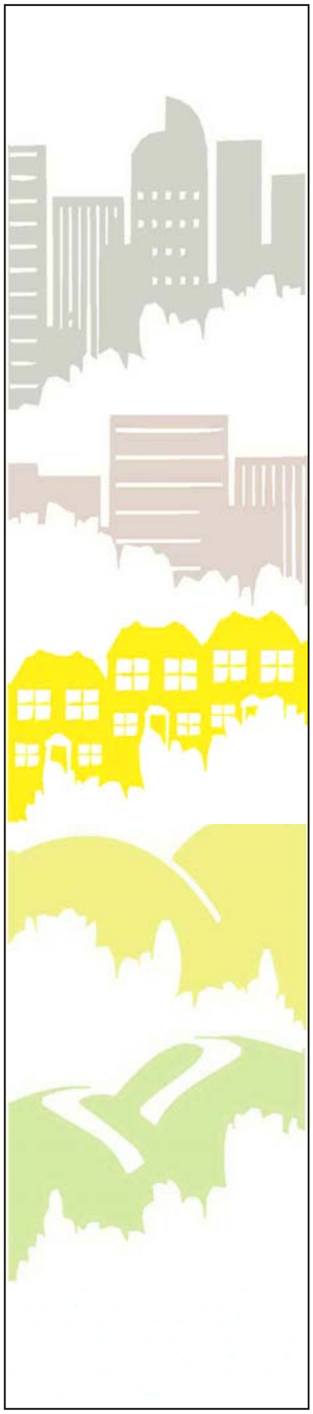

SMART GROWTH INDEX®

A Sketch Tool for Community Planning

Version 2.0

Indicator Dictionary

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Prepared for the

U.S. ENVIRONMENTAL PROTECTION AGENCY

by

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LAND-USE SHAPEFILE EXPLANATORY NOTE

Smart Growth INDEX uses the following land-use polygon shapefiles:

- *Parcel Land-Use – Base Sketches.* These shapefiles are used in base sketches to represent baseline conditions that alternatives can be measured against. Base sketch parcel land-use can either be actual existing land-use in an area, or it can be a baseline concept of proposed uses, e.g. an initial development proposal for a greenfield area.

- *Parcel Land-Use – Alternate Sketches.* These shapefiles are used in alternate sketches to represent uses that are alternatives to base sketch uses. When the base sketch represents actual existing conditions, alternate sketch land-uses often represent alternative planning scenarios that can be compared to existing conditions. In cases where the base sketch represents a baseline development proposal for a greenfield area, alternate sketch uses often represent alternative designs of the development proposal.

- *Planned Land-Use.* The term "planned" is used to distinguish land-use shapefiles that represent designations contained in official plans that govern development in a sketch area. These shapefiles are used by indicators that score sketch consistency with applicable plans. At the user's discretion, these shapefiles may also be used for the base or alternate parcel land-use purposes described above, e.g. planned land-use could be used for base sketch parcel land-use in evaluating an area's current adopted plan; or planned land-use could be used for alternate sketch parcel land-use when the adopted plan is being reevaluated among several alternative plans in comparison to baseline conditions.

Indicator: S100. Population density

Definition and Units: Persons per gross acre including residents and employees; also used in 4D method (see Appendix A).

Formula:

$$\frac{\sum Emps + \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf\,2-4} * ppHH_{mf\,2-4} + \sum DU_{mf\,5+} * ppHH_{mf\,5+} + \sum DU_{GQ} * ppHH_{GQ}}{SketchArea\ Boundary}$$

DU = dwelling units by Dwelling Subscript
$ppHH$ = persons per household by Dwelling Subscript

Dwelling Subscripts:
sf = single family
mh = mobile home
$mf\,2-4$ = multi-family (2-4 units)
$mf\,5+$ = multi-family (5+ units)
GQ = Group Quarters

Shapefiles/Attributes:
Parcel land-use (polygon) / dwelling unit count (integer)
Parcel land-use (polygon) / dwelling unit structure type (string)
Employee (point) / employment count (integer)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters:
Single family persons per household
Mobile home persons per household
Multi-family 2-4 units persons per household
Multi-family 5+ units persons per household
Group quarters persons per household

Indicator: S101. Use mix

Definition and Units: Index of use dissimilarity among one-acre grid cells expressed on a 0-1 scale with 1 being the highest dissimilarity.

Formula:

$$\frac{\sum D_i}{\sum C_i}$$

D_{i} = number of dissimilar cells adjacent to cell i

C_i = number of cells adjacent to cell i

$0 \leq C_i, D_i \leq 8$

Shapefiles/Attributes: Parcel land-use (polygon) / Parcel land-use class (string)

User-Defined Parameters: None.

Scores: Varies by location, e.g. 0.1 in rural areas, up to 0.6 in highly mixed urban areas. This indicator measures use mix in terms of diversity among spatial units of a sketch area, in this case an imaginary grid of 1-acre cells laid over the top of land-uses. In effect, the model determines whether the eight cells adjacent to a subject cell contain different uses than the subject cell; this process is repeated for all cells and summed into a single value for the entire area. Instead of characterizing the absolute amount of different uses in an area, it measures the frequency of encountering different uses when moving across an area. The score can be read as the percentage of time a person would encounter different uses as they walked through an area. For this reason, any score above 0.5 indicates a relatively high-mixed area.

Indicator: S102. Average parcel size

Definition and Units: Avg. size of parcels in sq.ft.

Formula:

$$\frac{\sum A_i}{n}$$

A_i = Area of parcel i
n = number of parcels

Shapefiles/Attributes: Parcel land-use (polygon) / Parcel land-use class (string)

User-Defined Parameters: None.

Scores: This indicator calculates the average size of all parcels in a sketch area regardless of use type or relationship to a study subject. It is intended to generally characterize an area's "grain" of parcelization, building massing, and other urban design contributors to the physical scale of the built environment. To calculate average size for a subgroup of parcels in a sketch area, the user must redraw the Sketch boundary (created in sketch) to coincide with the smaller group of parcels, or make the calculation outside of SGI in ArcView.

Indicator: S103. Developed acres per capita

Definition and Units: Total developed residential and nonresidential net acres divided by total number of residents. Any parcel with one or more dwellings or employees is considered developed, unless it is designated with a land-class defined by the user as non-buildable, e.g. natural resource activity.

Formula:

$$\frac{\sum A_{DEV}}{TotPop}$$

$$TotalPop = \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf\,2-4} * ppHH_{mf\,2-4} + \sum DU_{mf\,5+} * ppHH_{mf\,5+} + \sum DU_{GQ} * ppHH_{GQ}$$

A_{DEV} = total acres of developed residential ($DU \geq 1$) and nonresidential (EmpCount ≥ 1) parcels of existing land use, unless designated as undeveloped.

DU = dwelling units from Existing Land Use
$ppHH$ = persons per household

Subscripts:
sf = single family
mh = mobile home
$mf\,2-4$ = multi-family (2-4 units)
$mf\,5+$ = multi-family (5+ units)
GQ = Group Quarters

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Parcel land-use (polygon) / dwelling unit structure type (string)
Employment (point)

User-Defined Parameters: Single family persons per household
Mobile home persons per household
Multi-family 2-4 units persons per household
Multi-family 5+ units persons per household
Group quarters persons per household

Indicator: S200. Conforming dwelling density

Definition and Units: DU/net acre of residential land. Only developed parcels that conform to the planned land-use are included.

Formula:

$$\frac{\sum DU_{res}}{\sum A_{res}}$$

DU_{res} = dwelling units in parcels that overlay planned residential land - use
A_{res} = area (acres) of pacels that overlay planned residential land - use
where $DU_{res} \geq 1$

Shapefiles/Attributes: Planned land-use (polygon) / land-use class (string)
Parcel land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: None

Scores: The “conforming” nature of this calculation means that it only includes dwellings in residential zones, and does not include “non-conforming” dwellings that have been built in non-residential zones. This indicator is therefore appropriate when the user is evaluating a case against plan and/or zoning standards, e.g. if an area’s planned goal is 10 DU/ac, then how close is it to achieving the goal?

Indicator: S201. Non-conforming dwelling density

Definition and Units: DU/net acre of all land regardless of plan designation.

Formula:

$$\frac{\sum DU_{ALL}}{\sum A_{ALL}}$$

DU_{ALL} = dwelling units in all parcels
A_{ALL} = area (acres) of all parcels where $DU \geq 1$

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: None

Illustrative Scores: The “non-conforming” nature of this calculation means that it includes all residences, including non-conforming dwellings that have been built outside of residential zones. This indicator is appropriate when the user is not concerned about plan or zoning compliance, but instead wants to identify all residential impacts to the transportation system regardless of their plan or zoning status, e.g. a “grandfathered” apartment building will still generate significant numbers of vehicle trips even after its area has been up-zoned.

Indicator: S202. Single-family housing share

Definition and Units: % of dwelling units that are single family.

Formula:

$$\frac{\sum DU_{sf}}{\sum DU}*100 \quad \frac{\sum DU_{mh}}{\sum DU}*100 \quad \frac{\sum DU_{mf\,2-4}}{\sum DU}*100 \quad \frac{\sum DU_{mf\,5+}}{\sum DU}*100 \quad \frac{\sum DU_{GQ}}{\sum DU}*100$$

$DU =$ total dwelling units
$DU_{sf} =$ single family dwelling units
$DU_{mh} =$ mobile home dwelling units
$DU_{mf\,2-4} =$ multi - family (2 - 4 units) dwelling units
$DU_{mf\,5+} =$ multi - family (5 + units) dwelling units
$DU_{GQ} =$ Group Quarters dwelling units

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling type (string)
Parcel land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: None

Indicator:	S203. Mobile home housing share
Definition and Units:	% of dwelling units that are mobile home.
Formula:	See Indicator S202.
Shapefiles/Attributes:	See Indicator S202.
User-Defined Parameters:	None

Indicator: S204. Multi-family 2-4 housing share

Definition and Units: % of dwelling units that are multi-family 2-4 units.

Formula: See Indicator S202.

Shapefiles/Attributes: See Indicator S202.

User-Defined Parameters: None

Indicator:	S205. Multi-family 5+ units housing share
Definition and Units:	% of dwelling units that are multi-family 5 or more units.
Formula:	See Indicator S202.
Shapefiles/Attributes:	See Indicator S202.
User-Defined Parameters:	None

Indicator: S206. Group quarters housing share

Definition and Units: % of dwelling units that are group quarters.

Formula: See Indicator S202.

Shapefiles/Attributes: See Indicator S202.

User-Defined Parameters: None

Indicator: S207. Housing proximity to transit

Definition and Units: Avg. distance from all dwellings to closest transit stop in ft.

Formula:

$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in feet from parcel p to a transit stop

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Transit stops (point)

User-Defined Parameters: None

Indicator: S208. Housing proximity to recreation

Definition and Units: Avg. distance to closest park or school in ft., weighted by number of dwelling units on each parcel.

Formula:

$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in feet from parcel p to parcels designated as parks or schools with $Year \leq SnapshotYear$

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Parks and schools (polygon) / year (4-digit year)

User-Defined Parameters: Snapshot year

Indicator: S209. Housing proximity to education

Definition and Units: Avg. distance to closest school and/or day care in ft., weighted by number of dwelling units on each parcel.

Formula:

$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in miles from parcel p to points designated as schools or day care with $Year \leq SnapshotYear$

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Schools and daycare facilities (point) / year (4-digit year)

User-Defined Parameters: Snapshot year

Indicator: S210. Housing proximity to key amenities

Definition and Units: Avg. distance to closest key service/amenity in ft., weighted by number of dwelling units on each parcel.

Formula:

$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in miles from parcel p to parcels designated as a key service or amenity with $Year \leq SnapshotYear$

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Key amenities (point) / year (4-digit year)

User-Defined Parameters: Snapshot year

Note: Key services and amenities are user-defined, e.g. schools, shopping, etc.

Indicator: S211. Dwellings within 1/8 mi. of 3+ modes

Definition and Units: % of dwellings within 1/8 mi. of three or more modes.

Formula:

$$\frac{\sum DU_{mm}}{\sum DU}$$

DU_{mm} = dwelling units contained in 1/8 mi. buffer of three or more modes with $Year \leq SnapshotYear$

DU = dwelling units

Shapefiles/Attributes:

Parcel land-use (polygon) / dwelling unit count (integer)
Street centerlines (line) / sidewalk presence (integer: 0 = none; 1 = one side of street only; 2 = both sides)
Transit routes (line) / year (4-digit year)
Bike route centerlines (line) / year (4-digit year)

User-Defined Parameters: Snapshot year

Indicator: S212. Housing proximity to employment center

Definition and Units: Average distance to closest employment center in ft., weighted by number of dwelling units on each parcel.

Formula:

$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in miles from parcel p to employment center points

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Employment centers (point)

User-Defined Parameters: None

Indicator: S213. Residential water consumption

Definition and Units: Gallons/day/capita for single-family residential parcels of 15,000 sq.ft. or less, and all other residential types regardless of parcel size.

Formula:

$$\frac{0.85*Grass_{\%}+0.5*GrndCov_{\%}+0.2*Shrub_{\%}}{100}*\frac{\sum A_{pervious}*VFactor*0.623}{365*TotalPop}+HHIWU$$

$Grass_{\%}=$ % Typical Landscaping - Grass

$GrndCov_{\%}=$ % Typical Landscaping - Groundcover

$GrndCov_{\%}=$ % Typical Landscaping - Shrubs and Trees

$APerv_i=$ pervious area on Parcel i

$VFactor=$ V Factor from Water Requirement Region

$HHIWU=$ Household Internal Water Use

$TotalPop=$ From Housing Share Indicators

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters:
Household internal water use
% typical landscaping - grass
% typical landscaping - groundcover
% typical landscaping - shrubs and trees
V factor from water requirement region

Nested Indicators: Housing share indicators (S202-206), which produce *TotalPop* calc.

Illustrative Scores: This indicator calculates water use inside homes for domestic consumption purposes, and outside for landscape irrigation. Guidance for user-defined internal and external water use parameters should be obtained from local water agencies. A recent comprehensive survey of usage rates among North American cities appears in the Handbook of Water Use and Conservation, 2001, WaterPlow Press, Amherst, Massachusetts.

Indicator: S214. Residential energy consumption

Definition and Units: MMBtu/yr/capita for housing and auto travel.

Formula:

$$E_{auto} + E_{du}$$

$$E_{auto} = \frac{VMT_{capita-day}}{MPG_{lightvehicle}} * (0.1154 \text{ MMBtu/gal}) * 365 \text{ days/year}$$

$$E_{du} = \frac{\sum (E_p * D_p)}{TotalPop}$$

$$E_p = \overbrace{\begin{matrix} \overbrace{BaseEnergy}^{p \le 13} \\ \overbrace{BaseEnergy * 0.86}^{\rho > 20} \\ \overbrace{BaseEnergy * (1 - ((2 * \rho - 26)/100))}^{13 < \rho \le 20} \end{matrix}}^{if}$$

$$TotalPop = \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf\,2-4} * ppHH_{mf\,2-4} + \sum DU_{mf\,5+} * ppHH_{mf\,5+} + \sum DU_{GQ} * ppHH_{GQ}$$

D_p = number of dwelling units on parcel p
E_p = density based energy coefficient for parcel p
DU = dwelling unit count by Dwelling Subscript
$ppHH$ = persons per household by Dwelling Subscript

Dwelling Subscripts:
sf = single family
mh = mobile home
$mf\,2-4$ = multi - family (2 - 4 units)
$mf\,5+$ = multi - family (5 + units)
GQ = Group Quarters

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Parcel land-use (polygon) / dwelling unit structure type (string)

User-Defined Parameters: Base building energy usage
Light vehicle miles per gallon

Nested Indicators: VMT (indicators S610, S611)

Indicator: S300. Employment

Definition and Units: Total number of employees.

Formula: $\sum Employees_{sa}$

$Employees_{sa} = \text{Employees inside the sketch boundary}$

Shapefiles/Attributes: Employment (point) / employment count (integer)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters: None

Indicator: S301. Jobs/housed workers balance

Definition and Units: Ratio of total jobs to total housed workers.

Formula:

$$\frac{\sum Employees}{\sum DU_{sf} * wpHH_{sf} + \sum DU_{mh} * wpHH_{mh} + \sum DU_{mf\,2-4} * wpHH_{mf\,2-4} + \sum DU_{mf\,5+} * wpHH_{mf\,5+} + \sum DU_{GQ} * wpHH_{GQ}}$$

DU = dwelling units by Dwelling Subscript
$wpHH$ = workers per household by Dwelling Subscript

Dwelling Subscripts:
sf = single family
mh = mobile home
$mf\,2-4$ = multi-family (2-4 units)
$mf\,5+$ = multi-family (5+ units)
GQ = Group Quarters

Shapefiles/Attributes:
Parcel land-use (polygon) / dwelling unit structure type (string)
Parcel land-use (polygon) / dwelling unit count (integer)
Employment (point) / employee count (integer)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters:
Single family workers per household
Mobile Home workers per household
Multi-family 2-4 units workers per household
Multi-family 5+ units workers per household
Group Quarters workers per household

Indicator: S302. Conforming employment density

Definition and Units: Employees per net acre of employment-designated land. Only developed parcels that conform to the planned land-use are included.

Formula:

$$\frac{\sum Emp_{nonres}}{\sum A_{nonres}}$$

Emp_{nonres} = employees in parcels that overlay planned non-residential land-use
A_{nonres} = area (acres) of pacels that overlay planned non-residential land-use
where $Emp_{nonres} \geq 1$

Shapefiles/Attributes: Planned land-use (polygon) / land-use class (string)
Employment (points) / employee count (integer)

User-Defined Parameters: None

Scores: The "conforming" nature of this calculation means that only businesses inside non-residential zones are included, and business located outside of non-residential zones are excluded. This indicator is appropriate when the user is evaluating a sketches' compliance with applicable plan and/or zoning standards.

Indicator: S303. Non-conforming employment density

Definition and Units: Employees per net acre of all land regardless of plan designation.

Formula:

$$\frac{\sum Emp_{ALL}}{\sum A_{ALL}}$$

Emp_{ALL} = total employees in all parcels
A_{ALL} = area (acres) of all parcels containing emp points with $EmpCount \geq 1$

Shapefiles/Attributes: Employment (points) / employee count (integer)

User-Defined Parameters: None

Scores: The "non-conforming" nature of this calculation means that all businesses are included, including those establishments located outside of non-residential zones. This indicator is appropriate when the user is not concerned with plan or zoning compliance, but rather employment impacts to the transportation system, e.g. a "grandfathered" manufacturing plant will still generate significant vehicle trips even after being changed to a non-manufacturing designation.

Indicator: S304. Employment proximity to transit

Definition and Units: Avg. distance to closest transit stop in ft., weighted by number of employees on each parcel.

Formula:

$$\frac{\sum P_{par} * E_{par}}{\sum E_{par}}$$

P_{par} = shortest network path length in feet from parcel p to a transit stop
E_{par} = number of employees on parcel p

Shapefiles/Attributes: Parcel land-use (polygon)
Employment (points) / employee count (integer)
Transit stops (points)

User-Defined Parameters: None

Indicator: S400. Imperviousness

Definition and Units: Amount of impervious surface in acres per DU.

Formula:

$$\frac{\sum Length_i * Width_i / 43560\,(sf\ /\ acre) + \sum A_p * Coverage_p}{\sum DU}$$

$Length_i$ = Length of street segment i intersecting parcel p
$Width_i$ = StreetWidth of street segment i
A_p = Area of parcel p
$Coverage_p$ = Coverage percent by land - use class for parcel p
DU = DU count

Shapefiles/Attributes: Parcel land-use (polygon) / parcel land-use class (string)
Parcel land-use (polygon) / dwelling unit count (integer)
Street centerlines (line) / street width in ft. (integer)

User-Defined Parameters: Impervious surface coverage % (exclusive of streets) by parcel land-use class

Note: This indicator assumes that % impervious coverage is the same for all parcels sharing the same parcel land-use class, regardless of dwelling unit or employee count which may vary between parcels sharing the same parcel land-use class. Therefore, the user should enter a % imperviousness for each land-use class as a weighted value that reflects study area densities for each land-use class. Table S400 provides guidance on imperviousness values for generic land-use categories; note that these are unweighted values. Also, it is important to note that the % imperviousness value is exclusive of streets in the sketch area; street imperviousness is calculated separately from parcel imperviousness using the street centerline attribute of street width.

Revised 9/10/02

Table S400: Imperviousness Guidance

Land Use Category	Characteristics	Curve Number by Soil Type A	B	C	D
Residential	Average lot 1/8 acre or less, 65% average impervious area	77	85	90	92
	Average lot ¼ acre, 38% average impervious area	61	75	83	87
	Average lot 1/3 acre, 30% average impervious area	57	72	81	86
	Average lot ½ acre, 25% average impervious area	54	70	80	85
	Average lot 1 acre, 20% average impervious area	51	68	79	84
Commercial and business areas	85% impervious	81	88	91	93
Mixture of above land uses	85% impervious	89	92	94	95
Industrial districts	72% impervious	81	88	91	93

Source: EPA/GKY

Indicator:	S401. Stormwater runoff
Definition and Units:	Total cubic ft/yr of stormwater runoff from sketch area.
Formula:	Contained in separate documentation for EPA SGWATER software.
Shapefiles/Attributes:	Soil (polygon) / NRCS hydrologic group type (string: A, B, C, or D) Parcel land-use (polygon) / land-use class (string) Street centerlines (line) / street width in ft. (integer)
User-Defined Parameters:	Annual precipitation file Rainfall.csv Imperviousness coverage % by parcel land-use class (excluding streets)
Notes:	Rainfall.CSV file must be a comma-separated text file containing only 2 fields/row: Date, Rainfall (in inches). Rainfall.CSV must contain at least one row for every day of the year (365 rows). A minimum of 10 years of data should be provided.

Indicator: S402. Total suspended solids

Definition and Units: Kg/yr contained in stormwater.

Formula: Contained in separate documentation for EPA SGWATER software.

Shapefiles/Attributes: Soil (polygon) / NRCS hydrologic group type (string: A, B, C, or D)
Parcel land-use (polygon) / land-use class (string)
Street centerlines (line) / street width in ft. (integer)
Stormwater best mgmt. practice (polygon for each BMP type and location set)/percent TSS removal (integer)

User-Defined Parameters: Annual precipitation file Rainfall.csv
Imperviousness coverage % by parcel land-use class (excluding streets)
EMC pollutant runoff: TSS (mg/L) by parcel land-use class

Note: A stormwater best management practice is a user-defined mechanism that reduces non-point source pollutant runoff from a site, e.g. grass swales, porous pavement, constructed wetlands. For each type of BMP, the user characterizes its spatial extent using a polygon shapefile, and its pollutant removal efficiency expressed as percent of pollutant removed by the BMP. The following table provides guidance on common types of BMPs and their removal efficiencies.

BMP Type	Total Suspended Solids	Total Phosphorus	
Wet Ponds	90	65	48
Extended Detention Ponds	80	45	35
Grassed Swales	70	30	25
Filter Strips	70	40	30
Infiltration Trenches	85	65	60
Infiltration Basins	85	65	60
Sand Filters	80	60	40
Constructed Wetlands	90	65	48
Water Quality Inlets	30	5	5
Porous Pavement	90	65	85

Source: EPA/GKY

Indicator: S403. Phosphorus

Definition and Units: Kg/yr contained in stormwater.

Formula: Contained in separate documentation for EPA SGWATER software.

Shapefiles/Attributes:
Soil (polygon) / NRCS hydrologic group type (string: A, B, C, or D)
Parcel land-use (polygon) / land-use class (string)
Street centerlines (line) / street width in ft. (integer)
Stormwater best mgmt. practice (polygon for each BMP type and location set)/percent phosphorus removal (integer)

User-Defined Parameters:
Annual precipitation file Rainfall.csv
Imperviousness coverage % by parcel land-use class (excluding streets)
EMC pollutant runoff: phosphate (mg/L) by parcel land-use class

Note: A stormwater best management practice is a user-defined mechanism that reduces non-point source pollutant runoff from a site, e.g. grass swales, porous pavement, constructed wetlands. For each type of BMP, the user characterizes its spatial extent using a polygon shapefile, and its pollutant removal efficiency expressed as percent of pollutant removed by the BMP. The following table provides guidance on common types of BMPs and their removal efficiencies.

BMP Type	**Total Suspended Solids**	**Total Phosphorus**	
Wet Ponds	90	65	48
Extended Detention Ponds	80	45	35
Grassed Swales	70	30	25
Filter Strips	70	40	30
Infiltration Trenches	85	65	60
Infiltration Basins	85	65	60
Sand Filters	80	60	40
Constructed Wetlands	90	65	48
Water Quality Inlets	30	5	5
Porous Pavement	90	65	85

Source: EPA/GKY

Indicator: S404. Nitrogen

Definition and Units: Kg/yr contained in stormwater.

Formula: Contained in separate documentation for EPA SGWATER software.

Shapefiles/Attributes: Soil (polygon) / NRCS hydrologic group type (string: A, B, C, or D)
Parcel land-use (polygon) / land-use class (string)
Street centerlines (line) / street width in ft. (integer)
Stormwater best mgmt. practice (polygon for each BMP type and location set)/percent nitrogen removal (integer)

User-Defined Parameters: Annual precipitation file Rainfall.csv
Imperviousness coverage % by parcel land-use class (excluding streets)
EMC pollutant runoff: phosphate (mg/L) by parcel land-use class

Note: A stormwater best management practice is a user-defined mechanism that reduces non-point source pollutant runoff from a site, e.g. grass swales, porous pavement, constructed wetlands. For each type of BMP, the user characterizes its spatial extent using a polygon shapefile, and its pollutant removal efficiency expressed as percent of conventional practice pollutant loading removed by the BMP. The following table provides guidance on common types of BMPs and their removal efficiencies.

BMP Type	**Total Suspended Solids**	**Total Phosphorus**	
Wet Ponds	90	65	48
Extended Detention Ponds	80	45	35
Grassed Swales	70	30	25
Filter Strips	70	40	30
Infiltration Trenches	85	65	60
Infiltration Basins	85	65	60
Sand Filters	80	60	40
Constructed Wetlands	90	65	48
Water Quality Inlets	30	5	5
Porous Pavement	90	65	85

Source: EPA/GKY

Indicator: S407. Open space

Definition and Units: % of total study area land dedicated to open space.

Formula:

$$\frac{\sum Area_{Open}}{\sum Area_{All}}$$

$Area_{Open}$ = area of Parcels designated Open Space

$Area_{All}$ = area of all Parcels

Shapefiles/Attributes: Parcel land-use (polygon) / parcel land-use class (string)

User-Defined Parameters: None

Indicator: S408. Park space availability

Definition and Units: Acres of park space per 1,000 persons.

Formula:

$$\frac{\sum A_{park}}{(TotPop/1000)}$$

$$TotalPop = \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf\,2-4} * ppHH_{mf\,2-4} + \sum DU_{mf\,5+} * ppHH_{mf\,5+} + \sum DU_{GQ} * ppHH_{GQ}$$

A_{park} = total acres of parkland or schoolyards with $Year \le SnapshotYear$

DU = dwelling units by dwelling subscript

$ppHH$ = persons per household by dwelling subscript

Dwelling Subscripts:

sf = single family

mh = mobile home

$mf\,2-4$ = multi-family (2-4 units)

$mf\,5+$ = multi-family (5+ units)

GQ = Group Quarters

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit count (integer)
Parks and schools (polygon) / year (4-digit year)

User-Defined Parameters: Persons per household: single family, mobile home, multi-family (2-4 units), multi-family (5+ units), group quarters

Indicator: S500. Residential wastewater production

Definition and Units: Total gallons/day.

Formula:

$$\sum DU_{sf} * wppHH_{sf} + \sum DU_{mh} * wppHH_{mh} + \sum DU_{mf\,2-4} * wppHH_{mf\,2-4} + \sum DU_{mf\,5+} * wppHH_{mf\,5+} + \sum DU_{GQ} * wppHH_{GQ}$$

DU = dwelling units by dwelling subscript
$wppHH$ = wastewater production per household by dwelling subscript

Dwelling Subscripts:
sf = single family
mh = mobile home
$mf\,2-4$ = multi-family (2-4 units)
$mf\,5+$ = multi-family (5+ units)
GQ = Group Quarters

Shapefiles/Attributes: Parcel land-use (polygon) / dwelling unit structure type (string)
Parcel land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: Single family wastewater production (gals/day/DU)
Mobile home wastewater production (gals/day/DU)
Multi-family 2-4 units wastewater production (gals/day/DU)
Multi-family 5+ units wastewater production (gals/day/DU)
Group quarters wastewater production (gals/day/DU)

Indicator: S501. Nonresidential wastewater production

Definition and Units: Total gallons/day.

Formula: $\sum Employees * wppWORKER$

$Employees$ = total number of employment points in study area
$wppWORKER$ = wastewater production per employee

Shapefiles/Attributes: Employment (point)

User-Defined Parameters: Employee wastewater production (gals/day/employee)

Indicator: S502. Street centerline distance

Definition and Units: Total street centerline distance in ft.

Formula: $\sum L_s$

s = the length in feet of the part of the street centerline segment s that is inside the sketch area.

Shapefiles/Attributes: Street centerline (line)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters: None

Note: This indicator can be used to roughly estimate street, sewer, and water construction costs for new development by multiplying the indicator score by local cost/ft. multipliers for each type of infrastructure.

Indicator: S600. Sidewalk completeness

Definition and Units: Ratio of total sidewalk centerline distance vs. total street centerline distance; also used in 4D method (see Appendix A).

Formula:

$$\frac{\sum SW_s}{\sum CL_s * 2}$$

CL_s = length of street centerline segment s
SW_s = sidewalk count for street centerline segment s

Shapefiles/Attributes: Street centerline (line) / sidewalk presence (integer: 0 = none; 1 = one side of street only; 2 = both sides)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters: None

Indicator: S601. Pedestrian route directness

Definition and Units: Average ratio of walking distances from random sample origin points to central node versus straight line distances between same points; also used in 4D method (see Appendix A). Calculated for a one-half mile straight line radius of central node.

Formula:

$$\frac{\sum \frac{Network_{p-cn}}{Straightline_{p-cn}}}{n}$$

$Network_{p\text{-}cn}$ = nework distance from parcel p to the closest central node
$Straightline_{p\text{-}cn}$ = straightline distance from parcel p to the closest central node
n = number of parcels with 1/2 mile of a central node (straightline distance)

Shapefiles/Attributes: Parcel land-use (polygon)
Street centerlines (line)
Central nodes (point) (created by user in sketch)

User-Defined Parameters: None

Scores: Areas with favorable route directness will score 1.5 or less; unfavorable areas will score higher than 1.5.

Note: Measurement is only for one-half mile straight line radius from central node.

Indicator:	S602. Street network density
Definition and Units:	Street centerline mi./sq.mi.; also used in 4D method (see Appendix A).
Formula:	$\frac{\sum StCL}{A}$ $StCL$ = length, street centerlines A = area, sketch boundary
Shapefiles/Attributes:	Street centerline (line) Sketch boundary (polygon) (created in sketch)
User-Defined Parameters:	None
Scores:	Varies by location in county, e.g. 2.0 in rural areas, 20.0 in urban areas.

Indicator: S603. Street connectivity

Definition and Units: Ratio of intersections vs. intersections and cul-de-sacs expressed on a 0-1 scale with greatest connectivity at 1.

Formula:

$$\frac{\sum I}{\sum (I + C)}$$

I = studyarea intersections
C = study area cul-du-sacs

Shapefiles/Attributes: Street centerline (line)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters: None

Scores: Favorable areas will score 0.75 or higher.

Indicator: S605. Bicycle network

Definition and Units: % of total street centerline distance with designated bike route.

Formula:

$$\frac{\sum BR_s}{\sum CL_s}$$

CL_s = length of street centerline segment s
BR_s = length of bike route centerline segment s

Shapefiles/Attributes: Street centerline (line)
Bike route centerline (line) / year (4-digit year)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters: None

Indicator: S606. Transit stop coverage

Definition and Units: Transit stops per sq.mi.

Formula:

$$\frac{\sum Stop_i}{A}$$

$Stop_i$ = stop i
A = area, sketch boundary

Shapefiles/Attributes: Transit stops (point)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters: None

Note: The transit stop shapefile should include bus and rail stops.

Indicator: S607. Regional accessibility

Definition and Units: Mean travel time from study area centroid to all other regional destinations (TAZs) weighted by mode shares; used only in the 4D method (see Appendix A).

Formula: Uses local travel demand model-calculated value.

Shapefiles/Attributes: N/A

User-Defined Parameters: Accessibility value is entered by user based on separate local travel demand model calculation for a given study area.

Note: This indicator should be used when a local travel demand model is available, with sketches include transportation feature changes that would impact accessibility, e.g. new street construction, expanded transit service.

Indicator: S608. Home-based vehicle trips

Definition and Units: HB VT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VT = VT_{input\ parameter}$

Alternate case sketch:

$$VT_{base} * (1 + \Delta VT)$$
$$\Delta VT = (-0.043 * \Delta Den) + (-0.051 * \Delta Div) + (-0.031 * \Delta Des) + (-0.036 * \Delta Dest)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$
$$\Delta Dest = \frac{(Accessibility_{altcase} - Accessibility_{basecase})}{Accessibility_{basecase}}$$

Shapefiles/Attributes: N/A

Nested Indicators: Population density
Street network density
Sidewalk completeness
Pedestrian route directness

Indicator: S609. Non home-based vehicle trips

Definition and Units: NHB VT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VT = VT_{input\ parameter}$

Alternate case sketch:

$$VT_{base} * (1 + \Delta VT)$$
$$\Delta VT = (-0.043 * \Delta Den) + (-0.051 * \Delta Div) + (-0.031 * \Delta Des) + (-0.036 * \Delta Dest)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$
$$\Delta Dest = \frac{(Accessibility_{altcase} - Accessibility_{basecase})}{Accessibility_{basecase}}$$

Shapefiles/Attributes: N/A

Nested Indicators: Population density
Street network density
Sidewalk completeness
Pedestrian route directness

Indicator: S610. Home-based vehicle miles traveled

Definition and Units: HB VMT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VMT = VMT_{input\ parameter}$

Alternate case sketch:

$$VMT_{base} * (1 + \Delta VMT)$$
$$\Delta VMT = (-0.035 * \Delta Den) + (-0.032 * \Delta Div) + (-0.039 * \Delta Des) + (-0.204 * \Delta Dest)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$
$$\Delta Dest = \frac{(Accessibility_{altcase} - Accessibility_{basecase})}{Accessibility_{basecase}}$$

Shapefiles/Attributes: N/A

Nested Indicators: Population density
Street network density
Sidewalk completeness
Pedestrian route directness

Indicator: S611. Non home-based vehicle miles traveled

Definition and Units: NHB VMT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VMT = VMT_{input\ parameter}$

Alternate case sketch:

$$VMT_{base} * (1 + \Delta VMT)$$
$$\Delta VMT = (-0.035 * \Delta Den) + (-0.032 * \Delta Div) + (-0.039 * \Delta Des) + (-0.204 * \Delta Dest)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$
$$\Delta Dest = \frac{(Accessibility_{altcase} - Accessibility_{basecase})}{Accessibility_{basecase}}$$

Shapefiles/Attributes: N/A

User-Defined Parameters:
Population density
Street network density
Sidewalk completeness
Pedestrian route directness

Indicator: S612. Parking demand

Definition and Units: Required parking spaces at user-defined rates.

Formula:

$$\sum DU_i * LUCoeff_{res} + \sum \frac{BANonR_i * LUCoeff_{NonRes}}{1000}$$

DU_i = Dwelling Unit Count in residential parcel i

$LUCoeff_{res}$ = Parking space demand per du for residential parcel i by existing land - use class

$BANonR_i$ = building area of non - residential parcel i

$LUCoeff_{NonRes}$ = Parking spaces per 1000 sq.ft. $BANonR_i$ by existing land - use class

Shapefiles/Attributes: Parcel land-use (polygon) / parcel land-use class (string)
Parcel land-use (polygon) / dwelling unit count (string)
Parcel land-use (polygon) / building floor area in sq.ft. (integer)

User-Defined Parameters: Residential parking spaces per dwelling unit by parcel land-use class

Non residential parking spaces per 1000 sq.ft. of building area by parcel land-use class

Indicator: S613. Parking supply

Definition and Units: Number of existing on-street and off-street spaces.

Formula: $\sum OnStreet_s + \sum OffStreet_p$

$OnStreet_s = \text{on - street parking for street segment s}$
$OffStreet_p = \text{off - street parking for parcel p}$

Shapefiles/Attributes: Parcel land-use (polygon) / off-street parking space count (integer)
Street centerlines(line) / on-street parking space count (integer)

User-Defined Parameters: None

Indicator: S614. Transit service density

Definition and Units: Miles of transit routes multiplied by number of transit vehicles traveling those routes each day, divided by total acres.

Formula:

$$\frac{\sum (V_t * L_t)}{A}$$

V_t = the number of vehicles for transit route t.
L_t = the length in feet of the part of the transit route t that is inside the study area.
A = the area in acres of the study area.

Shapefiles/Attributes: Transit routes (line) / transit vehicles per day on route (integer)
Transit routes (line) / year (4-digit year)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters: Snapshot year

Indicator: S615. Rail transit boardings

Definition and Units: Average daily number of persons boarding light rail transit.

Formula:

$$\frac{\sum\left[\left(e^{5.48}\right)*\left(e^{0.8T_s}\right)*\left(e^{-0.15P_s}\right)*\left({M_{ns}}^{0.65}\right)*\left({M_{cbds}}^{0.27}\right)*\left({D_{ps}}^{0.24}\right)*\left({D_{es}}^{0.49}\right)\right]}{N}$$

T_s = is station s a terminal (yes=1, no=0).
P_s = does station s have parking (yes=1, no=0).
M_{ns} = distance in miles from station s to next nearest stop.
M_{cbds} = distance in miles from station s to central business district.
D_{ps} = population density in persons per acre within a two miles of station s.
D_{es} = employment density in employees per acre within a half-mile of station s.
N = the number of light rail stations in the study area.
e = the base of natural logarithms or approximately 2.71828.

Shapefiles/Attributes:
Light rail stations (points) / is terminal (boolean: Y/N)
Light rail stations (points) / has parking (boolean: Y/N)
Central business district (point)
Parcel land-use (polygons) / dwelling unit count (integer)
Parcel land-use (polygons) / dwelling unit structure type (string)
Employment (points) / employee count (integer)
Sketch boundary (polygon) (created in sketch)

User-Defined Parameters:
Single-family persons per household
Mobile home persons per household
Multi-family 2-4 persons per household
Multi-family 5+ persons per household
Group quarters persons per household

Note: The CBD shapefile must contain the rail-served CBD closest to the sketch area.

Indicator: S700. Carbon monoxide (CO)

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$P_{trav} + P_{dwell}$$

$$P_{trav} = VMT_{percapita} * COCoef * 365 / 453.6$$

$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyPolCoeff$$

$$EnergyPolCoeff = \left(Elec_{\%} * COBldgElecPolCoef + NatGas_{\%} * COBldgNatGasPolCoef + HeatOil_{\%} * COBldgHeatOilPolCoef\right)$$

Shapefiles/Attributes: None

Nested Indicators: Residential energy consumption (indicator S214, building portion only)
VMT (indicators S610-611)

User-Defined Parameters: Building energy fuel shares
Building energy air pollutant coefficients
Travel energy air pollutant coefficients

Indicator: S701. Hydrocarbon (HC)

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$P_{trav} + P_{dwell}$$
$$P_{trav} = VMT_{percapita} * HCCoef * 365 / 453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyPolCoeff$$
$$EnergyPolCoeff = \left(Elec_{\%} * HCBldgElecPollCoef + NatGas_{\%} * HCBldgNatGasPollCoef + HeatOil_{\%} * HCBldgHeatOilPollCoef \right)$$

Shapefiles/Attributes: None

Nested Indicators: Residential energy consumption (indicator S214, building portion only)
VMT (indicators S610-611)

User-Defined Parameters: Building energy fuel shares
Building energy air pollutant coefficients
Travel energy air pollutant coefficients

Indicator: S702. Oxides of sulphur (SOX)

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$P_{trav} + P_{dwell}$$
$$P_{trav} = VMT_{percapita} * SOXCoef * 365 / 453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyPolCoeff$$
$$EnergyPolCoeff = \left(Elec_{\%} * SOXBldgElecPollCoef + NatGas_{\%} * SOXBldgNatGasPollCoef + HeatOil_{\%} * SOXBldgHeatOilPollCoef\right)$$

Shapefiles/Attributes: None

Nested Indicators: Residential energy consumption (indicator S214, building portion only)
VMT (indicators S610-611)

User-Defined Parameters: Building energy fuel shares
Building energy air pollutant coefficients
Travel energy air pollutant coefficients

Indicator: S703. Oxides of nitrogen (NOX)

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$P_{trav} + P_{dwell}$$
$$P_{trav} = VMT_{percapita} * NOXCoef * 365 / 453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyPolCoeff$$
$$EnergyPolCoeff = \left(Elec_{\%} * NOXBldgElecPollCoef + NatGas_{\%} * NOXBldgNatGasPollCoef + HeatOil_{\%} * NOXBldgHeatOilPollCoef\right)$$

Shapefiles/Attributes: None

Nested Indicators: Residential energy consumption (indicator S214, building portion only)
VMT (indicators S610-611)

User-Defined Parameters: Building energy fuel shares
Building energy air pollutant coefficients
Travel energy air pollutant coefficients

Indicator: S704. Particulate matter (PM)

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$P_{trav} + P_{dwell}$$
$$P_{trav} = VMT_{percapita} * PMCoef * 365/453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyPolCoeff$$
$$EnergyPolCoeff = (Elec_{\%} * PMBldgElecPollCoef + NatGas_{\%} * PMBldgNatGasPollCoef + HeatOil_{\%} * PMBldgHeatOilPollCoef)$$

Shapefiles/Attributes: None

Nested Indicators: Residential energy consumption (indicator S214, building portion only)
VMT (indicators S610-611)

User-Defined Parameters: Building energy fuel shares
Building energy air pollutant coefficients
Travel energy air pollutant coefficients

Indicator: S705. Carbon dioxide (CO2)

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$P_{trav} + P_{dwell}$$

$$P_{trav} = VMT_{percapita} * CO2Coef * 365 / 453.6$$

$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyPolCoeff$$

$$EnergyPolCoeff = \left(Elec_{\%} * CO2BldgElecPollCoef + NatGas_{\%} * CO2BldgNatGasPollCoef + HeatOil_{\%} * CO2BldgHeatOilPollCoef \right)$$

Shapefiles/Attributes: None

Nested Indicators: Residential energy consumption (indicator S214, building portion only)
VMT (indicators S610-611)

User-Defined Parameters: Building energy fuel shares
Building energy air pollutant coefficients
Travel energy air pollutant coefficients

Appendix A
4D METHOD TECHNICAL MEMORANDUM

Introduction

This appendix summarizes the “4D” methodology for estimating travel demand impacts from land-use and urban design changes. The methodology uses a set of elasticity factors that relate a neighborhood’s built environment characteristics and regional accessibility to the amount of vehicular travel generated in the neighborhood. These factors are used to compute the percentage change in vehicle trips (VT) and vehicle miles traveled (VMT) resulting from different land-use plans and urban designs. The method’s name derives from the four factors used to characterize the built environment and regional accessibility: density, diversity, design, and destinations or the 4Ds.

In Smart Growth INDEX, the 4D method is used only in snapshot sketches. The 4D method is applied in snapshot sketches by defining baseline VT and VMT in base cases, and then altering built environment characteristics whose impacts on travel are computed in terms of VT and VMT change.

Research Approach

The 4D method is based on research into the relationship between land-use and travel behavior. Nationally, over forty studies are available on this subject by such noted authors as Robert Cervero of the University of California and the authors of Portland’s LUTRAQ study. Taken as a group, the studies indicate how changes in land-use characteristics, such as density, relate to changes in travel generation as measured by vehicle trips and vehicle miles of travel. A bibliography of the research appears at the conclusion of this memorandum.

Using this research data, the 4D method was developed as follows:

- Elasticities were derived between vehicular travel (VT and VMT) and primary descriptors of the built environment and accessibility for each study in Attachment A whose research provided valid, comparable results. An elasticity is a measure of the percentage change that occurs in an dependent variable (VT or VMT) as a result of a percentage change in an influential variable (density, diversity, design or destinations). For example, if vehicle trips increase by 0.1% for each 1% increase in development density, then vehicle trips are said to have an elasticity of 0.1 with respect to density. If vehicle trips *decrease* by 0.05% for each 1% increase in density, then vehicle trips are said to have an elasticity of -0.05 with respect to density.

- Individual study results were synthesized into a unified matrix of partial elasticities. These express percentage changes in VT and VMT as a function of percentage changes in each of the 4Ds. The 4Ds are expressed in terms of: 1) density (population and employment per square mile); 2) diversity (the ratio of jobs to population); 3) design (pedestrian environment variables including street grid density, sidewalk completeness, and route directness); and 4) destinations (accessibility to other activity concentrations, expressed as the mean travel time to all other destinations within the region, e.g. a location within the regional core will ordinarily have a higher 'destinations' rating than a location on the fringe of the urban area, because the central location offers greater accessibility to a higher percentage of the region's employment).

- Creation of a table of elasticities as a quick-response tool for assessing the relative benefits of one land-use pattern compared with another.

Research Findings

Table A-1 presents the data synthesis. These results advance the state-of-the-art for quick response evaluations in the following respects:

- They include a larger number and wider range of research studies than previous syntheses, including recent studies in Portland (Sun, Lawton, PBQD), Seattle (Hess) and the San Francisco Bay Area (Cervero, Kockelman, Holtzclaw). These three were tightly controlled and statistically sophisticated.

- One of the research studies directly measures pedestrian travel through counts of pedestrian volumes entering commercial centers, whereas most studies rely on household or workplace questionnaires which are known to under-report walk travel.

- The fourth D or accessibility factor accounts for the fact that the other 3Ds (density, diversity, and design) will not produce the same effects on travel behavior in remote areas surrounded by typical suburban neighborhoods as they will at centrally-located infill locations. Several studies (including the research on which LUTRAQ is based) have demonstrated that the effects of the first three 4Ds on travel are weaker in outlying areas than infill areas, even if the areas are similar in other respects, such as transit service and average household income. When used in region-wide analysis, the accessibility factor also enables the analysis to recognize the benefits of placing development near transportation corridors, and at locations that are centrally located relative to compatible activities.

Table A-1
4D ELASTICITIES

	Vehicle Trips	Vehicle Miles Traveled
Density	–0.043	–0.035
Diversity	–0.051	–0.032
Design	–0.031	–0.039
Destinations	–0.036	–0.204

Density = Percent Change in [(Population + Employment) per Square Mile]

Diversity = Percent Change in {1 - [ABS(b * population - employment) / (b * population + employment)]}

where: *b* = regional employment / regional population

Design = Percent Change in Design Index

Design Index = 0.0195 * street network density + 1.18 * sidewalk completeness + 3.63 * route directness

where:

0.0195 = coefficient applied to street network density, expressing the relative weighting of this variable relative to the other variables in the Design Index formula,

street network density = length of street in miles/area of neighborhood in square miles

1.18 = coefficient applied to sidewalk completeness, expressing the relative weighting of this variable relative to the other variables in the Design Index formula,

sidewalk completeness = length of sidewalk/length of public street frontage

3.63 = coefficient applied to route directness, expressing the relative weighting of this variable relative to the other variables in the Design Index formula,

route directness = average airline distance to center/average road distance to center

Destinations (accessibility) = Percent Change in Gravity Model denominator for study TAZs "I": Sum[Attractions(j)*Travel Impedance(i,j)] for all regional TAZs "j"

Application of the Elasticities

Ideally, the 4D method should only be applied in areas covered by a regional transportation demand model of the type normally operated by metropolitan planning organizations. A regional transportation model is needed to provide accurate baseline inputs for vehicle travel, as well as characterizing existing and future accessibility levels. If a transportation model is not available, the method should be applied with the assistance of a qualified transportation planner using professional judgment based on experience in the area.

The density, diversity, and design elasticities in Table A-1 may be used in cases where multiple land-use alternatives are being considered for the same site. The accessibility elasticities in Table A-1 do not need to be applied in this instance since a single site's relative regional accessibility would not vary from one land-use alternative to another. However, even when one site is under consideration and accessibility is not expected to change over time or as a function of different transportation concepts at the site, it is important to start the analysis with realistic baseline trip rates as influenced by the site's location within its region and its relative level of accessibility.

The accessibility elasticities in Table A-1 must be applied when accounting for changes in transportation systems or services to a single site. They require that a travel demand forecasting model be used to account for differences in accessibility that such transportation changes would create.

In summary, the method is applied to single sites as follows:

A. Define Study Area, Baseline Urban Form, Accessibility, and Trip Generation

1. Using the regional transportation model, identify which traffic analysis zone (TAZ) or TAZs encompass the study area. The boundaries of these host TAZs should match the study area boundary as closely as possible.

2. Compute the baseline density, diversity, design, and accessibility factors of the host TAZ as described in the variable definitions in Table A-1. If the area is greater than two miles in diameter or 2,000 acres, measure its density, diversity, and design by sampling those variables within 2-mile diameter subareas inside the larger area, and calculating average values.

3. Compute the baseline trip rates for the host TAZ. If the host TAZ is largely vacant or undeveloped, trip rates should be estimated at levels appropriate for the location using nearby developed TAZs for guidance. The baseline trip rates should be calculated as home-based (HB) VT and VMT per TAZ resident, and non home-based (NHB) VT and VMT per TAZ employee.

B. Calculate Change in 4D's for Each Land-Use Alternative

1. Compute the percentage change in density, diversity, and design under each land-use alternative relative to the base case.

2. Estimate any changes in regional accessibility envisioned for the study area using indicators such as projected change in highway travel speeds, transit frequency, or walk distance to transit. Data from the regional transportation model should be used in this step, such as percentages of transit trip time spent walking to, waiting for, and riding transit; or vehicle hours of delay or average highway travel speed.

C. Estimate Changes in Travel Indicators for Each Land-Use Alternative

1. For each land-use alternative, apply the elasticity value for density to the computed percentage change in area density from the baseline, to obtain the percentage change in HB VT and HB VMT per capita as a result of the density change. Similarly, compute the percentage changes in HB VT and HB VMT per capita resulting from changes in diversity and design. Sum the resulting percentage changes to obtain the total percentage change in trip generation resulting from the combined effects of density, diversity and design. Apply the resulting sum to the baseline HB VT and HB VMT per capita to obtain the new HB VT and HB VMT per capita resulting from the land-use alternative.

2. Repeat the process to obtain the NHB VT and NHB VMT per employee resulting from the land-use alternative.

3. If regional accessibility is expected to change from one land-use alternative to another, apply the Table A-1 accessibility elasticity to the percentage change in accessibility from baseline to obtain the percent change expected in HB and NHB VT and VMT per capita and per employee, if any.

4. Compare the resulting VT and VMT changes between land-use alternatives to obtain relative differences in transportation performance.

This procedure assumes that study area household size and auto ownership does not change from one land-use alternative to another.

A hypothetical example of applying the method is given in worksheet form in Table A-2. This example assumes that a 1.5 sq.mi. study area is undergoing redevelopment in a region of 50,000 persons and 35,000 jobs. The study area's proposed redevelopment includes an increase in population and employment, with a greater share of residential uses than before; construction of new streets and sidewalks to improve the area's pedestrian environment; and expanded transit service that will improve the area's accessibility by reducing transit travel time to and from the area. The Table A-2 worksheet illustrates HB VMT calculations; the same procedure would be used for NHB VMT, HB VT, and NHB VT calculations.

Size and Homogeneity of Study Areas

As noted above, the areas to which the 4D elasticities are directly applied should be less than two miles in diameter or 2,000 acres. If larger areas are under study, the 4D's should be sampled within two-mile subareas of the larger area, and the results averaged. This is because the effects of the 4Ds on auto travel and trip length are primarily due to the proximity of supportive and well-designed land-uses to one another, and the opportunity this provides for walk and bicycle travel between them. For example, a large area with employment clustered at one end and residential uses at the other should not be considered as diverse as an area with block-by-block mixing of land-uses. Therefore, this sampling and averaging technique is recommended to better capture the 4D effects in large study areas. Users should not allow undeveloped subareas within a study area to dilute the calculated density unless the undeveloped subarea lies well within active areas, thereby lengthening the travel distance for those traveling from one point to another within the active area. Open acreage on the edge of the study area should not be counted in the density calculation.

Regional or Multi-Site Analysis

The 4D method may also be used for comparison of growth scenarios for an entire region or for multiple development sites scattered throughout a region. Regional analysis includes comprehensive assessments of development patterns over a large, relatively homogeneous area, or a large area consisting of multiple communities. Growth scenarios can be comparisons of existing versus future conditions, or comparisons of "trends" versus "smart growth," or comparisons of several community plan or specific plan alternatives. Regional analysis methods will generally be used for areas of 25 square miles or greater, subject to the sampling technique described above. Multi-site analysis refers to analyses that attempt to compare the effects of allocating growth to one site within the region versus others. Sites would differ with respect to one or more of the following: 1) their degree of centralization; 2) their distance to jobs and housing; 3) their context within the urban fabric (infill within a dense area versus an edge or suburban setting); and/or 4) their proximity to transportation facilities. As with the individual site analysis, the regional and multi-site analyses use data from the regional transportation model for baseline VT and VMT generation rates for each individual geographic unit within the region. The VT and VMT rates should be for the forecast year under study, so that the relevant transportation network characteristics are reflected in the accessibility measure for each

Table A-2
HYPOTHETICAL EXAMPLE WORKSHEET

1. STUDY PARAMETERS

I. Study Area:

Square miles:	1.5

1.2 Region Demographics:

▸ Population	50,000
▸ Employment	35,000

1.3 Study Area Base Case Conditions:

▸ Population:	1,000
▸ Employment:	2,000
▸ Street network density:	17 mi./sq.mi.
▸ Sidewalk completeness:	75%
▸ Pedestrian route directness:	0.6
▸ Accessibility:	23 mean min.
▸ HB VMT/capita/day:	20

1.4 Study Area Alternative Case Conditions:

▸ Population:	2,000
▸ Employment:	2,500
▸ Street network density:	19 mi./sq.mi.
▸ Sidewalk completeness:	100%
▸ Pedestrian route directness:	0.8
▸ Accessibility:	20.75 mean min.

Table A-2 *Continued*

2. DENSITY

2.1 Base Density:

1,000	population
+ 2,000	employees
3,000	persons ÷ 1.5 sq.mi. = 2,000

(1.5 sq.mi. = study area; 2,000 = persons/sq.mi.)

2.2 Alternative Density:

2,000	population
+ 2,500	employees
4,500	persons ÷ 1.5 sq.mi. = 3,000

(1.5 sq.mi. = study area; 3,000 = persons/sq.mi.)

2.3 Density Change:

3,000	persons
- 2,000	persons
1,000	persons ÷ 2,000 persons = 0.5 or 50%

(0.5 or 50% = density increase)

2.4 HB VMT Change From Density Change:

50% x -0.035 = -1.75%

(50% = density increase; -0.035 = elasticity; -1.75% = HB VMT decrease)

Table A-2 *Continued*

3. DIVERSITY

3.1 Base Diversity:

study area pop *study area pop*

{ 1 - [ABS (0.7 x 1,000 - 2,000) ÷ (0.7 x 1,000 + 2,000)] } = 0.52

region emp/pop *study area emp* *region emp/pop* *study area emp*

3.2 Alternative Diversity:

study area pop *persons/ sq.mi. pop*

[1 - [ABS (0.7 x 2,000 - 2,500) ÷ (0.7 x 2,000 + 2,500)] } = 0.72

region emp/pop *study area emp* *region emp/pop* *study area emp*

3.3 Diversity Change:

0.72
- 0.52
0.20 ÷ 0.52 = 0.38 or 38%

diversity increase

3.4 HB VMT Change From Diversity Change:

38% x -0.032 = -1.22%

diversity increase *elasticity* *HB VMT decrease*

Table A-2 *Continued*

4. DESIGN

4.1 Base Design:

st.mi./sq.mi. *% walk complete* *route directness*

(0.0195 x 17) + (1.18 x 0.75) + (3.63 x 0.6) = 3.39

var. weight coefficient *var. weight coefficient* *var. weight coefficient* *design index*

4.2 Alternative Design:

st.mi./sq.mi. *% walk complete* *route directness*

(0.0195 x 19) + (1.18 x 1.00) + (3.63 x 0.8) = 4.45

var. weight coefficient *var. weight coefficient* *var. weight coefficient* *design index*

4.3 Design Change:

4.45
-3.39
1.06 ÷ 3.39 = 0.31 or 31%

design index increase

4.4 HB VMT Change From Design Change:

31% x -0.039 = -1.21%

design index increase *elasticity* *HB VMT decrease*

Table A-2 *Continued*

5. DESTINATIONS

5.1 Base Accessibility:

Mean travel time to all regional employment:

auto	20 min
transit	40 min
% transit	15%

Weighted average travel time:

auto		transit		
20 min x 85%	+	40 min x 15%	=	23 min

5.2 Alternative Accessibility:

Mean travel time:

auto	20 min
transit	25 min

Weighted average travel time:

auto		transit		
20 min x 85%	+	25 min x 15%	=	20.75 min

5.3 Accessibility Change:

$$1 - \frac{20.75 \text{ min}}{23.00 \text{ min}} = 1 - 0.902 = -9.8\%$$

5.4 HB VMT Change From Accessibility Change:

-9.8% x -0.204 = -0.02 = -2%

accessibility increase (-9.8%)

elasticity (-0.204)

Table A-2 *Continued*

6. CUMULATIVE VMT CHANGE

6.1 HB VMT changes from:

Density change	- 1.75%
Diversity change	- 1.22%
Design change	- 1.17%
Accessibility change	- 2.00%
Total	- 6.14%

6.2 Alternative case HB VMT calculation:

20 x 0.0614 = 1.23

base case — *% reduction* — *VMT/capita/day reduction*

20 - 1.23 = 18.77

base case HB VMT /capita/day — *VMT reduction* — *alternate case HB VMT /capita/day* geographic unit. If the comparison is being made between two different forecast years, each year should be represented via regional transportation model data. In all cases, the VT and VMT should each be expressed as:

- HB VT per Resident: HB VT / TAZ Population
- NHB VT Trips per Employee: NHB VT / TAZ Employment
- HB VMT per Resident: HB VMT / TAZ Population
- NHB VMT per Employee: NHB VMT / TAZ Employment

These rates can be obtained by taking the appropriate ratios among the zonal population, employment, home-based vehicle trips produced, and non-home-based vehicle trips attracted for the TAZs that encompasses the study area. The advantages of this approach include: a) multiple regional development patterns can be tested without running the four-step for each case; regional land-use form can be reflected (the effects of intensifying land-use in infill versus greenfield locations) and measured along with the effects of design, density and diversity within each development area; and b) the evaluation of land-use alternatives can be sensitive to the proximity of growth to regional transportation facilities, including fixed transit corridors.

<u>Opportunities for Further Review and Enhancement</u>

The 4D elasticities are based on a wide array of primary research studies. Some of the studies show results that disagree with one another. As a result of these disagreements, the resulting elasticities exhibit some apparent anomalies. For example, many experts may expect that the elasticity of VMT with respect to design should be lower than the elasticity of VT with respect to design. This is because many believe that the biggest impact of good urban design is to convert short-distance auto trips to walk or bike trips, while longer distance auto trips might not be affected by good design. However, the current elasticity results show a higher relationship for VMT than for VT. This is because, even though one of the reference studies indicated that the VMT elasticity should be lower than the VT elasticity, several other reputable studies disagreed. The LUTRAQ study, for example, found an elasticity of VMT to design significantly higher than the result of the 4D method synthesis. Two other studies found VMT/design elasticities very close to the 4D results and higher than the 4D VT/design elasticity. Therefore, the preponderance of empirical data available to the 4D synthesis suggests that good design reduces not only the amount of vehicle trip-making, but the average length of vehicle trips as well. While this may be counter-intuitive to some, the conventional wisdom on how the VMT and VT rates “should” compare with one another may not take into consideration the following phenomena:

- The effects of self-selection, where individuals who move to well-designed neighborhoods may have a pre-disposition to drive less for trips of any length.

- Developments that score high on the design index are often at infill locations nearer to a greater proportion of regional jobs and housing; therefore, average trip lengths may be shorter.

- Developments that score high on the design index are often at locations nearer to high-quality transit service than are locations with poorer design indices; therefore, residents of high-design neighborhoods may have better non-auto choices even for their longer trips than do residents of low-design neighborhoods.

Further research, using additional household survey datasets, could clarify these issues and otherwise improve the current 4D elasticities.

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Appendix B
AIR POLLUTANT & GREENHOUSE GAS EMISSION FACTORS

Smart Growth INDEX estimates air pollutant and greenhouse gas emissions for residential buildings and household travel as part of the indicator results for each sketch.

Table B-1 lists the emission coefficients used for electricity and natural gas consumption in the buildings sector. These coefficients are based on data published by the U.S. Department of Energy's Lawrence Berkeley Laboratory for natural gas utilization, and the Energy Information Administration for electricity utilization.

Table B-2 presents emission coefficients used for autos and light trucks in the transportation sector based on data published by U.S. EPA's Office of Mobile Sources. SGI presently assumes a 50/50 mix of autos and light trucks when estimating transportation emissions.

It should be noted that estimates for both the buildings and transportation sectors are based on current emission rates, and do not take into consideration potential changes in future emission rates when long-range forecast sketches are prepared.

Table B-1
RESIDENTIAL BUILDING EMISSION FACTORS

	LBS/MMBTU					
	NOx	**SOx**	**HC**	**CO**	**CO2**	**PM**
Electricity	0.413	0.6514	0.003	0.0206	125.65	0.0653
Natural Gas	0.137	0.00059	0.00058	0.034	115	0.006
Heating Oil	0.140	0.5528	0.0004	0.035	170	0.014

Source: U.S. DOE, LBL and EIA, 1997.

Table B-2
VEHICLE EMISSION FACTORS

A. Annual Emissions and Fuel Consumption for an "Average" Passenger Car [1]

Pollutant Problem	Amount [2]	Miles [3]	Pollution or Fuel Consumption [4]
Hydrocarbons	2.9 grams/mile	12,500	80 lbs of HC
Carbon Monoxide	22 grams/mile	12,500	606 lbs of CO
Nitrogen Oxides	1.5 grams/mile	12,500	41 lbs of NOx
Carbon Dioxide	0.8 pound/mile	12,500	10,000 lbs of CO2

B. Annual Emissions and Fuel Consumption for an "Average" Light Truck [1]

Pollutant Problem	Amount [2]	Miles [3]	Pollution or Fuel Consumption [4]
Hydrocarbons	3.7 gram/mile	14,000	114 lbs of HC
Carbon Monoxide	29 gram/mile	14,000	894 lbs of CO
Nitrogen Oxides	1.9 gram/mile	14,000	59 lbs of NOx
Carbon Dioxide	1.2 pound/mile	14,000	16,800 lbs of CO2

Notes:

[1] These values are averages. Individual vehicles may travel more or less miles and may emit more or less pollution per mile than indicated here. Emission factors and pollution/fuel consumption totals may differ slightly from original sources due to rounding.

[2] The emission factors used here come from standard EPA emission models. They assume an "average," properly maintained car or truck on the road in 1997, operating on typical gasoline on a summer day (72 to 96 degrees F). Emissions may be higher in very hot or very cold weather.

[3] Average annual mileage source: EPA emissions model MOBILE5.

[4] Fuel consumption is based on average in-use passenger car fuel economy of 22.5 miles per gallon and average in-use light truck fuel economy of 15.3 miles per gallon.

Source: U.S. Environmental Protection Agency
National Vehicle and Fuel Emissions Laboratory, April 1997

Appendix C

INDICATORS BY SHAPEFILE AND ATTRIBUTE

Shapefile	Shapefile Attributes	
Bike route centerline (line)	Year of establishment (4-digit year).	S211: Dwellings within 1/8 mi. of 3+ modes
		S605: Bicycle network
Central business district (point)	None.	S615: Rail transit boardings
Employment (point)	Employee count (integer).	S100: Population density
		S103: Developed acres per capita
		S104: Land-use diversity
		S300: Employment
		S301: Jobs/housed workers balance
		S302: Conforming employment density
		S303: Non-conforming employment density
		S304: Employment proximity to transit
		S501: Nonresidential wastewater production
		S608: Home-based vehicle trips (alt case)
		S609: Non-home-based vehicle trips (alt case)
		S610: Home-based vehicle miles traveled (alt case)
		S611: Non-home-based vehicle miles traveled (alt case)
		S615: Rail transit boardings
Employment centers (point)	None.	S212: Housing proximity to employment center
Key amenities (point)	Year of establishment (4-digit year).	S210: Housing proximity to key amenities
Light rail stations (point)	Is terminal station (boolean: Y/N).	S615: Rail transit boardings
	Has parking (boolean: Y/N).	S615: Rail transit boardings
Parcel land-use *(base & alternate)* (polygon)	Land-use class (string).	S101: Use mix
		S102: Average parcel size
		S400: Imperviousness
		S401: Stormwater runoff
		S402: Total suspended solids
		S403: Phosphorus
		S404: Nitrogen

Shapefile	Shapefile Attributes	
Parcel land-use *Continued*	Land-use class *Continued*	S407: Open space
		S612: Parking demand
	Dwelling unit structure type (string).	S100: Population density
		S103: Developed acres per capita
		S202: Single-family housing share
		S203: Mobile home housing share
		S204: Multi-family 2-4 housing share
		S205: Multi-family 5+ units housing share
		S206: Group quarters housing share
		S214: Residential energy consumption
		S301: Jobs/housed workers balance
		S400: Imperviousness
		S500: Residential wastewater production
		S608: Home-based vehicle trips (alt case)
		S609: Non home-based vehicle trips (alt case)
		S610: Home-based vehicle miles traveled (alt case)
		S611: Non home-based vehicle miles traveled (alt case)
		S615: Rail transit boardings
	Dwelling unit count (integer).	S100: Population density
		S103: Developed acres per capita
		S200: Conforming dwelling density
		S201: Nonconforming dwelling density
		S202: Single-family housing share
		S203: Mobile home housing share
		S204: Multi-family 2-4 housing share
		S205: Multi-family 5+ units housing share
		S206: Group quarters housing share
		S207: Housing proximity to transit
		S208: Housing proximity to recreation
		S209: Housing proximity to education
		S210: Housing proximity to key amenities
		S211: Dwellings within 1/8 mi. of 3+ modes
		S212: Housing proximity to employment center
		S213: Residential water consumption

Shapefile	Shapefile Attributes	
Parcel land-use *Continued*	Dwelling unit count *Continued*	S214: Residential energy consumption
		S301: Jobs/housed workers balance
		S400: Imperviousness
		S408: Park space availability
		S500: Residential wastewater production
		S612: Parking demand
		S615: Rail transit boardings
	Off-street parking space count (integer).	S613: Parking supply
	Building floor area in sq.ft. (integer).	S612: Parking demand
	Shapefile only – no attribute required.	S304: Employment proximity to transit
		S601: Pedestrian route directness
Parks and schools (polygon)	Year of establishment (4-digit year).	S208: Housing proximity to recreation
		S408: Park space availability
Planned land-use (polygon)	Land-use class (string).	S200: Conforming dwelling density
		S302: Conforming employment density
Schools and daycare facilities (point)	Year of establishment (4-digit year).	S209: Housing proximity to education
Soils (polygon)	NRCS hydrologic group type (string: A, B, C, or D).	S401: Stormwater runoff
		S402: Total suspended solids
		S403: Phosphorus
		S404: Nitrogen
Stormwater best management practices (a polygon for each BMP/location set)	Percent removal for each BMP and pollutant (integer).	S402: Total suspended solids
		S403: Phosphorus
		S404: Nitrogen
Street centerlines (line)	Street width in ft. (integer).	S211: Dwellings within 1/8 mi. of 3+ modes
		S400: Imperviousness
		S401: Stormwater runoff
		S402: Total suspended solids
		S403: Phosphorus
		S404: Nitrogen

Shapefile	Shapefile Attributes	Indicators Affected
Street centerlines *Continued*	Sidewalk presence (integer: 0 = none; 1 = one side of street only; 2 = both sides).	S600: Sidewalk completeness
		S608: Home-based vehicle trips (alt case)
		S609: Non home-based vehicle trips (alt case)
		S610: Home-based vehicle miles traveled (alt case)
		S611: Non home-based vehicle miles traveled (alt case)
	On-street parking space count (integer).	S613: Parking supply
	Shapefile only – no attribute required.	S207: Housing proximity to transit
		S208: Housing proximity to recreation
		S209: Housing proximity to education facilities
		S210: Housing proximity to key amenities
		S212: Housing proximity to employment center
		S502: Street centerline distance
		S601: Pedestrian route directness
		S602: Street network density
		S603: Street connectivity
		S605: Bicycle network
		S608: Home-based vehicle trips (alt case)
		S609: Non home-based vehicle trips (alt case)
		S610: Home-based vehicle miles traveled (alt case)
		S611: Non home-based vehicle miles traveled (alt case)
Transit routes (line)	Transit vehicles per day on route (integer).	S211: Dwellings within 1/8 mi. of 3+ modes
		S614: Transit service density
	Year of route establishment (4-digit year).	S211: Dwellings within 1/8 mi. of 3+ modes
		S614: Transit service density
Transit stops (point)	None.	S207: Housing proximity to transit
		S304: Employment proximity to transit
		S606: Transit stop coverage

Note:
1. *No nulls are allowed in any record.*
2. *The attribute "year of establishment" is the year a feature becomes operable. If the feature already exists, then the year is the current year in which the sketch is being prepared; if the feature is planned to become operable in a future year, then the future year is entered. By naming the attribute field NONE the feature will always be recognized regardless of sketch year.*
3. *Street centerlines must have perfect connectivity to support indicator calculations.*