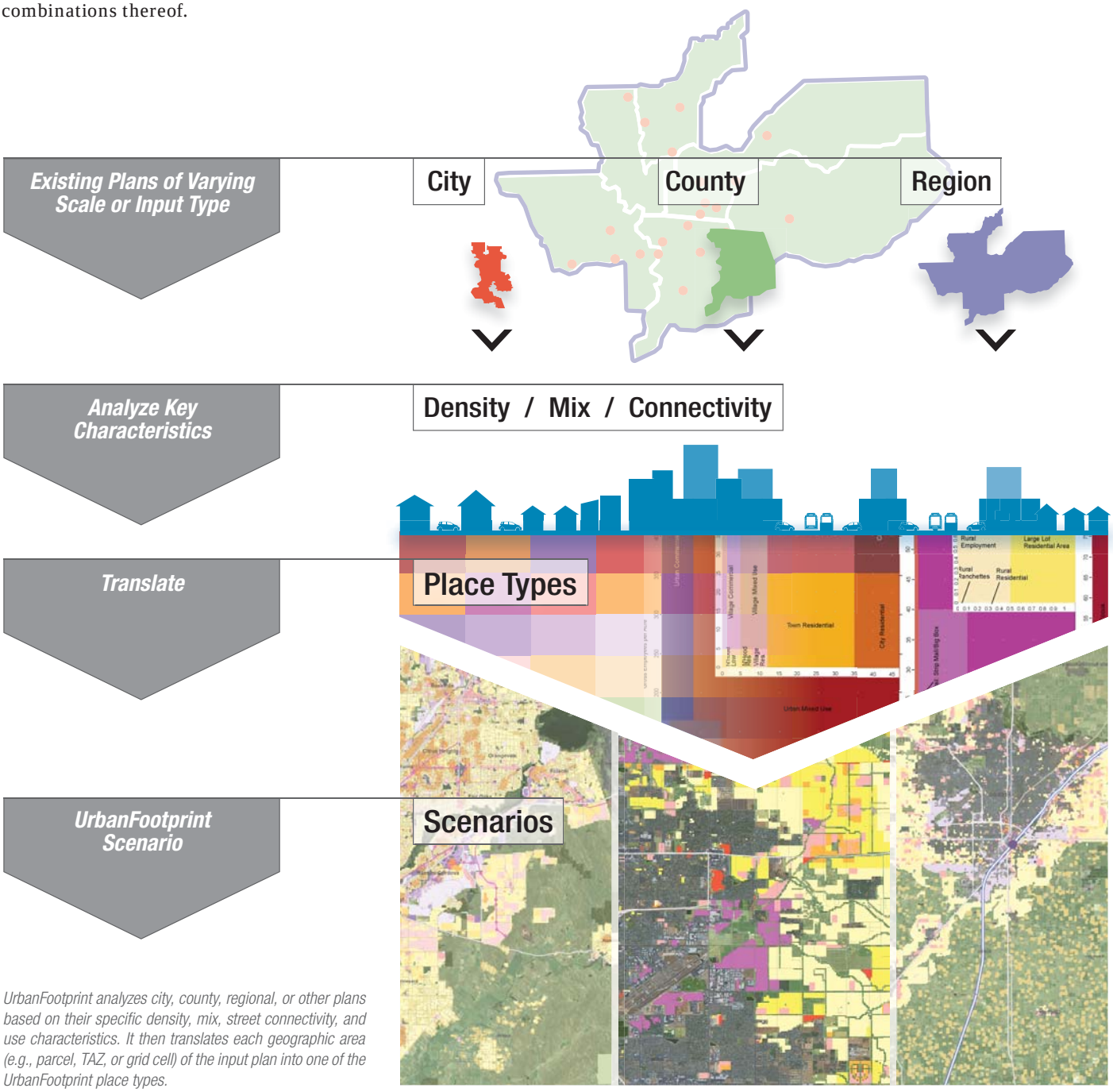
Other assumptions are related to each Place Type's unique density, location, transportation network, demographic context, and combination of buildings. These assumptions combine to predict the travel behavior of a scenario's residents and employees and are thus critical in measuring passenger vehicle miles traveled (VMT); roadway congestion; and transportation-related greenhouse gas emissions, air pollutant emissions, public health outcomes, and state, regional, local, and household cost burdens.



Existing Plan Translation

UrbanFootprint includes tools that quickly translate any existing plan or scenario into the model's common language of Place and Building types. The model can translate jurisdictional, county, regional, and other plans, no matter what tool or process was used to create them. Once an existing plan is translated into UrbanFootprint, additional editing or scenario painting can be performed, and analytical engines can be run. The translation tools also provide the capacity to maintain a common "quilt" of local land use and transport plans, and perform consistent, compatible analysis on individual plans or combinations thereof.

At the state and regional levels, UrbanFootprint can be used to integrate or stitch together Sustainable Community Strategies (SCSs), Regional Transportation Plans (RTPs) or similar regional scenarios, and general/local-scale plans as they are produced. This comprehensive plans database can be made available to local governments looking to coordinate their land-use assumptions with other localities and regions for SCS/regional planning and analysis.



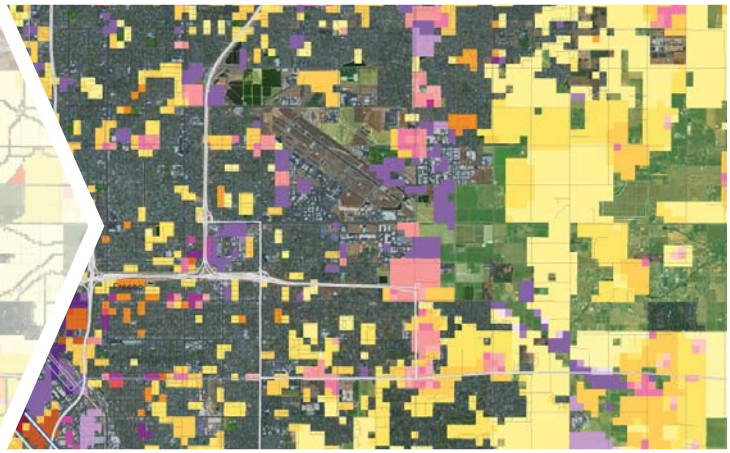
UrbanFootprint analyzes city, county, regional, or other plans based on their specific density, mix, street connectivity, and use characteristics. It then translates each geographic area (e.g., parcel, TAZ, or grid cell) of the input plan into one of the UrbanFootprint place types.

Translated Plans

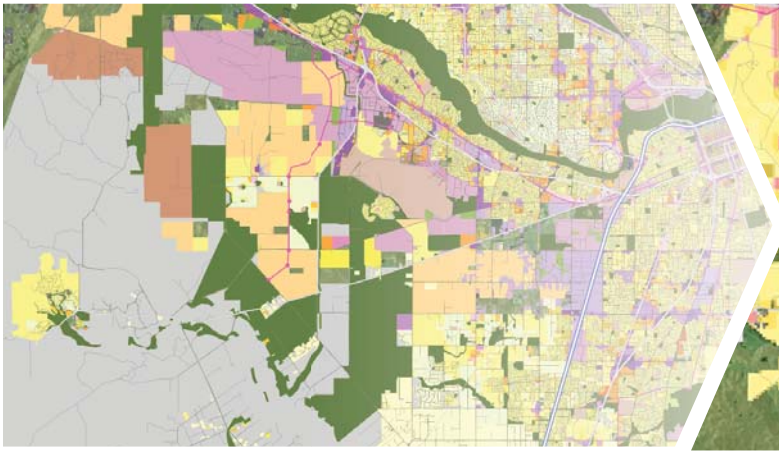
UrbanFootprint can translate local or regional plans or scenarios produced by other land use tools or "sketch models", as well as those that were not created using a specific tool or process.

San Joaquin Valley 'UPlan' Scenario

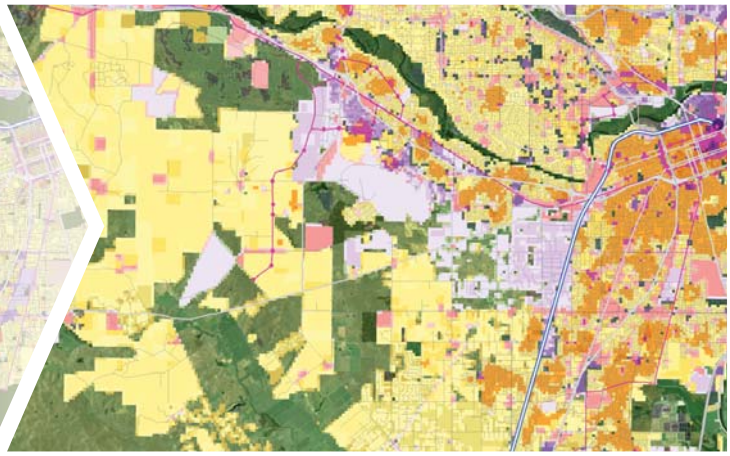
San Joaquin Valley UrbanFootprint Scenario



Sacramento Area Council of Governments 'iPlaces' Scenario



Sacramento Area UrbanFootprint Scenario



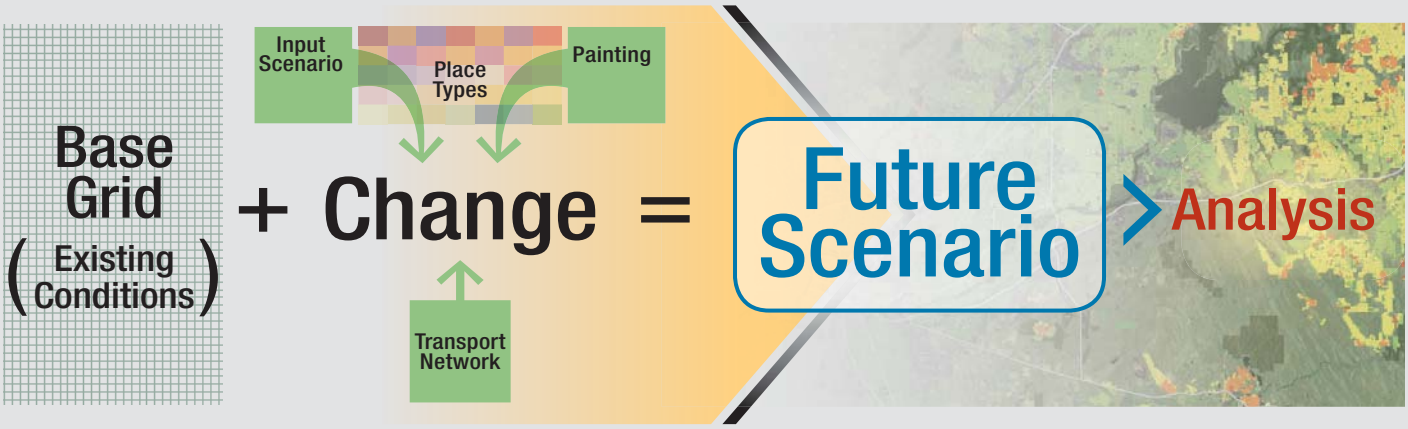
Base + Future Modeling

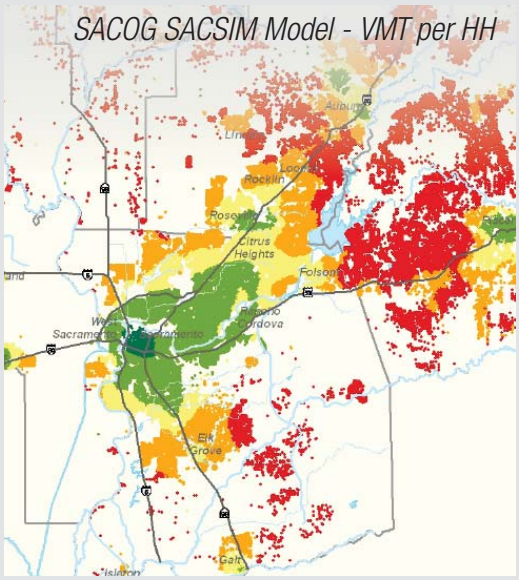
Many of the land use models in use today translate the existing environment into Place Types or similar theoretical building blocks, thus creating a virtual depiction of the present or base condition. The base environment is translated into the same language as that of the future. While this can be expedient, it can also lose valuable detail about the base environment, and limit the depth and research capacity of the models and resulting analysis.

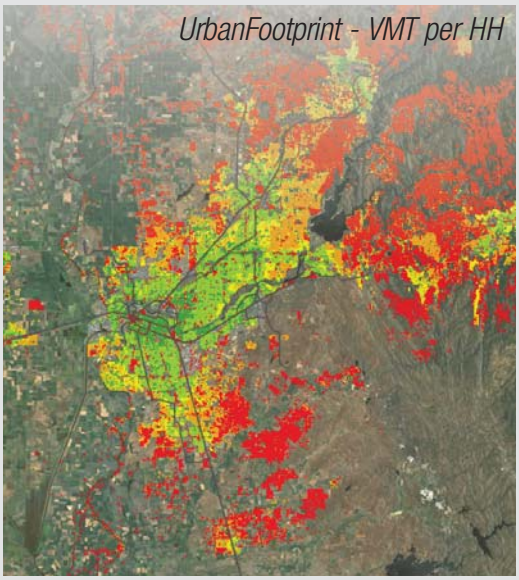
The UrbanFootprint model is designed to overcome this limitation via processes that significantly cut down on the time and effort required to build a detailed depiction of the physical, demographic, and other key characteristics of the base environment required by the model's many analytical engines. The model includes tools that help methodically assess the intricate details of the existing urban (and non-urban) environment, and assign as much detail as possible to the smallest level of geography. The resulting base data framework allows UrbanFootprint to analyze future scenarios as a mixture of places that have physically changed, and those that have not.

This depiction of the future as a combination of "change" and "no-change" areas is significant, as physical changes in change areas can impact behavior in adjacent no-change areas. UrbanFootprint estimates travel and other impacts of these conditions (e.g., where infill or new development occurs around but not directly within a district or neighborhood, or where parcels receiving infill development are surrounded by parcels that remain the same as in the base year). It also allows for validation of the many analytical engines in the UrbanFootprint model, as model outputs can be compared to and calibrated against known qualities (using empirical data about existing conditions) and other model depictions of the existing/base environment.

UrbanFootprint can analyze the Base / Existing Environment or a Future Scenario that combines the Base with Changes to land use and transportation networks.





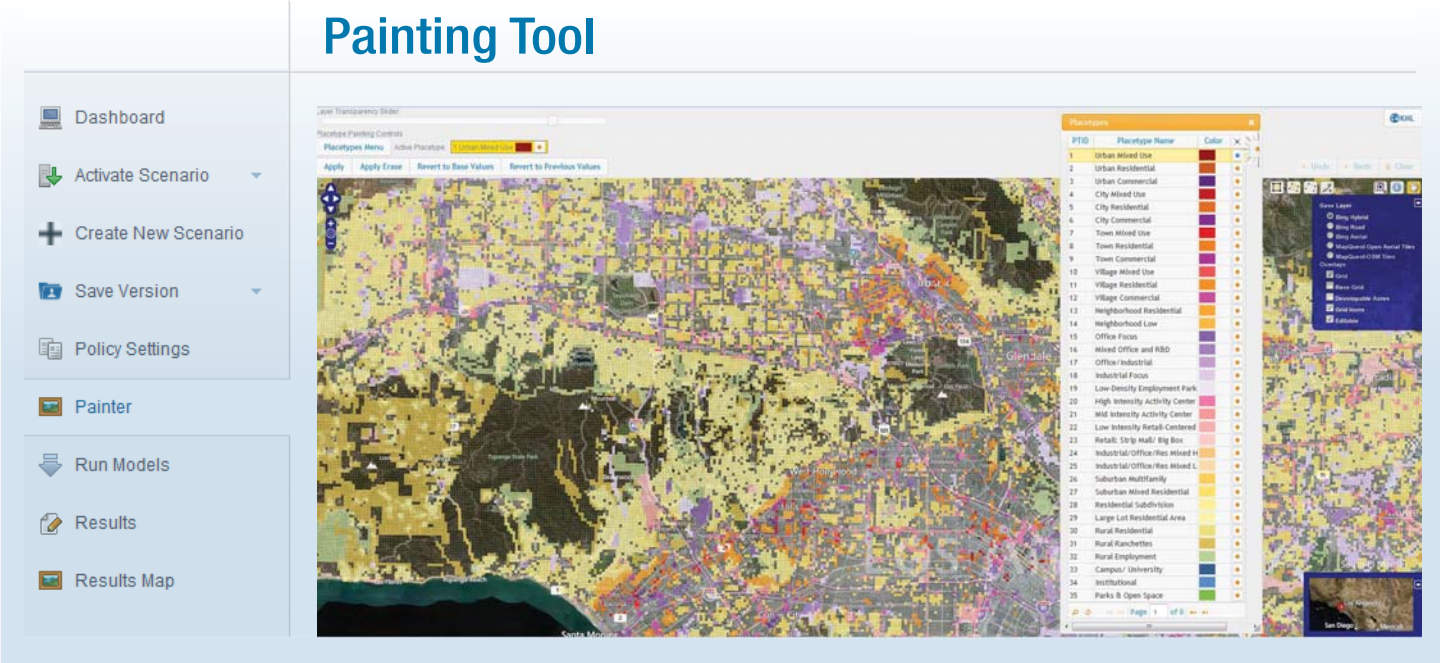


Detailed depiction of the existing environments allows UrbanFootprint's models to be calibrated to known / empirical conditions. At left a comparison of UrbanFootprint's depiction of 2010 VMT per Household compared to that of the Sacramento Area Council of Government's cutting-edge SACSIM Travel Model.

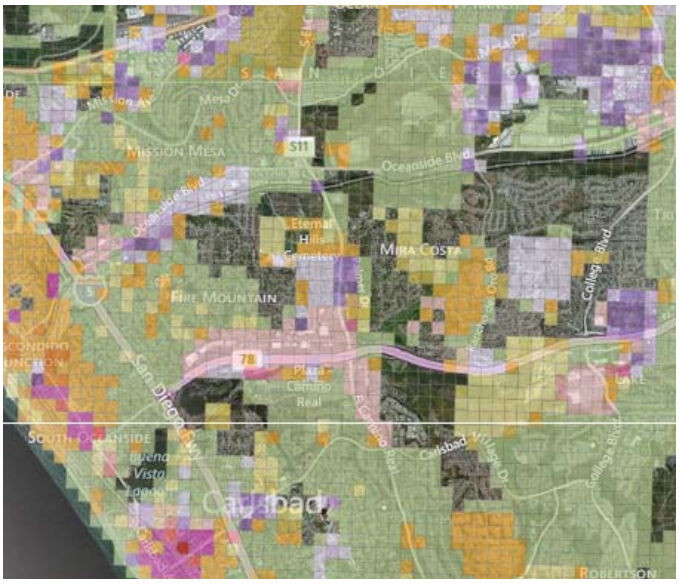
Scenario Painting and Editing

UrbanFootprint's web-based painting tool is integrated into the model's graphical user interface. It allows the user to edit or build upon a translated plan or scenario, or create new scenarios from scratch. The current version (1.0) of the model utilizes the 5.5-acre grid cell as the unit of painting and analysis. The model will soon be updated to work at parcel-level geography as well.

The web-based scenario painter can display and link to regularly updated base maps and data available on the web today (e.g., Google Maps, Mapquest, Bing), in addition to scenario- or project-specific data or imagery. The scenario painter's tools enable quick painting and editing of place types, and dynamic viewing of scenario results.



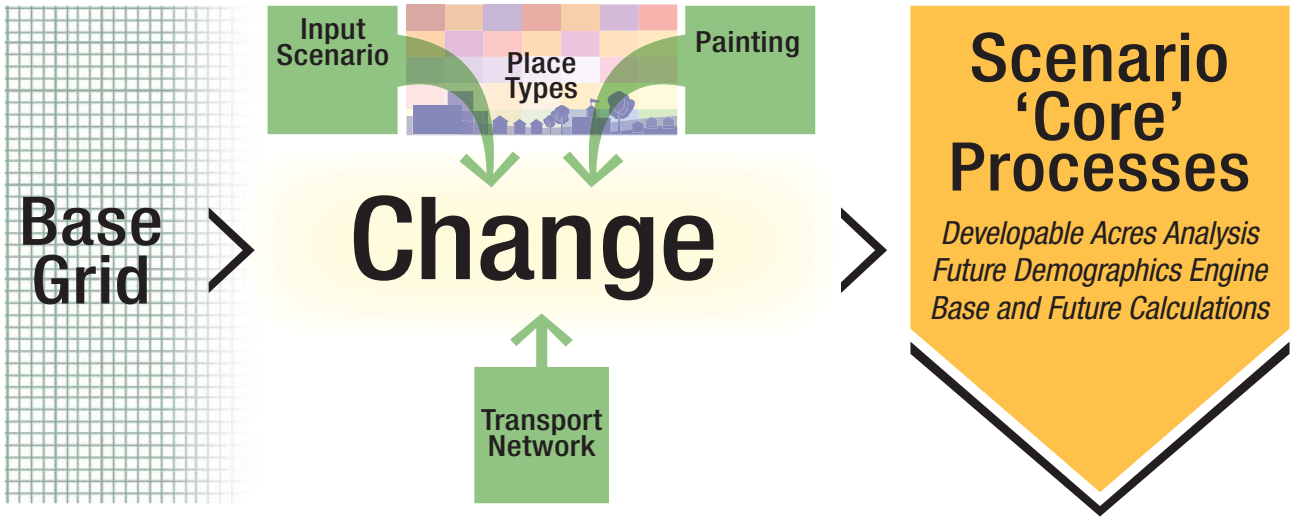
Place types are selected and applied to the landscape via a suite of selection and viewing tools.

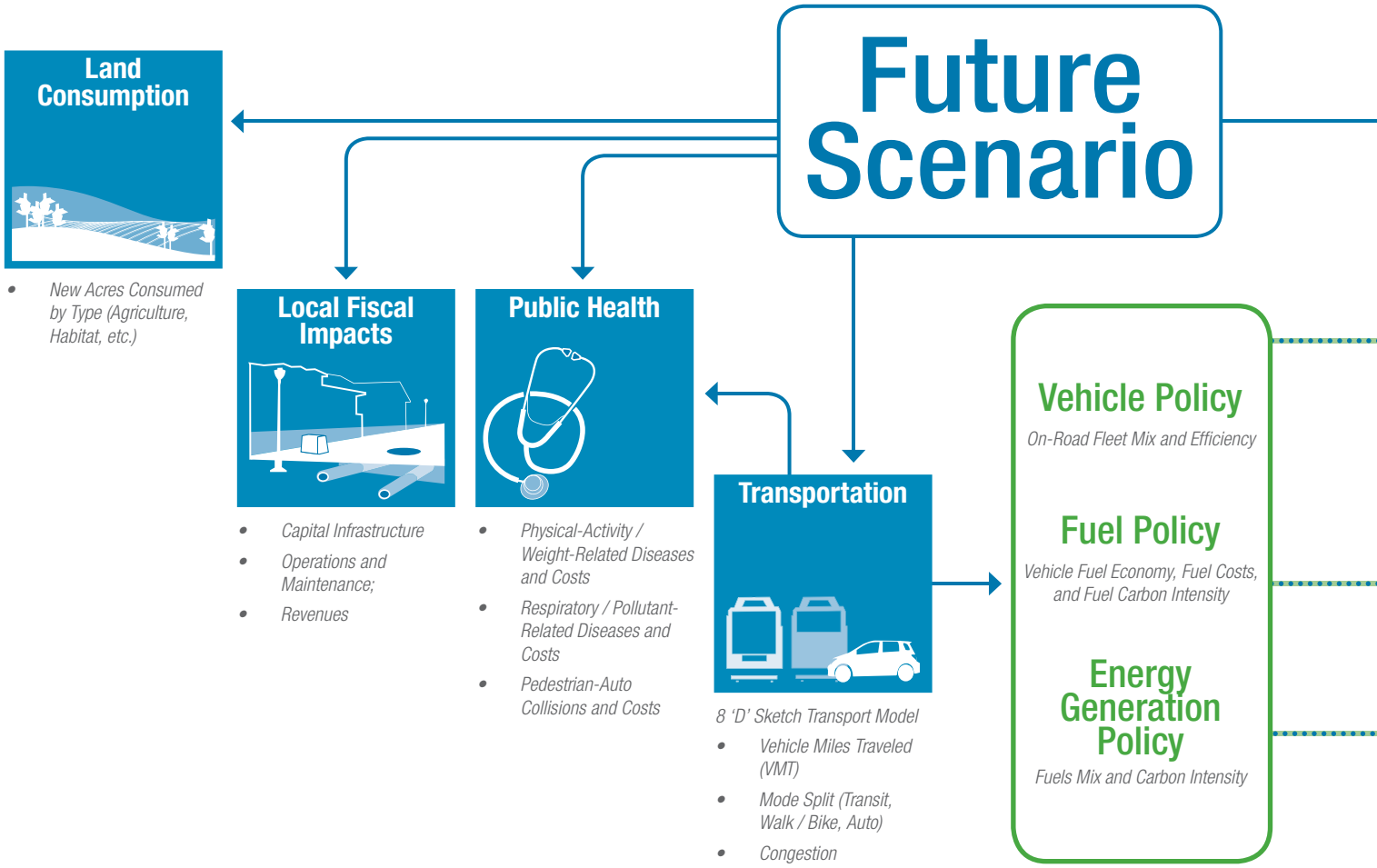


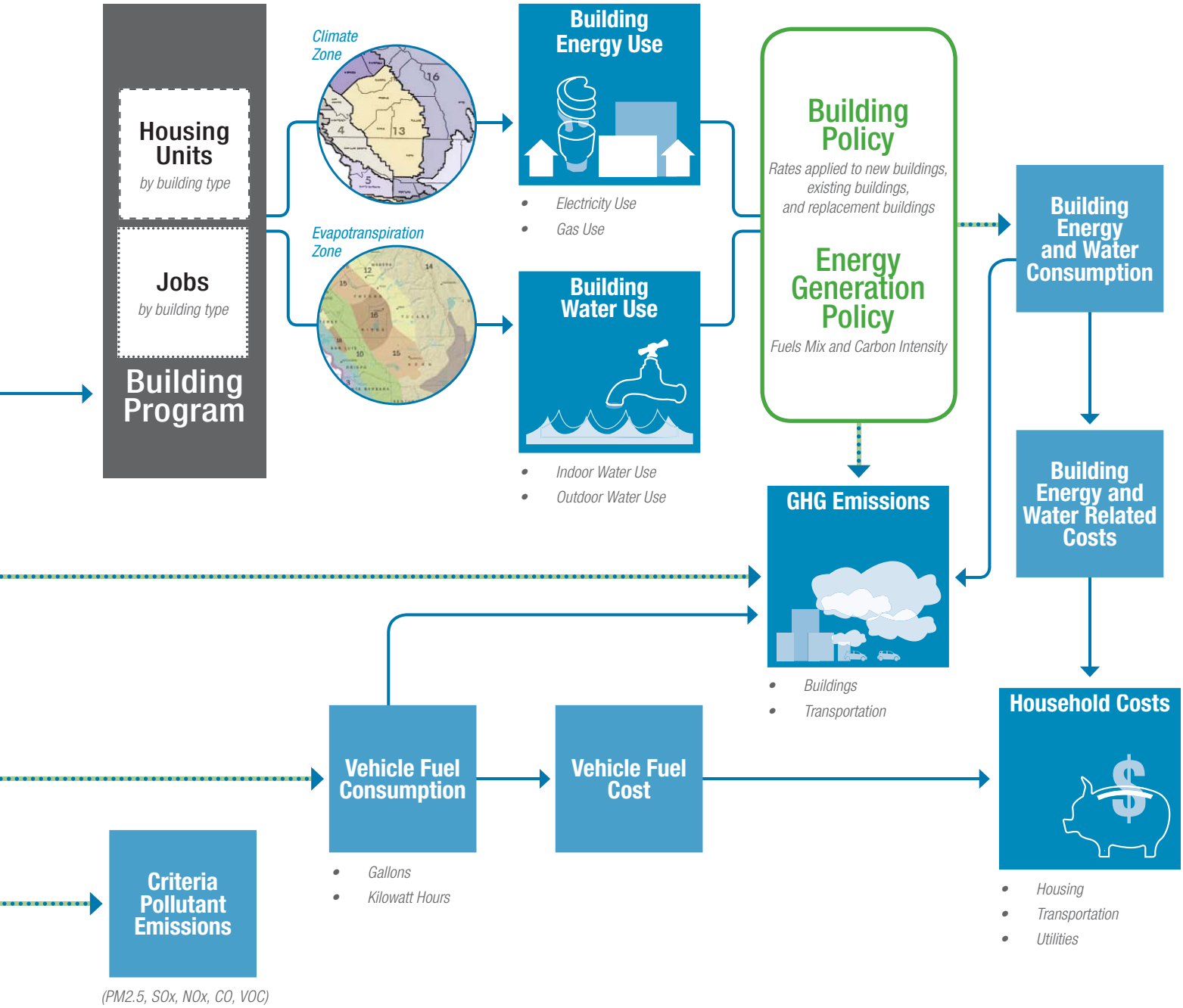
Select scenario results can be viewed iteratively in order to inform the scenario creation process.

Scenario Analysis

As described in the diagram below, UrbanFootprint's scenario development and analytical engines produce a wide range of inter-related metrics that allow for robust, meaningful comparisons of alternative land use + transportation scenarios. A series of scenario 'core' processes work to combine the existing physical and demographic environment with change or growth input via existing plans and/or newly painted scenarios. These scenarios are then run through land use, transportation, fiscal impacts, public health, energy and water, household cost, and emissions engines that produce the range of metrics described below and detailed in the following pages.





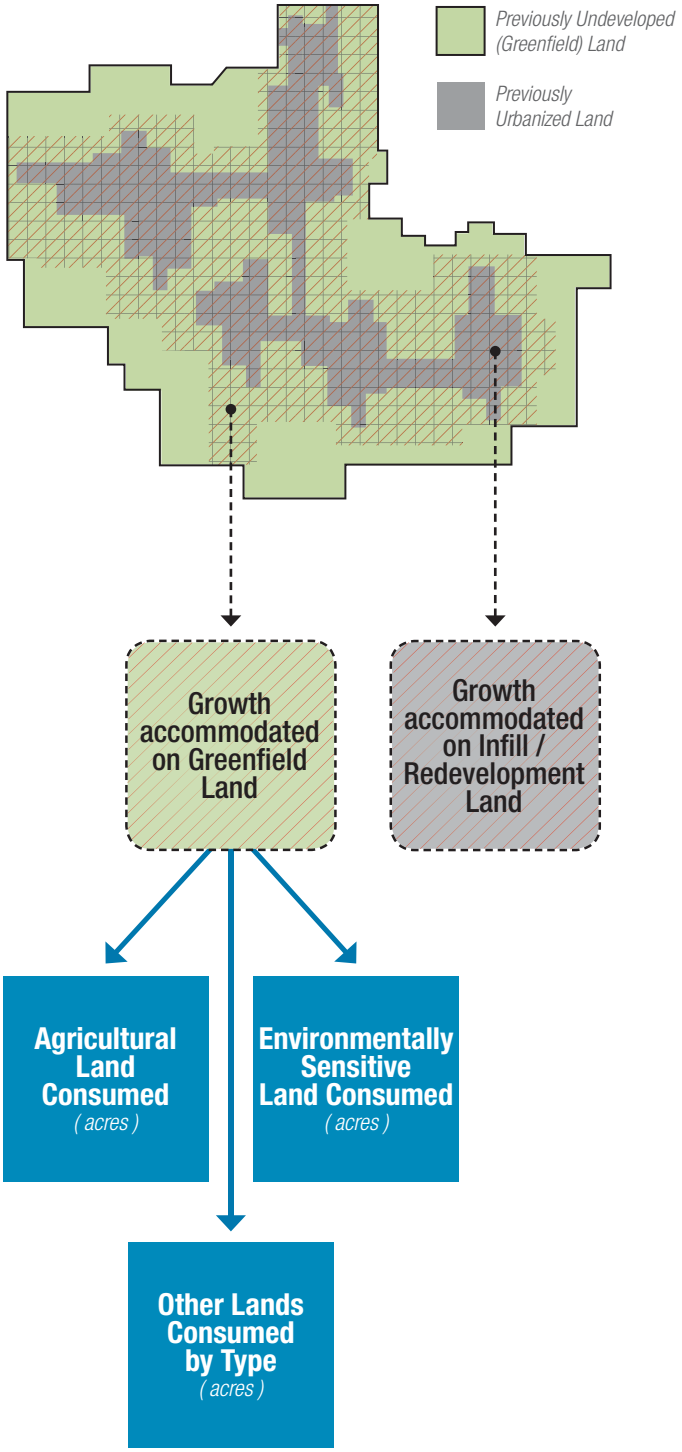

Housing Units
by building type
Jobs
by building type
Building Program
Climate Zone
Evapotranspiration Zone
Building Energy Use
Electricity Use
Gas Use
Building Water Use
Indoor Water Use
Outdoor Water Use
Building Policy
Rates applied to new buildings, existing buildings, and replacement buildings
Energy Generation Policy
Fuels Mix and Carbon Intensity
Building Energy and Water Consumption
Building Energy and Water Related Costs
GHG Emissions
Buildings
Transportation
Household Costs
Housing
Transportation
Utilities
Vehicle Fuel Consumption
Gallons
Kilowatt Hours
Vehicle Fuel Cost
Criteria Pollutant Emissions
(PM2.5, SOx, NOx, CO, VOC)

Land Consumption Analysis

As a spatial model, UrbanFootprint produces fine-grained assessments of how land is developed. In the context of the model, "land consumption" refers to the measurement of land area needed to accommodate new growth. This includes 'greenfield' development on previously undeveloped land, as well as infill and redevelopment in existing urban areas.

Land consumption calculations for future scenarios are built upon an assessment of the base (existing) environment. The base data loading process assigns each grid cell descriptors of its land type conditions – including whether land is developable, redevelopable, or constrained for environmental or other reasons (see page 12 for a more details about constraints in the base loading process). For a future scenario, UrbanFootprint analyzes the greenfield land consumed to accommodate new residential and employment growth, as well as the growth that occurs via reuse or intensification on previously urbanized land (refill development).

Given that the base environmental data includes sufficient detail, UrbanFootprint will report the specific types of land that are consumed to accommodate growth, including types of agricultural lands, habitat lands, aquifers, or other land types. For the Vision California process, using UrbanFootprint version 1.0, the model uses California Farmland Mapping and Monitoring Program (FMMP) and California Protected Areas Database (CPAD) data loaded into the base grid to assess greenfield land consumption, including specific types of prime agricultural land. Additional base data components would allow the model to provide further detail on land consumption. Near term advancements to the model will include assigning cost and carbon implications to the portfolio of land consumption outputs.



Fiscal Impact Analysis

UrbanFootprint calculates three metrics that reflect the fiscal impacts of new residential growth on local jurisdictions: capital infrastructure costs, operations and maintenance (O&M) costs, and revenues. Empirical data from local, regional, state, and utility sources are used to derive the cost and revenue factors, which vary by housing unit type, land development category, and land condition.

One-time capital costs for the following infrastructure elements are included:

- Local streets and transportation
- Water supply
- Sewage and wastewater
- Local parks

Annual operations and maintenance (O&M) costs include the following categories of general fund expenditures:

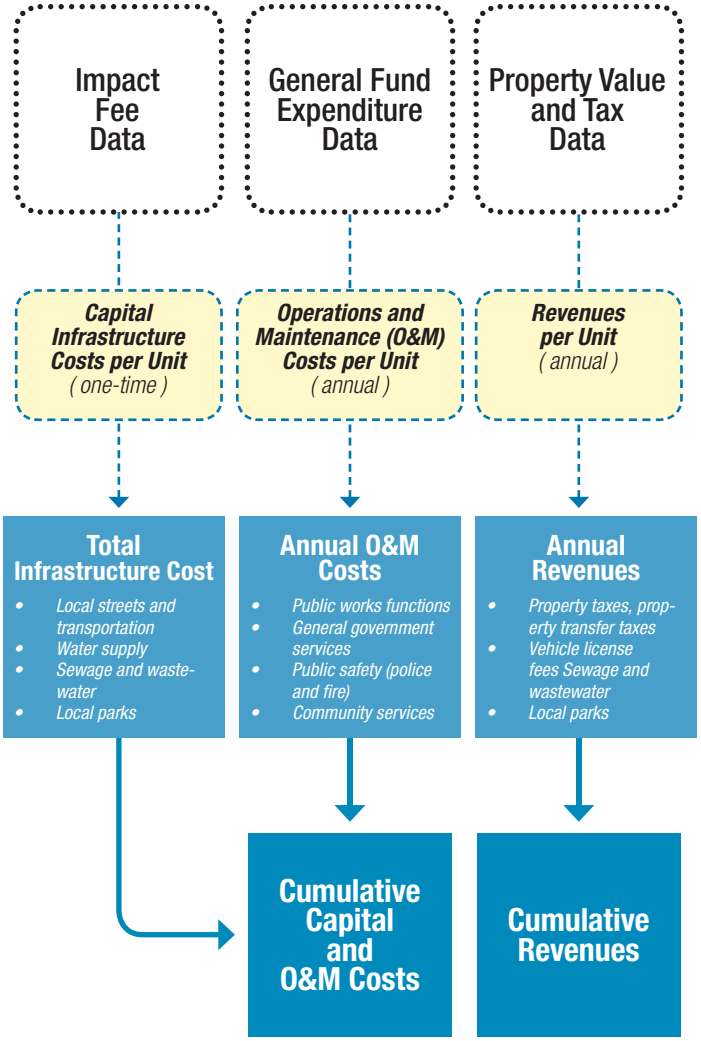
- Public works functions
- General government services
- Public safety (police and fire)
- Community services

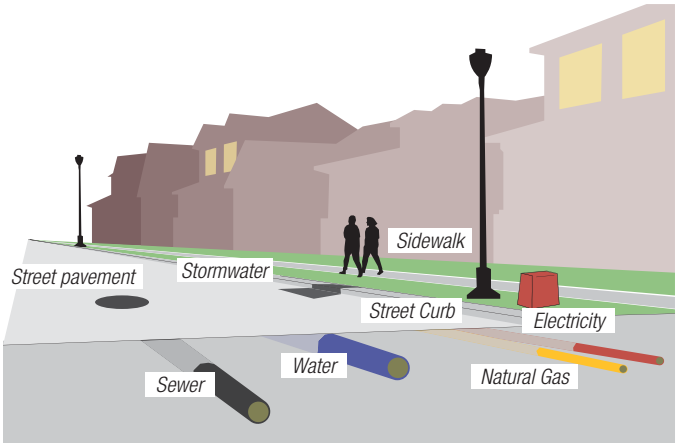
Annual revenues are estimated from the following tax and fee types:

- Property taxes, property transfer taxes
- Vehicle license fees

The per-unit assumptions are applied as factors to counts of new housing units by type. Costs and revenues vary by land condition (greenfield or infill/redevelopment) and general land development category – a classification that categorizes all place types as either urban, compact walkable, or standard suburban. The model's current cost and revenue assumptions are derived from studies of exemplary places throughout California[1], though assumptions can be localized for other study areas. Cost and revenue assumptions at a finer scale, generated through other processes or tools (such as the Sacramento Area Council of Governments's iMPACS infrastructure cost model), can also be integrated. The cost and revenue assumptions are expressed in constant dollars, and are not assumed to change over time.

The current version of the model estimates the impacts of variations in residential development unit types and patterns; future versions will incorporate the fiscal impacts due to commercial development variations, as well as other methods for calculating fiscal impacts (i.e. the SACOG iMPACS model). The chart at right summarizes the process of calculating fiscal impacts.





Building Energy Analysis

UrbanFootprint calculates residential and commercial building energy use, and their related costs and greenhouse gas (GHG) emissions, for both new and existing buildings. Scenarios ultimately vary in their building energy use profiles due to their building program, the location of where new growth occurs, and policy-based assumptions about improvements in energy efficiency.

Calculating Energy Consumption

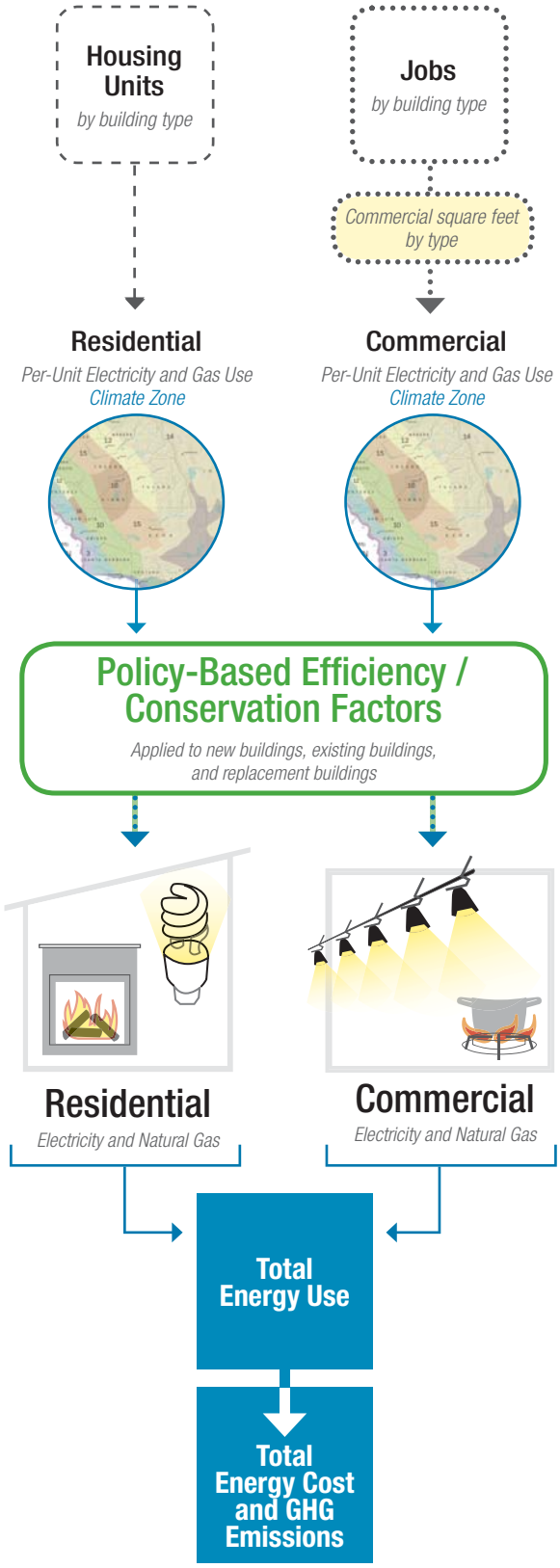
Residential energy use is calculated as a function of three factors: housing type, location by climate zone, and policy-based assumptions about building efficiency. Base-year energy use for housing units varies by building type, with larger home types requiring more energy, and climate zone, which affects heating and cooling needs. Base-year residential energy use factors for California come from California Energy Commission (CEC) Residential Appliance Saturation Survey data[2]. Energy efficiency policy assumptions lead to reductions in energy use in future years. These assumptions vary for new and existing buildings, with new buildings assumed to meet increasingly stringent standards, and existing buildings assumed to be retrofitted or eventually replaced by new buildings. The figure at right summarizes the process of calculating energy use.

Similarly, commercial energy use is calculated using base-year rates and policy-based assumptions about future energy efficiency. Commercial energy intensities (electricity and natural gas use per square foot) vary by building type and climate zone. In California, these rates come from CEC Commercial End-Use Survey data[3]. Efficiency standards are different for new and existing units, with changes assumed to occur gradually over time as buildings age.

All calculations are based on data that resides at the grid-cell level – for instance, building square feet by commercial type. Thus, estimates can be made for user-defined geographies, such as a city within a region.

Calculating Energy Cost and Greenhouse Gas Emissions

The costs and GHG emissions associated with residential and commercial building energy use are calculated by applying retail prices and emissions rates to electricity and natural gas use results. Base-year energy prices and emissions rates are derived from state-level data, while future-year prices and rates are dependent upon policy-based assumptions. If necessary, energy prices and emission rates can be localized to the regional, county, or even local scale.



Water Analysis

UrbanFootprint calculates indoor and outdoor residential and commercial water use, and their related costs and greenhouse gas (GHG) emissions, for both new and existing buildings. Scenarios ultimately vary in their water use profiles due to their building program, as well as policy-based assumptions about conservation and improvements in efficiency. Water use among scenarios varies most according to irrigation needs, or outdoor water use, which relates strongly to urban form and climate.

Calculating Water Consumption

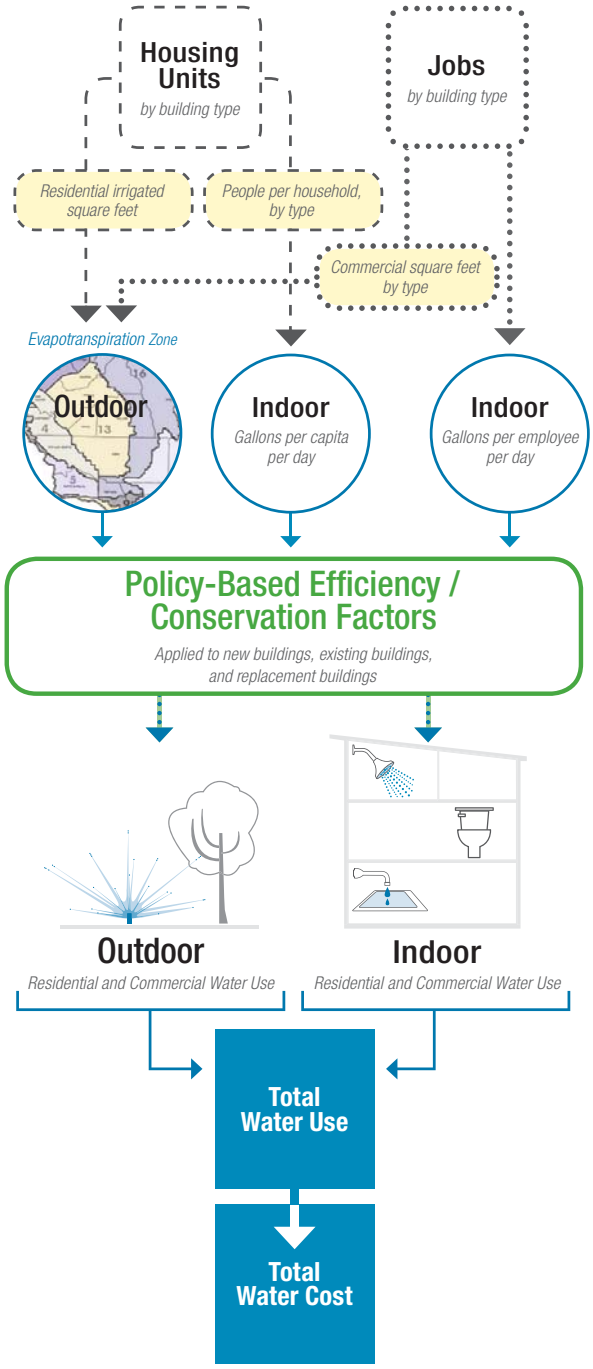
Residential water use is calculated as a function of three basic sets of assumptions: base-year indoor water use per capita, which varies by building type; base-year outdoor water use per household, which varies by building type and location; and policy-based conservation/efficiency assumptions that lead to reductions in water use in future years. Indoor water use factors reflect statewide averages, while outdoor residential water use factors are estimated based on lot size and landscaped area assumptions, and subsequent irrigation needs as determined by evapotranspiration zone[4], a locational designation related to climate. The water efficiency policy assumptions vary for new and existing buildings, with new buildings assumed to meet increasingly stringent standards, and existing buildings assumed to be retrofitted or eventually replaced by new buildings. The figure at right summarizes the process of calculating water use.

Similarly, commercial water use is calculated using base-year rates and policy-based assumptions about future conservation and efficiency policies. Indoor commercial water use is based on per-employee use assumptions, which vary by job category. Outdoor water use is based on landscaped area assumptions, which vary by building type, and irrigation needs as determined by evapotranspiration zone. Efficiency standards are different for new and existing units, with changes assumed to occur gradually over time as standards evolve.

All calculations are based on data that resides at the grid-cell level – for instance, jobs by type. Thus, estimates can be made for user-defined geographies, such as a city within a region.

Calculating Water-Related Costs, Electricity Use, and Greenhouse Gas Emissions

The costs, electricity use, and GHG emissions associated with residential and commercial building water use are calculated by applying retail prices and energy intensities (expressed in kilowatt-hours per acre-foot of water) to water use results. Water-related electricity use refers to the energy required to transport, distribute, and treat water. Water-related GHG emissions are in turn calculated by applying electricity emission rates to the electricity use results. Base-year water prices and energy intensities are derived from state-level data[5,6], while future-year prices are dependent upon policy-based assumptions. Energy intensities associated with delivering and treating water are not assumed to change over time. If necessary, water prices can be localized to the regional, county, or even local scale.



Transportation Analysis

UrbanFootprint incorporates a comprehensive "sketch" travel model that produces vehicle miles traveled (VMT), mode choice, and congestion estimates for land use + transportation scenarios, as well as transportation-related costs, greenhouse gas (GHG) emissions, and pollutant emissions. The travel forecasting capabilities within UrbanFootprint are based on a comprehensive body of research on the relationships between travel generation and the characteristics of the built environment[7].

This and other research has found that urban form, transportation supply, and management policies affect VMT, automobile, and transit travel through at least eight mechanisms, referred to as the "8 Ds":

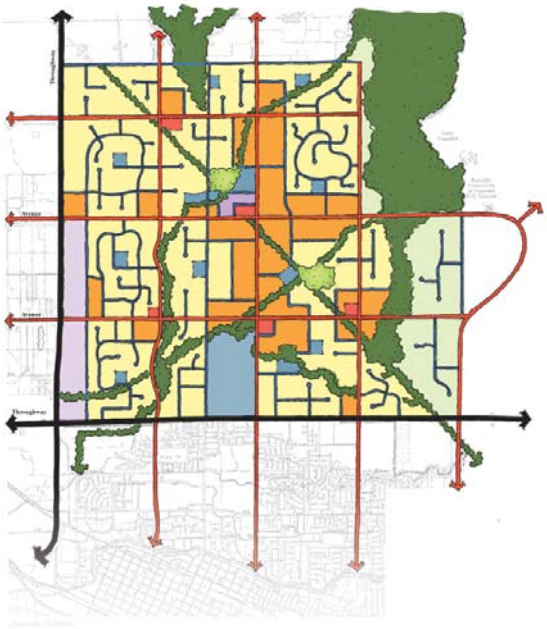
1. Density – residential and employment concentrations
2. Diversity – jobs/housing, jobs mix, retail/housing
3. Design – connectivity, walkability of local streets, and non-motorized circulation
4. Destination – accessibility to regional activities
5. Distance to Transit – proximity to high quality rail or bus service
6. Development Scale – critical mass and magnitude of compatible uses
7. Demographics – household size, income level, and auto ownership
8. Demand Management – pricing and travel disincentives

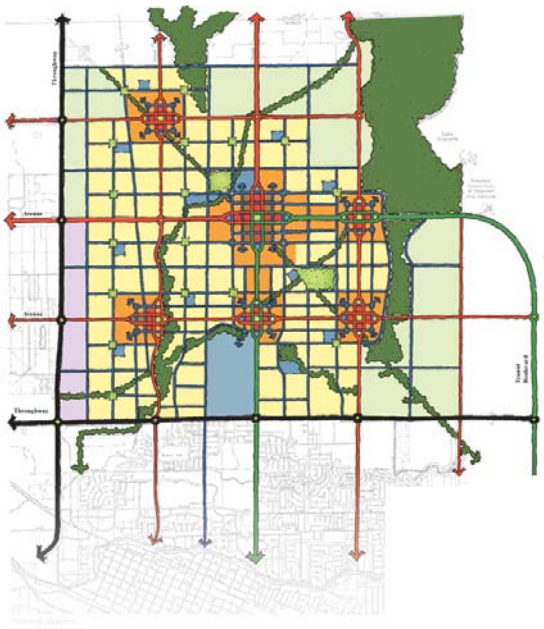
UrbanFootprint quantifies these relationships to the first seven "Ds" through a series of equations from the most recent and rigorous statistical study: *Traffic Generated by Mixed-Use Developments—Six-Region Study Using Consistent Built Environmental Measures*, prepared for the United States Environmental Protection Agency and the American Society of Civil Engineers. The study developed hierarchical models that capture the relationships between the "D" factors and the amount of travel generated by over 230 mixed-use developments in a wide variety of settings and sizes across the US, including developments in the Sacramento and San Diego regions. The predictive accuracy of the methods were validated through field surveys of traffic at almost 30 other development sites including locations in San Diego, Orange County, Sacramento, and the San Francisco Bay Area.

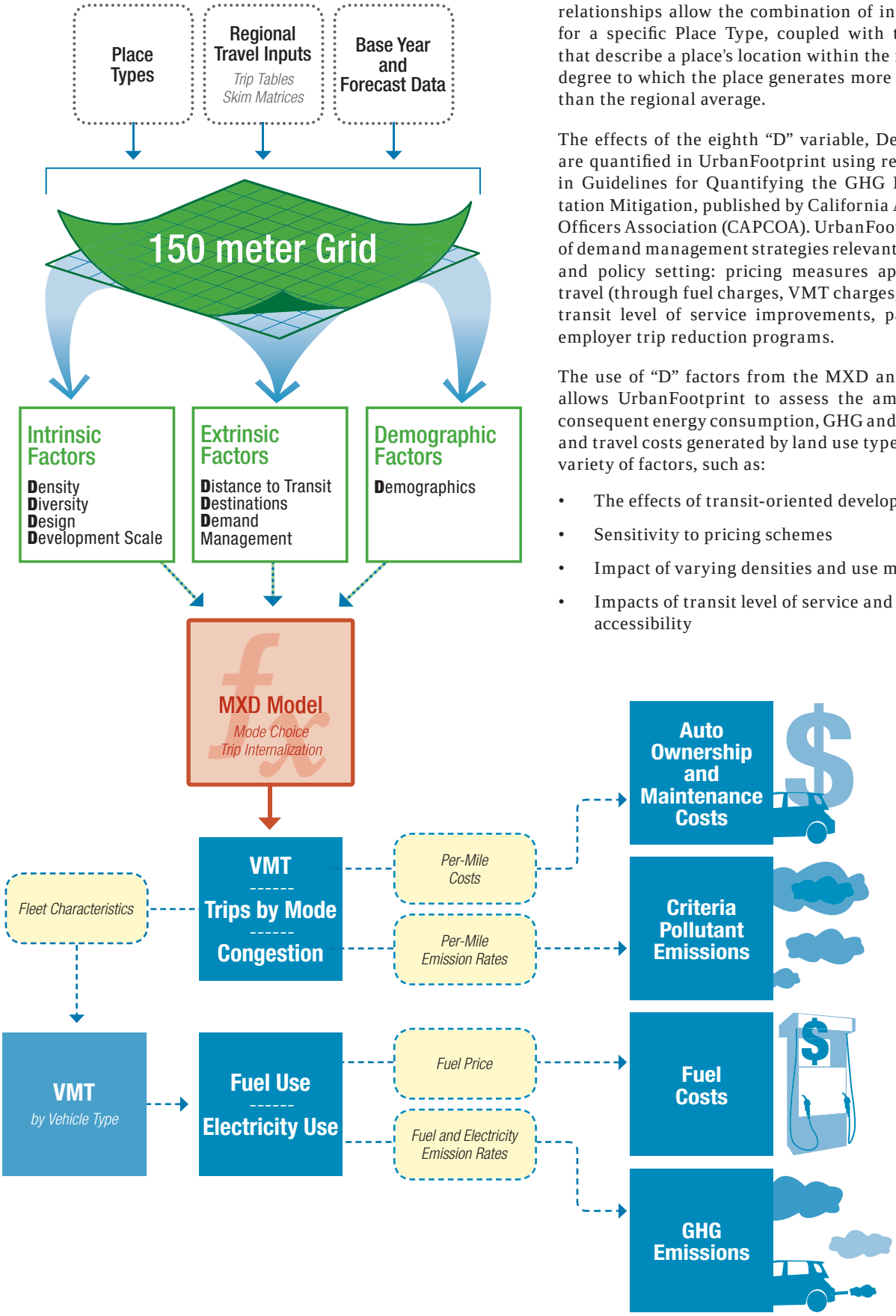
The MXD Method

The resulting method, known as the MXD method, uses a series of equations to estimate the likely degree to which a development area's external traffic generation will be reduced due to: a) trip internalization, b) walking, or c) transit use for off-site travel. The MXD method allows differentiation among a broad array of land use Place Types, the building blocks of UrbanFootprint future scenarios, calculating the vehicle trip reductions resulting from the specific combination of "D" variables that characterize each Place Type. MXD transportation-demand

The diagrams below illustrate the relationship between land use and travel behavior. A more connected configuration of streets, blocks, and land uses (right diagram) exhibits quantifiable reductions in auto trip generation, lowering social costs related to traffic congestion and air quality and increasing community livability, than a conventional suburban configuration of streets, blocks, and land uses (left diagram).







relationships allow the combination of intrinsic "D" variables for a specific Place Type, coupled with the extrinsic factors that describe a place's location within the region, to dictate the degree to which the place generates more or less vehicle travel than the regional average.

The effects of the eighth "D" variable, Demand Management, are quantified in UrbanFootprint using relationships reported in Guidelines for Quantifying the GHG Effects of Transportation Mitigation, published by California Air Pollution Control Officers Association (CAPCOA). UrbanFootprint considers a set of demand management strategies relevant to regional planning and policy setting: pricing measures applied to automobile travel (through fuel charges, VMT charges, or roadway tolling), transit level of service improvements, parking policies, and employer trip reduction programs.

The use of "D" factors from the MXD and CAPCOA research allows UrbanFootprint to assess the amounts of travel and consequent energy consumption, GHG and pollutant emissions, and travel costs generated by land use types and scenarios for a variety of factors, such as:

- The effects of transit-oriented development
- Sensitivity to pricing schemes
- Impact of varying densities and use mixes
- Impacts of transit level of service and regional accessibility

Transportation Analysis

Within UrbanFootprint, each Place Type is described in terms of the eight demand-side "D" variables, based on the combination of the intrinsic characteristics of each Place Type and the location of the place within the regional context. Each geographic grid cell or place location is described in terms of its spatial relationship to all other locations within the study area, expressed in terms of travel time and cost by auto, transit, and non-motorized modes. As a result, every area described by a given Place Type and grid-cell location has vehicle, transit and non-motorized trips, and VMT associated with the Place Type's density, diversity, design, destination accessibility, distance to transit, development scale, demographic, and demand management attributes.

Regional Travel Inputs

In addition to data contained within the Place Type and grid cell description of each region, UrbanFootprint exchanges, with each region's official travel demand model, data on transportation network characteristics, regional accessibility, and travel distances and times among regional activities. These data, obtained from each Metropolitan Planning Organization's (MPO) transportation model, include baseline "trip tables," or matrices of travel origins and destinations for the region's baseline land use, as well as "skim matrices" that capture travel time, distance, and cost among travel origins and destinations for the MPOs' existing or planned transportation infrastructure and services.

These data allow the "8D" MXD and CAPCOA methods contained in UrbanFootprint to assess key factors related to regional accessibility and to translate vehicle trips between locations in the region into travel distance and VMT and, in the case of initial deployment in the Vision California process, to do so consistently with the transportation system plans and modeling methods of California's major MPOs: SACOG, MTC, SCAG, SANDAG, and the eight MPOs of the San Joaquin Valley.

UrbanFootprint also uses the MPO transportation networks to ascertain each region's transportation network supply, including the number of existing and future lane miles of freeway, arterials and local streets. This information, coupled with UrbanFootprint estimates of regional VMT, is used to estimate average regional travel speeds for purposes of refining the estimate of greenhouse gas and other emissions per VMT. These calculations are based on traffic data collected in over 100 regions across the US over the past 20 years by the Texas Transportation Institute (TTI) and the relationships between the TTI regional congestion indices and regional VMT per lane mile, as computed by the Oregon Department of Transportation for its GreenSTEP model.

Travel Model Validation

UrbanFootprint estimates of VMT, vehicle trips, and transit and non-motorized travel were validated, in the Vision California process, through a series of regional and local tests. The regional testing included comparing the UrbanFootprint travel estimates to those produced by the MPOs' state-of-practice regional transportation models, which are themselves validated with respect to traffic count data from Caltrans Highway Performance Monitoring System (H PMS), transit ridership data, and household travel surveys. These comparisons were used to verify UrbanFootprint's ability to replicate currently measured travel conditions in each region and to forecast change for future baseline scenarios in a manner consistent with the calibrated regional travel models developed under California Transportation Commission guidelines[8].

Base-Year Vehicle Miles Traveled (VMT) Validation Chart

Region	Base Year Validation Daily VMT	UrbanFootprint Modeled Base Year Daily VMT
Sacramento Area (6 Counties, SACOG)	50,040,540 (Fehr & Peers, SACOG - SACMET model, 2008 MTP)	53,632,530
San Francisco Bay Area (9 counties, ABAG/MTC)	143,681,890 (Fehr & Peers, MTC - MTC model, 2009 RTP)	143,784,640
Southern California (6 Counties, SCAG)	378,105,370 (Fehr & Peers, SCAG - SCAG model, 2008 RTP)	378,117,580
San Diego (SANDAG)	80,584,670 (Fehr & Peers, SANDAG - SANDAG model, 20011 RTP/SCS)	82,432,940
San Joaquin Valley (8 Counties)	114,532,890 (Fehr & Peers, UC Davis - CSTDM 2009 Model)	111,197,210

UrbanFootprint travel model validation included comparisons of base/existing environment VMT to model outputs in the major regions of California. This chart shows base year daily VMT as reported by the regions, and VMT as modeled by UrbanFootprint.

To assess UrbanFootprint's ability to capture travel variations associated with regional, community, and local scale urban form, the 8D methods used in the model were validated in the following ways:

- *Mapping of VMT Variations* – SACOG produces maps of VMT generation for households in all neighborhoods throughout the greater Sacramento region from its sophisticated, validated activity-based travel model. This mapping of variability of VMT generation by neighborhood, or traffic analysis zone, was compared with neighborhood VMT generation estimates produced by UrbanFootprint for the SACOG region.

- *Community Types* – Data developed by John Holtzclaw for his research on location-efficient mortgages includes measures of annual VMT taken from California Department of Motor Vehicles odometer data on vehicles in households within different communities in the Los Angeles and San Francisco regions[9]. UrbanFootprint estimates of household VMT in the same communities or clusters of communities with similar built environment "D" variables were compared against these data.
- *Place Types* – UrbanFootprint estimates of VMT generation for each of its 35 Place Types were compared to household VMT reported in the National Household Travel Survey or most recent California Statewide Travel Survey for households located in settings comparable to each Place Type description. Recognizing that a given Place Type generates different amounts of VMT depending on its location in the region, a range of VMT generation was expressed for each type, representing the difference in generation rates for the Place Type when located in regionally centric versus remote suburban settings. The range of VMT rates from the household survey were compared with the range of rates estimated by UrbanFootprint.

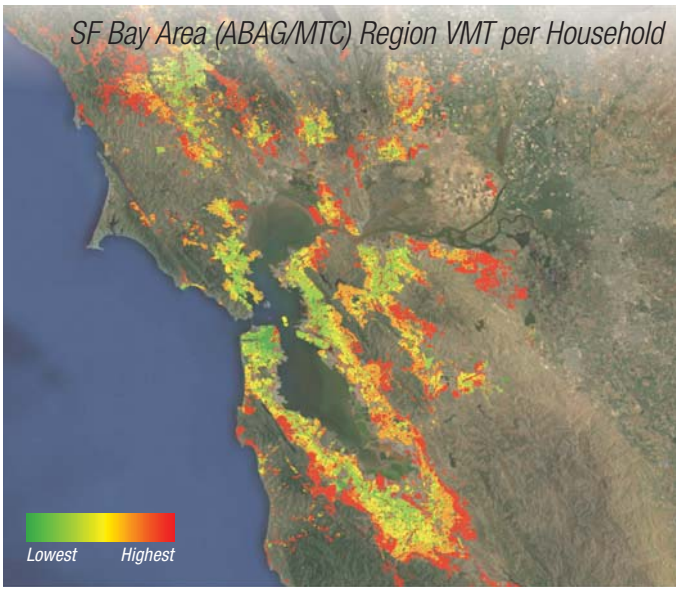
In each of these tests, the variation in trip generation throughout the region estimated by UrbanFootprint as a function of the built environment, as represented by Place Types, compared well with the empirical travel data, demonstrating that the transportation model within UrbanFootprint produces reasonable sensitivity to fine-grained land use variations, in addition to matching well at an aggregate level with regional VMT.

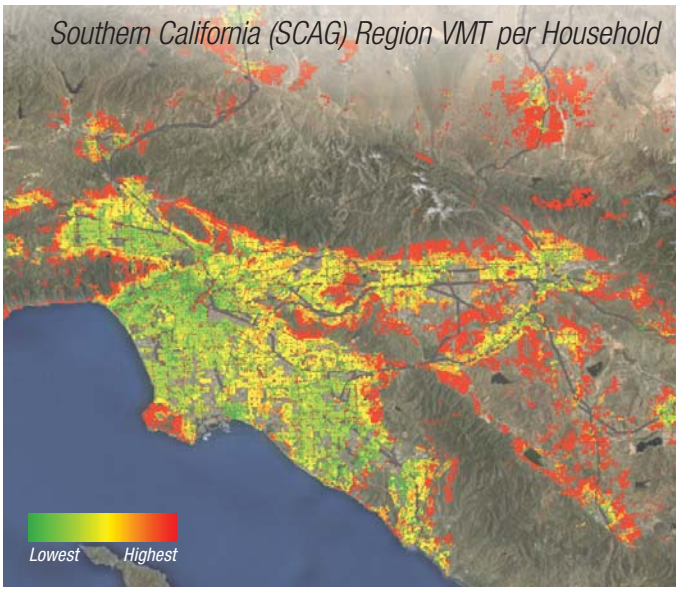
Fuel Use, Emissions, and Costs

UrbanFootprint calculates transportation fuel use, greenhouse gas (GHG) and criteria pollutant emissions, and costs by applying policy-based assumptions to output VMT. Travel model outputs interact with preset or user-defined assumptions for vehicle efficiency, fleet mix, fuel mix, energy generation, and fuel and energy costs.

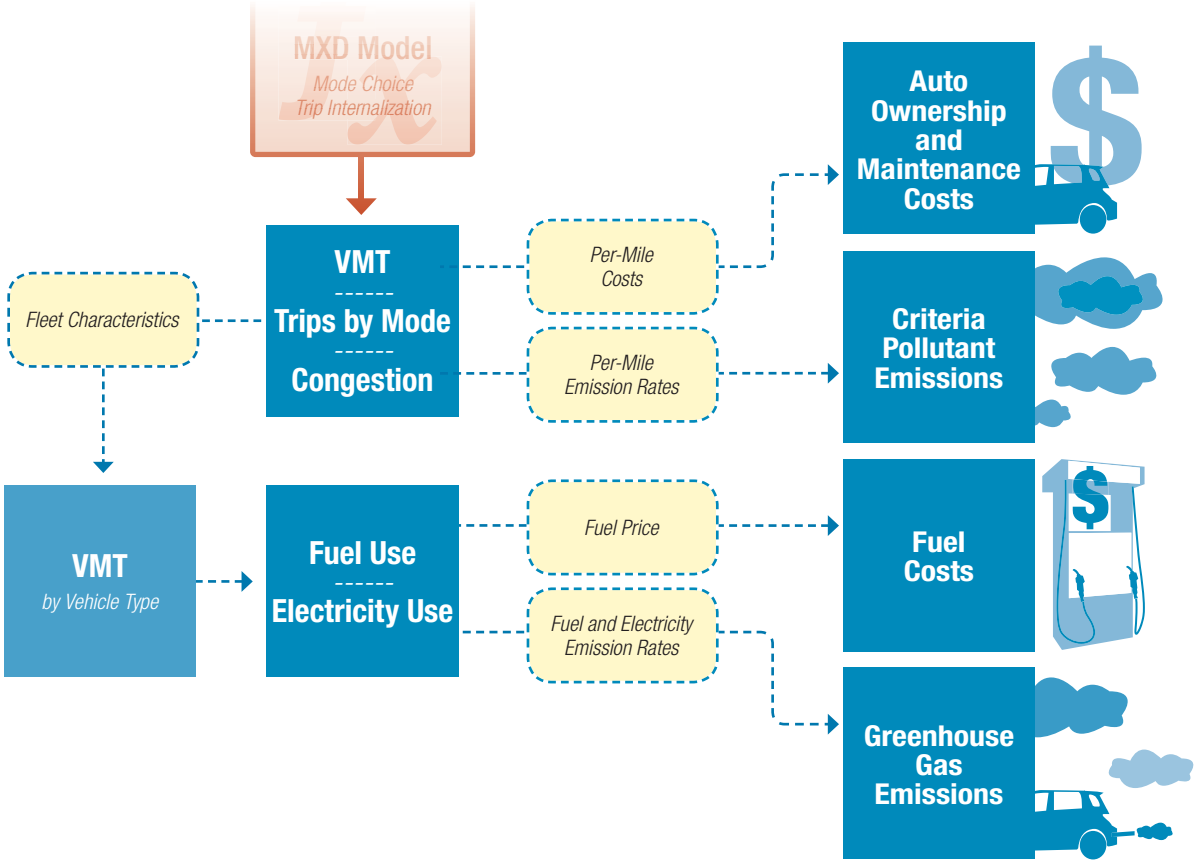
Fuel Use

Passenger vehicle fuel consumption estimates in UrbanFootprint are a function of VMT and assumptions about the mix of vehicle types in the on-road vehicle fleet (fleet mix), the efficiency of those vehicles, and the types of fuels they consume. Vehicle types include gas and diesel internal combustion engine (ICE) vehicles, battery electric vehicles (BEV), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and other zero-emission types (fuel cell, etc). VMT estimates from the travel modeling engine are assigned to the passenger vehicle fleet by type, and efficiency rates are applied to those types to generate liquid fuel and electricity use. Version 1.0 of the model accepts horizon-year efficiency rates by vehicle type, which are created using the fleet-mix model built into Calthorpe Associates' RapidFire[10] model. Near-term advancements to UrbanFootprint will integrate the fleet mix model into UrbanFootprint's user interface. Vehicle efficiency is applied via a miles-per-gallon (mpg) estimate for the liquid fuels component of VMT, and miles per kilowatt hour (m/kWh) for the portion of VMT driven by electricity. This in turn produces liquid fuel (in gallons) and electricity consumption (in kilowatt hours) for a given scenario.





Transportation Analysis



Greenhouse Gas Emissions

Transportation GHG emissions are calculated by applying carbon intensity assumptions, expressed in pounds of carbon dioxide equivalent (CO_2e) per gallon or per kilowatt hour, to fuel consumption. The carbon intensity of liquid fuel is a product of the fuel mix in a given model year, and can be adjusted by the user. The carbon intensity of electricity is derived from user-defined assumptions about the overall power generation mix (which also impacts electricity generated by buildings and other non-transport sectors).

UrbanFootprint was designed to calculate emissions that occur upon fuel combustion ("tank-to-wheel" emissions), as well as those emitted during the full fuel lifecycle, from extraction and processing to transport and storage ("well-to-wheel" emissions). Users can look to either or both; typically, emission inventories compare tank-to-wheel emissions, although full well-to-wheel assessments are critical to developing climate change mitigation strategies. UrbanFootprint has the capacity to calculate both types of emission rates based on fuel mix assumptions, enabling an analysis of the role of fuel carbon intensity standards in meeting GHG reduction goals.

Criteria Pollutant Emissions

Transportation criteria pollutant emissions include Nitrogen Oxides (NO_x), Particulate Matter (PM2.5 and PM10), Sulfur Oxides (SO_x), Carbon Monoxide (CO), and Reactive Organic Gases/Volatile Organic Chemicals (ROG/VOC). To calculate transportation criteria pollutant emissions, UrbanFootprint is loaded with default assumptions that are calculated using the California Air Resources Board's latest Emissions Factors model (EMFAC 2011). EMFAC was run using default assumptions to determine regional-average criteria pollutant emissions for passenger vehicles (light-duty vehicles and motorcycles) for the years 2005, 2010, 2020, and 2035; 2035 rates (the last year for which EMFAC 2011 produces projections) were used for 2050. Emissions factors should be localized for different study areas.

Fuel and Other Driving Costs

UrbanFootprint estimates three components of transportation costs, including fuel, auto ownership, and maintenance. These costs are calculated separately using different assumptions. Fuel costs are calculated by multiplying fuel consumed by fuel price per gallon or per kilowatt hour. Auto ownership and maintenance costs are calculated by multiplying VMT by average price-per-mile factors. All per-gallon and per-mile prices change year upon year according to horizon-year projections.

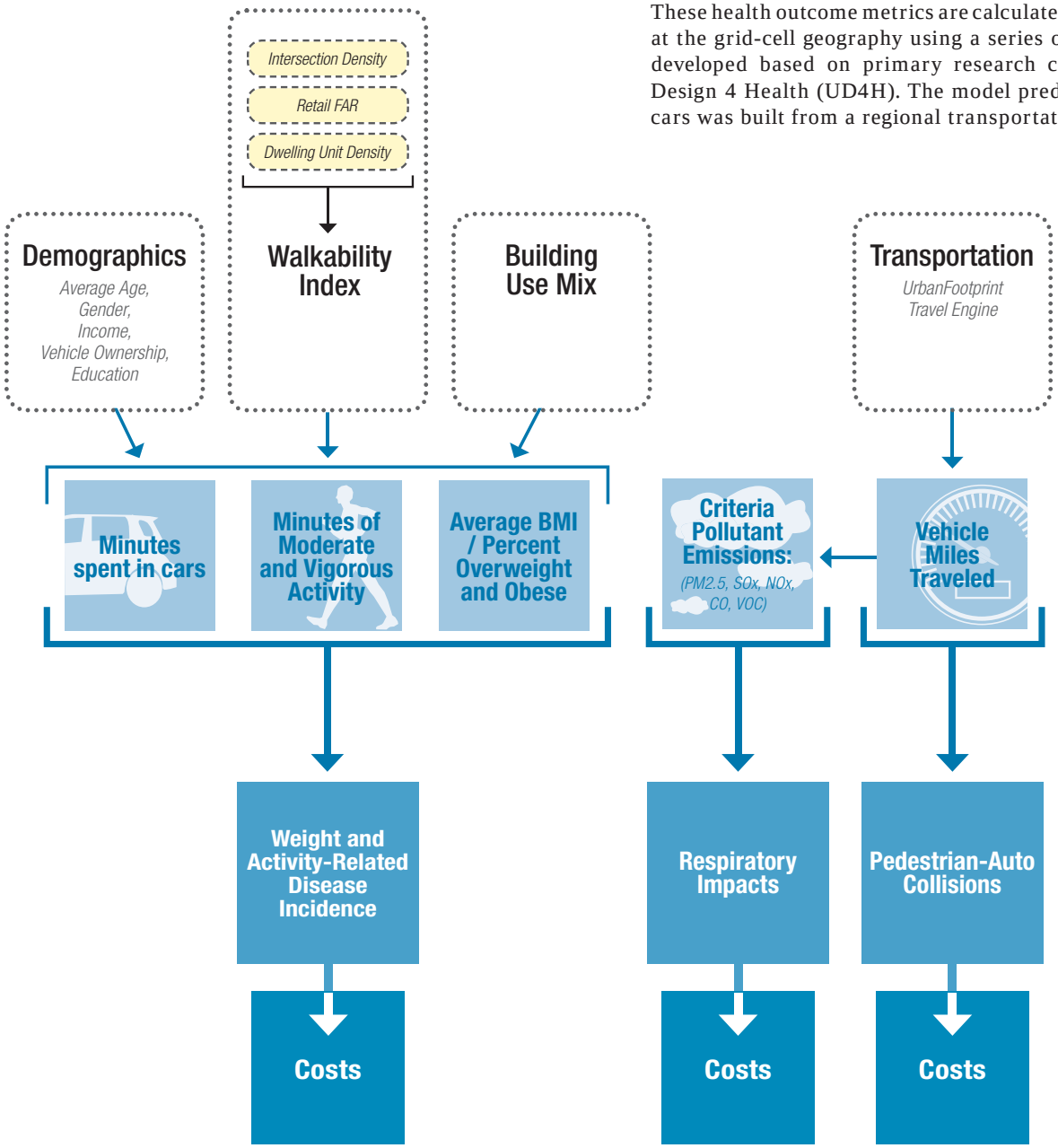
Public Health Analysis

UrbanFootprint measures the impact of land use patterns and urban form on a range of health-related indicators. Public health metrics include physical activity-related weight and disease incidences, pedestrian safety measures, and respiratory impacts. In all cases, costs are applied to health impacts to highlight the fiscal implications of comparative land use + transportation scenarios.

Weight and Activity-Related Metrics

The public health engine models five primary weight and physical activity metrics for the adult population: minutes per day of moderate and vigorous physical activity, daily time spent in cars, the percent of the adult population that is overweight and obese, and average BMI (body mass index). These indicators are all correlated with BMI, though each is estimated independently in UrbanFootprint.

These health outcome metrics are calculated by UrbanFootprint at the grid-cell geography using a series of regression models developed based on primary research conducted by Urban Design 4 Health (UD4H). The model predicting time spent in cars was built from a regional transportation study conducted



Public Health Analysis

as part of the Atlanta Regional Commission's Household Travel Survey[11], and the weight and physical activity models came out of the Neighborhood Quality of Life Study in Seattle and King County, Washington[12]. Where possible, data from California Health Interview Survey (CHIS)[13] and the San Diego Council of Governments (SANDAG)[14] was used to validate the use of the public health models in California.

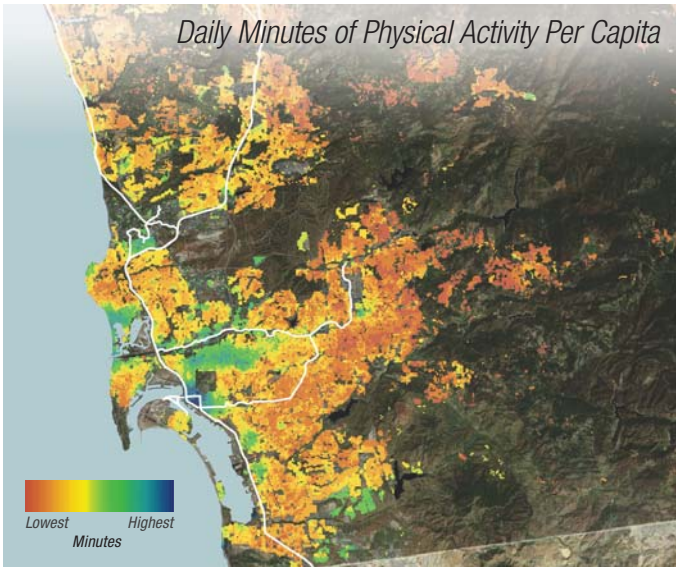
Primary data inputs for these five models include both measures of the built environment (intersection, retail floor area, and dwelling unit densities as well as building use mix) and demographics (gender, age, household income and auto ownership, and level of educational attainment). For public health modeling, future demographic variables were held constant with the base/existing conditions year data, calculated using US Census 2010 rates; this has the effect of isolating the effect of land use on public health.

A series of intermediate variables are calculated at the grid-cell level to allow the weight and activity-related models to run, including:

- *Walkability Index.* Produces a walkability rating via calculations of dwelling unit density, retail floor area ratio, and intersection density - all measured in a one-kilometer grid-cell buffer.
- *Building Use Mix.* Measures the distribution of residential, retail, office, and service sector building square feet within a one-kilometer grid-cell buffer.
- *Dwelling Unit Density.* A measure of housing density within a one-kilometer grid-cell buffer.
- *Network-Based Street Intersection Count and Density.* An estimate of network-based street connectivity within a one kilometer grid-cell buffer.
- *Household Income Categories Ranking Mean.* A weighted count of households in various income groups in each grid cell.
- *Educational Attainment Categories Ranking Mean.* A weighted count of population by educational attainment in each grid cell.

A series of coefficients, unique to each model, was applied to these intermediate variables as a part of a regression analysis to estimate final metrics.

As overweight and obesity rates are associated with numerous co-morbid health conditions, these weight metrics formed the basis for a series of post-process models predicting the adult incidence of type II diabetes, hypertension, coronary artery disease, osteoarthritis, chronic back pain, and colorectal and kidney cancer. Coefficients for these models were adapted from



UrbanFootprint measures physical activity levels based on the urban form and demographic characteristics of scenarios.

a range of published studies and validated and calibrated using CHIS data.

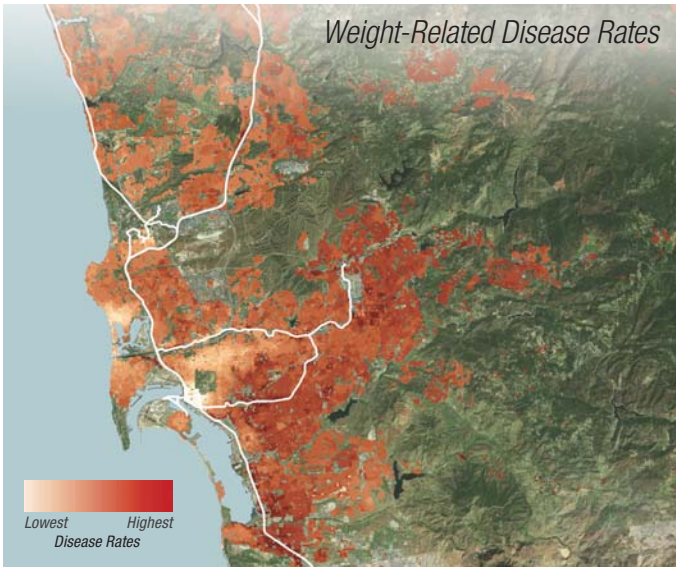
Relationships derived from published studies were used to calculate three classes of per capita fiscal impacts of estimated weight and activity-based health conditions. These costs are expressed in constant dollars, and include:

1. Medical costs: direct capital expenses related to a medical condition, such as doctor and hospital visits, prescription medicine, emergency services, etc.
2. Productivity costs: indirect costs related to lost or reduced work productivity as a result of a medical condition.
3. Quality-adjusted life years (QALYs) lost: an estimate of the economic value of a reduction in quality-of-life years lost as a result of a medical condition.

All public health models produce predictions that enable comparison not only across the range of future scenarios, but between base year and future states.

Pedestrian Safety

UrbanFootprint's estimates of pedestrian-vehicle collisions are informed by data that associates per capita vehicle miles traveled (VMT) and pedestrian-auto collisions[15]. This data demonstrates a strong relationship between changes in per capita VMT and changes in per capita collisions.



UrbanFootprint measures weight-related disease rates based on the urban form and demographic characteristics of scenarios.

UrbanFootprint's public health engine produces future scenario-wide estimates of pedestrian-auto collisions based on a predicted collision rate. A per capita collision rate is calculated by multiplying change in daily per capita VMT over time, as estimated by the UrbanFootprint travel engine, by the 2009 per capita California pedestrian-vehicle collision rate, as documented by California Highway Patrol data[16]. A scenario's collision incidence is calculated by multiplying this rate by future population.

As with weight and activity-related conditions, cost factors for medical costs, productivity costs, and QUALYs lost are applied to pedestrian-vehicle collisions to produce estimates of the fiscal impacts of a scenario's pedestrian-vehicle collisions estimates.

Respiratory Impacts

UrbanFootprint calculates the public health impacts of automobile transportation-related air pollution. The number of health incidences, and their related costs, are calculated on the basis of criteria air pollutant emissions (measured in tons). Note that these metrics express differences among scenarios, rather than measurements of total health incidences or costs.

UrbanFootprint's respiratory health assumptions were initially developed by TIAX LLC for the American Lung Association. Health incidence and valuation assumptions are based on research and national data from the EPA, Office of Air Quality Planning & Standards, Air Benefit and Cost Group[17, 18]. Version 1.0 of the model includes system-wide respiratory impacts. That is, it examines the respiratory impacts and costs associated with changes in overall VMT and pollutant emissions. Model advancements will allow for additional measurements of geographically-specific emissions and their associated health impacts.

Respiratory health incidences include cases of: premature mortality; chronic bronchitis; acute myocardial infarction; respiratory and cardiovascular hospitalizations; respiratory-related ER visits; acute bronchitis; work loss days; asthma exacerbation; and acute, lower, and upper respiratory symptoms. Per-ton assumptions for each of these incidences are individually applied to emissions of the following criteria pollutants: $PM_{2.5}$, SO_x, NO_x, and VOC. The incidences are then totaled.

Respiratory health costs are based on per-ton valuations of emissions of the following pollutants: $PM_{2.5}$, SO_x, NO_x, CO, VOC, and indirect PM from NO_x, SO_x, and VOC. As for health incidences, these valuations are applied to emissions of individual pollutants, and then totaled.

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