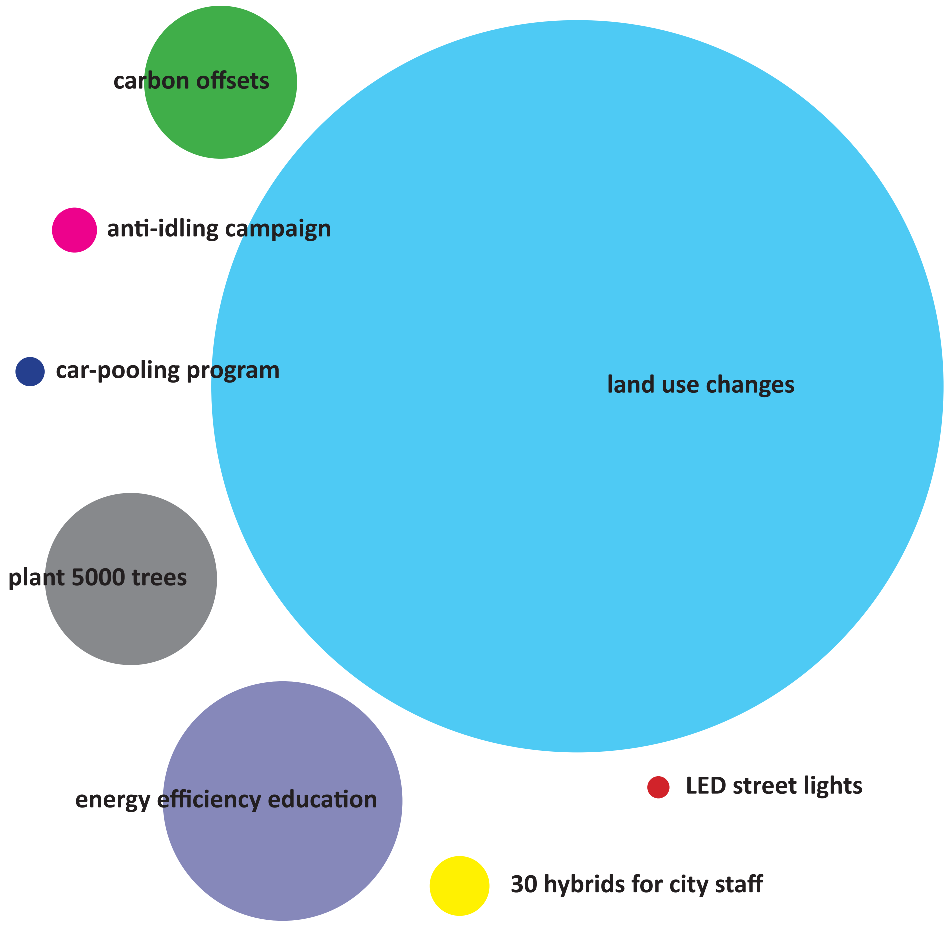
Sustainability Solutions Group

SSG is a full service sustainability management consulting co-operative.

GHGProof
Guidebook



Sustainability Solutions Group

Fraser Valley Regional District

Contents

Cover Illustration: the diagram demonstrates the relative impact of different strategies to reduce Greenhouse Gas emissions for a community with a population of 10,000 people. Land use change refers to doubling the average density of the community.

This guidebook refers to version 1.4 of GHGProof, available for download at www.sustainabilitysolutions.ca/landuse.

The Guidebook was written by Yuill Herbert and Lindsay Cole of Sustainability Solutions Group and Corey Newcomb and Alison Stewart of the Fraser Valley Regional District.

1. Introduction

GHGProof is designed to help local and regional governments explore and analyze the impacts of land-use planning on greenhouse gas emissions and public and private energy costs.

It is designed to be a simple model that uses standard GIS analysis and an excel-based tool. It is fully transparent and open source for non-profit purposes so communities can easily adapt it to their own context if required.

Communities can use the model to set targets, develop strategies to achieve targets, evaluate development proposals and design their community plans.

The model helps communities address state and provincial legislation that mandates the consideration of greenhouse gas emissions in land-use planning such as:

- British Columbia's Bill 27- Green Communities Act
- California's SB 375- Sustainable Communities and Climate Protection Act
- Washington Senate's Bill 6580- Growth Management Act

The model was developed with support from the Fraser Valley Regional District and Canada Mortgage and Housing Corporation.

www.sustainabilitysolutions.ca/landuse

2. Strengths and Capabilities

Key strengths of the model include:

- Comprehensive: Seeks to address all major land-use impacts on GHG emissions as well as some public and private energy costs.
- Adaptable: can be used for a rigorous analysis of a large city or in a one-day workshop for a small community.
- Affordable: Free to use for non-profit purposes, open source.
- Transparent: All assumptions and calculations are visible and can be altered.
- Scope: Can be used at the scale of a large-scale development, a municipal plan and a regional plan
- Policy relevant: Allows municipalities to develop or evaluate targets to address provincial or state legislation.
- Accessible: Uses simple GIS analysis and an excel-based calculator; limits number of inputs to those that have greatest potential GHG impacts.

Outputs of the model include:

GHG emissions	Other Metrics
• Private vehicles • Public transportation • Mode shift to walking • Embedded energy from road construction • Building energy consumption (residential) • Potential for district or community energy • Solid and liquid waste • Emissions related to the transportation of food • Perennial cropland • Tilled/no-tilled agricultural land • Enteric fermentation (cows) • Forest land	• Annual electricity and heating costs for residences • Annual fuel costs (private) • Annual waste disposal costs • Construction costs for additional roads (annualized) • Annual public transit costs • Annual GHG offset costs

3. Four ways to use GHGProof

1. Develop an achievable GHG target

Scenario: North Town sets a target.
The BC Government has mandated that communities include targets for GHG reductions into their Official Community Plans covering a period over the next 20 years. The council of North Town has indicated it wants a clear, step by step plan to an achievable yet ambitious target. North Town planners complete the GIS analysis to establish a baseline in the model and then hold a one day workshop to develop 3 scenarios. Each scenario consists of different actions such as building new apartments and townhouses in the town core, creating a node of neighbourhood commercial development in a residential cluster. These scenarios are then presented to the council and a target is created based on the results of the scenario selected.

2. Develop a realistic strategy to achieve a target

Scenario: South Town develops a strategy.
South Town also has to set a target. Their council, however, elects to use the default target set by the BC Government, a 33% reduction over 2007 levels by 2020. This is a challenging target. After entering the baseline and business as usual projections, planners in South Town use the model to plug in possible strategies they can use to achieve that target. After adjusting the variables, the planners at South Town can see the steps that are required to achieve that GHG target. They can also decide whether to set the target on a per capita basis or for their community as a whole.

3. Evaluate a large-scale development proposal

Scenario: East Town has a GHG target and a developer has proposed a project of 150 new homes for their community of 10,000.
The project is about 5 kilometres out of town. The planners use GHGProof to evaluate the GHG emissions and public and private cost of the project. It turns out that it will significantly increase the average trip length per household in the community and therefore increase the GHG emissions of the community. The model also shows that the fuel costs for residents in the project will be twice that of those living closer to town. Based on this information, Council can choose to approve the development proposal with a condition of the developer providing transit to the area or reject it as being inconsistent with the Town's GHG reduction policy as per the Official Community Plan.

4. Evaluate a land-use plan

Scenario: West Town is completing a review of its community plan.
It is seeking to balance community economic development, cultural aspects, and environmental issues. The town runs the model to evaluate the impact of possible directions for the plan on greenhouse gas emissions and energy costs.

4. Getting Started

The Tabs

The Documentation tab describes the model, its history, the creative commons license and future changes.

Tab 1: Inputs: The main data entry worksheet.

Tab 2: Assumptions: Numerical assumptions for the model. They can be adjusted if local data is available.

Tab 3: Calculations: Modelling calculations are illustrated step by step in this worksheet. Each number is linked from the inputs and assumptions sheets. When a number is changed in the Inputs or Assumptions sheets, it automatically changes in the Calculations sheet.

Tab 4: Results - Detailed: The result of each calculation is displayed on this page and the user can see the impact of each variable. Additionally, the financial impact of each of the variables is illustrated.

Tab 5: Results - Summary: An overview of the results by themes for easy access.

Tab 6: Charts: Charts are automatically generated in this worksheet.

A. Building Emissions Factor: Numbers related to buildings in the Assumptions tab are generated in this worksheet.

B. Trip length calculation: The trip length calculation which feeds into the Inputs tab is completed in this worksheet.

Preparing Data

The quality of the results from the model depends on several factors, including:

1. Primary Data quality for the spreadsheet inputs
2. The analysis tools available to generate the Secondary Data inputs
3. Financial and staff resources to obtain or generate input data

Primary Data

On the Inputs tab, Primary Data are the following factors, and can be obtained from sources such as Statistics Canada (Census) or provincial or local sources, where available:

- Total Households
- Total Population
- Road Length
- Buildings (Detached, Attached, Apartments ≤5, Apartments >5)
- Solid Waste
- Agriculture Data
- Forest Cover

The quality of the Primary Data is an important consideration, especially the level of detail of the spatial buildings data that are used to generate the Secondary Data inputs. For example, piloting the model in the Fraser Valley Regional District involved testing two levels of data quality/spatial accuracy in the buildings data – parcel data and census dissemination area data – to create baselines for each pilot community. See the discussion of data quality in Appendix A for further information.

Secondary Data

Secondary Data are derived through GIS analysis of Primary Data, and as a result are only as accurate as the data they are derived from. These data include:

- Trip Length
- CBD Access
- Public Transit Access
- Community Energy Estimates
- Liquid Waste

The quality of the Secondary Data depends both on the Primary Data quality as well as the level of analysis tools available, in particular the licensing level for GIS. To achieve the highest level of GIS analysis, ESRI ArcMap with the Network Analyst extension or similar tools are necessary. However, the model can provide very usable results with lower levels of data quality or analysis tools. The following sections describe some potential options for each:

1. No GIS. Use numeric data together with paper mapping or simple blocking out by hand of future land use changes to generate estimates for the spreadsheet inputs. The results from this method will be much less rigorous.

2. Basic GIS (no Network Analyst). Use basic buffering tools to generate inputs for the spreadsheet. While the basic buffer tool in ArcMap will provide less accurate results than the calculations done with the Network Analyst extension, for most of the inputs this will provide an acceptable but less detailed result. Without Network Analyst however, the trip length input will need to be estimated or derived from another source rather than calculated in GIS.

3. Full GIS (with Network Analyst). Run the analysis in ArcMap using the Network Analyst extension (See Appendix C for suggested workflow.)

5. Using the Model

Using inputs generated from the data sources, the model works by comparing present land use patterns against likely development scenarios for a future target year. This target year may coincide with existing land use planning processes in the community, or may be a standalone period. The data are used to develop scenarios for the community, including:

A) a baseline for the present or base year
B) a "business as usual" future scenario, which represents the current likely future development patterns
C) up to two alternative future scenarios, which illustrate a range of alternative land use patterns that might be possible for the community

A. Creating a baseline

The baseline is the reference point against which future changes are measured. The following steps are required to create a baseline:

On the "Inputs" tab:

Factor 1: Identify the number of households in the community. (Statistics Canada can provide this data)

Factor 2: Then enter the total population (Statistics Canada)

Factor 3: Divide population by number of households to calculate people per household

Factor 4: Enter the current year (format "2010").

Factor 5: Go to tab B. Trip Length Calculation.

Verify the assumptions, in particular "Trip Length" (Cell N24). If the community is from BC, the trip length can be calculated more accurately from Community Energy and Emissions Inventory data using the CEEI calculator.

Outputs from the GIS analysis (see Appendix C) will be entered into the distance cells (B9-B26). In cell B28, find the average destination length and repeat this calculation in cell B38 for schools.

A number will automatically appear in Factor 5 in the Inputs worksheet. Return to the Inputs Worksheet.

Factor 6-9 will be outputted from the GIS analysis.

Factor 10-13 are available from Statistics Canada.

At this stage, it is important to go into the worksheet A. Building emission factor and enter the total GJ of energy from residential buildings. In BC this number can be found in the Community Energy and Emissions Inventory. Please contact SSG for information on how to do this in other provinces.

Factor 14-17 will be outputted from the GIS analysis or other estimate of community energy potential.

Factor 18 and 19: Identify if the municipality collects methane from its waste collection centre. If not, enter the tonnes of waste in Factor 18; if yes, enter tonnes of waste in Factor 19.

Factor 20 and 21 will be outputted from the GIS analysis.

Factor 22 is available from Statistics Canada

Factor 23 is the percent of food which is locally grown that is locally consumed. There is an assumption for a provincial number in BC. Other studies may be available locally.

Factor 24-28 is available from Statistics Canada's Agricultural Census.

Factor 29 is the area of forest over which the municipality or region has control

Factor 30 can be calculated using GIS to identify the change in land cover

Factor 31 is not normally tracked but may be estimated by identifying the number of households heated with wood.

B. Business as Usual Scenario (BAU)

The BAU is a projection into the future, assuming the status quo. For example, it would involve projecting the current land use plan out into the future.

Firstly a date for the BAU is identified – it may be twenty years in the future, but can be any time period. This is entered into Factor 4. Population and household projections are usually available from Statistics Canada or other sources and these are entered into Factor 1 and 2. Factor 3 is calculated by dividing the total population by the number of households.

Factors 5 to 17, 20-22 and 29 are outputted from the GIS analysis using the scenario data generated and converted into GIS format. (See Appendix B)

Factors 18 and 19 are calculated using projections. In the baseline, total tonnes of waste are divided by the total population to identify tonnes of waste per person. This number is then multiplied by the population in the BAU. Estimate reduction in future solid waste tonnage from diversion rates if available.

Factor 23-28 and 30 and 31 stay the same as in the baseline, unless specific policies or plans are in place to change these over time. You may want to explore changing these variables in a separate version of the model to judge their overall effect on emissions.

C. Scenarios

Scenarios are developed by adjusting the variables.

A key variable for the scenarios is the change in geographic location of dwellings within the community. See Appendix B for a suggested methodology to build scenarios in GIS. Without using GIS, this can be calculated by subtracting the number of dwellings in the baseline from the number in the BAU- we will call this number the Y dwellings. The assumption is that dwellings in the baseline cannot be influenced but potential new dwellings can be moved around the map to influence the community plan.

Y dwellings can be grouped in nodes around clusters of services, distributed in rural areas or concentrated in the central business district. Each of these possibilities has implications for transportation, building design and consequently GHG emissions.

Factor 2 should be identical to those in BAU; otherwise the scenarios cannot be directly compared. Factors 1 and 3 may vary slightly depending on mix of housing types.

Factors 5-17 are generated in the GIS analysis after scenarios have been built.

Factors 18 and 19 are modified from BAU. For example the portion of waste that is collected with methane capture can be increased or decreased over BAU.

Factors 20 and 21 are calculated using GIS.

Factors 22-31 can be adjusted according to what makes sense for the scenarios.

D. Results

Once this data has been entered, results will be automatically calculated in Worksheets 4 and 5. A variety of charts are automatically produced in Worksheet 6.

6. Adjusting assumptions

Tab 2: Assumptions is a long list of variables organized by factor. These variables can be easily adjusted if they are incorrect, less accurate then local data or for whatever other reason. The default settings are appropriate as general assumptions for BC communities. The sources of each assumption are in column K.

When adjusting an assumption, it is important that the unit, described in column G, stays the same.

7. GIS Analysis

The purpose of the GIS analysis is to generate inputs for the model, and does not involve calculations related to emissions. To perform a full GIS analysis, the following are required:

- ESRI ArcMap (ArcView license or higher) with Network Analyst Extension
- The following spatial data (in shapefile or compatible format):
  - Dwellings layer
  - Roads layer
  - Secondary school layer
  - Elementary school layer
  - Destinations layer
  - Central Business District layer
  - Bus Stop layer
  - Sewage System Boundary layer

See Appendix A for details on each data layer and the options available.

A more basic analysis can be done without the Network Analyst extension. See Appendix C for details on how to run the GIS processes.

8. Customizing the model

There are many different ways in which the model can be customized. The key concept to note is that the Tab 3: Calculations captures numbers from Tabs 1 and 2. This means there are the following options:

Create new inputs or assumptions and adjust the formulae in Tab 3. For example, one user created a different variables for fuel efficiency standards for each scenario in Tab 2. The formula in Tab 3 was then modified to link to these fuel efficiency standards.

Overrule the links in Tab 3 and insert fixed numbers. Another method is to enter tab 3 and manually override inputs or assumptions. This is the quick and dirty technique for making adjustments.

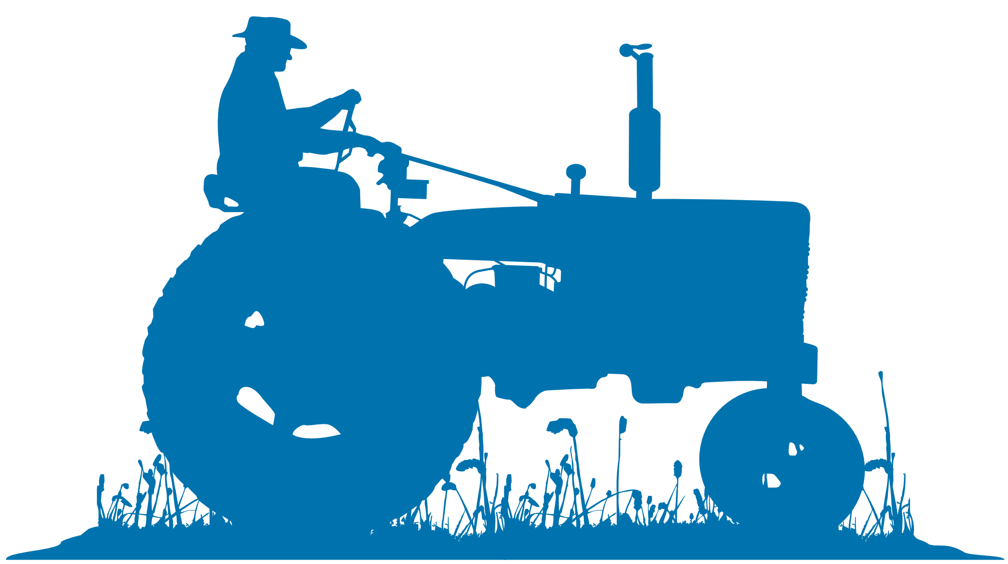
Please forward other strategies for customizing the model to yuill@sustainabilitysolutions.ca

9. Support

Support is available for the model both formally and informally.

Informally, a discussion board provides a community of support for users. It is available at www.sustainabilitysolutions.ca

Formally, SSG can provide support in blocks of 10 hours ($100 per hour). These funds allow us to continually evolve the model and issue new versions.



Appendix A: Data quality, sources and options for the model

Data for the model can be obtained from a number of sources, depending on the resources available in each community. At the most basic level (i.e. without access to GIS), census data from Statistics Canada can provide almost all of the necessary inputs for the model, while estimates for some of the more detailed inputs and future scenarios can be derived from these basic census numbers. For larger communities with the resources available to collect and process their own data, information in each category may also be available locally and be adjusted as needed to suit the model. The sections below outline some further considerations for both the GIS and tabular data necessary to run the model. This appendix is not exhaustive, and users are invited to explore data sources and options not covered below.

A. GIS Data

The following spatial data (in shapefile or feature class format) are the minimum necessary to complete the GIS analysis portion of the model:

- Dwellings layer
- Destinations layer
- Secondary school layer
- Elementary school layer
- Central Business District layer
- Bus Stop layer
- Roads layer
- Sewage System Boundary layer

It is important to keep in mind that each GIS shapefile will need to be edited to reflect the particulars of each future scenario being analyzed (see Appendix B).

1. Dwellings layer (Households data)

Assuming access to GIS software, the most important data file for the model is a spatial representation of total households (e.g. a shapefile) that is necessary to perform the subsequent GIS analyses for the model. Most of the secondary data inputs for the model are derived from this data layer. The objective for this file should be a geographically accurate representation of dwelling units across the community – a more accurate representation will provide more robust results. Each unit can be represented by its own discrete point, or one point can represent multiple units. (Where one point represents multiple units, trip length needs to be weighted by unit count. See Appendix C for details.) Note that for accurate comparisons between baseline and future scenarios, the same type of spatial layer should be used for both (e.g. DA-DA or Parcel-Parcel).

Some sources for this file are:

- Statistics Canada can provide (for a fee) a shapefile of dissemination areas or other spatial geography, which can then be joined to a dwelling units table. This must then be converted to a point file.
- PCensus, a census mapping software program, can also generate a DA point shapefile in nearly “ready to use” format.
- Parcel-based dwelling counts, based on the BC Assessment property roll, municipal housing inventory or other similar data source, with each parcel in the community represented as a point on the map.

The images below show two different spatial representations of the same number of dwellings (households) in Abbotsford, BC.

On the right is parcel-based data, where the centroid of each land parcel in the community is shown as a point representing the number of households on that particular parcel. For example, a highrise would be represented by a single point, but would have attributes identifying it as containing 56 households (units).

In the left hand image, each point represents the centroid of a census dissemination area (DA) and contains an attribute detailing how many total households are within the geographic area of the DA. While the secondary inputs derived from the parcel-based shapefile will have a higher degree of accuracy, at the parcel level scenarios will also be much more difficult and time consuming to develop (as well as have questionable accuracy as a spatial prediction of future development). The DA shapefile provides a middle ground providing an adequate level of detail for the model while still allowing scenarios to be fairly easily developed (see Appendix B).

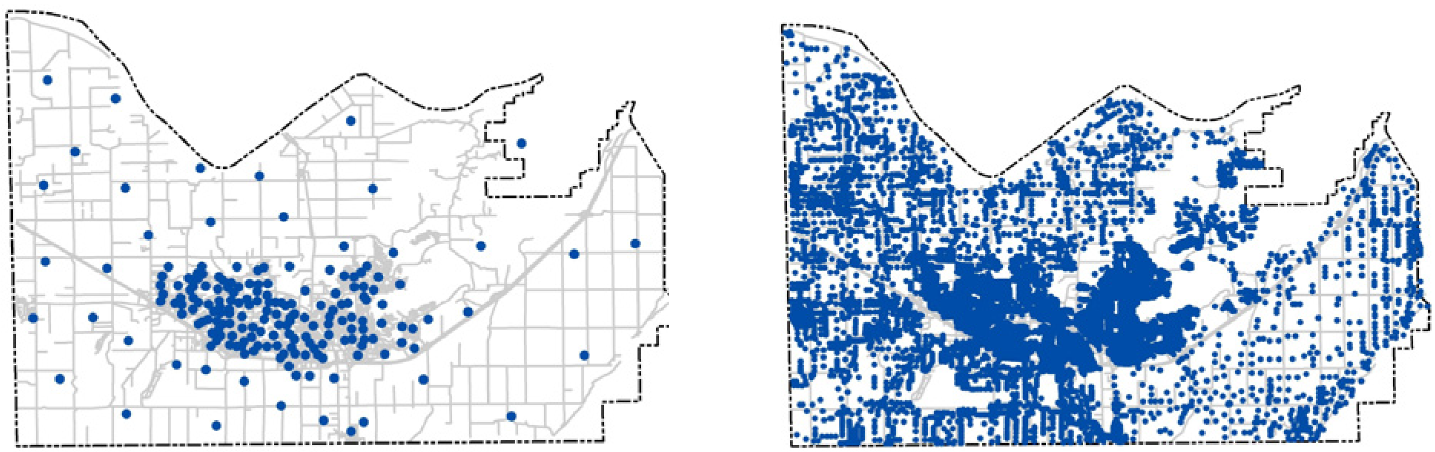


Figure 1: Same dwelling counts, different spatial accuracy – DA data on the left, parcel data on the right

As the screenshot of the attribute table of the dwellings shape file below shows (in this case a census-based DA file generated in PCensus) the DA file above contains total dwellings, population, people per household (PPU), unit and population densities and dwellings broken out by type. While only the total dwellings field is actually necessary to run the GIS analysis, the other fields make data management more effective through the ability of GIS to easily summarize data geographically.

Attributes of 2006_Abbotsford_Dwellings_Points

FID	Shape *	AREA_SQ_M	DAUID	DWELLINGS	HECTARES	PPU	TOTAL_POP_	UNIT_DENSI	POP_DENSI	SDET	SATT	AP5LS	AP5PL
124	Point	239222.45	59090113	602	24	1.6	915	25.083333	38	5.16295	232.332762	369.667238	5.16295
125	Point	93230.06	59090112	412	9	1.7	705	45.777778	78	0	47.694581	359.231527	0
126	Point	703816.2	59090111	191	70	1.8	290	2.728571	4	41.926829	41.926829	0	95.5
127	Point	178061.23	59090110	331	18	1.5	475	18.388889	26	0	5.204403	241.484277	84.311321
128	Point	203916.55	59090109	278	20	2.6	735	13.9	37	124	108	49	0
129	Point	167470.87	59090108	225	17	2.8	640	13.235294	38	97	124	0	0
130	Point	561275.88	59090107	310	56	2.2	680	5.535714	12	92.189542	37.48366	70.915033	103.333333
131	Point	261488.59	59090106	319	26	1.9	575	12.269231	22	93.886288	33.073579	192.040134	0
132	Point	98004.44	59090105	518	10	1.5	835	51.8	84	39	11	502	0
133	Point	46009.9	59090104	212	5	1.7	365	42.4	73	11.157895	5.07177	195.770335	0
134	Point	319425.37	59090103	491	32	1.9	980	15.34375	31	39	22	454	0
135	Point	102047.57	59090102	178	10	2.7	475	17.8	48	80.816092	31.712644	70.586207	0
136	Point	92507.07	59090101	108	9	2.9	305	12	34	91.542857	16.457143	0	0
137	Point	94626.05	59090100	102	9	3.3	340	11.333333	38	86	16	0	0

Record: 1 Show: All Selected Records (0 out of 186 Selected) Options

Figure 2: Attribute table for the DA data from Fig 1. Each line represents the geographic area for one DA.

The type of dwellings file used also has implications for subsequent analysis processes in GIS. When calculating the proximity of dwellings to a service such as transit for example, the greater spatial detail at the parcel level provides more accurate results. As Figures 3 and 4 demonstrate, the level of detail in the dwellings layer has an effect on the secondary data calculated in each analysis.

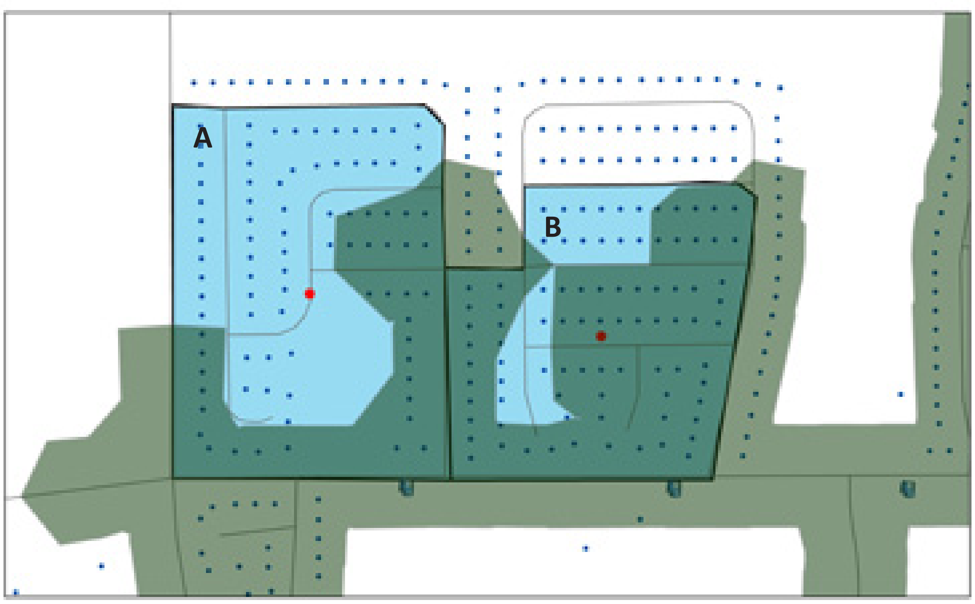


Figure 3: Comparison of DA-based dwellings data (red centroids) with parcel-based (blue centroids) for two DAs in the City of Abbotsford.

In calculating the number of dwellings within 400m of a transit stop (shaded areas) at the DA level, area B has 100% of its dwellings covered, while area A has none. Comparatively, at the parcel level, 78% of dwellings are covered in area B, while 36% are covered in area A. Also note the effect that the street network has on connections to public transit. A finer-grained network allows for greater accessibility for pedestrians using the transit system.

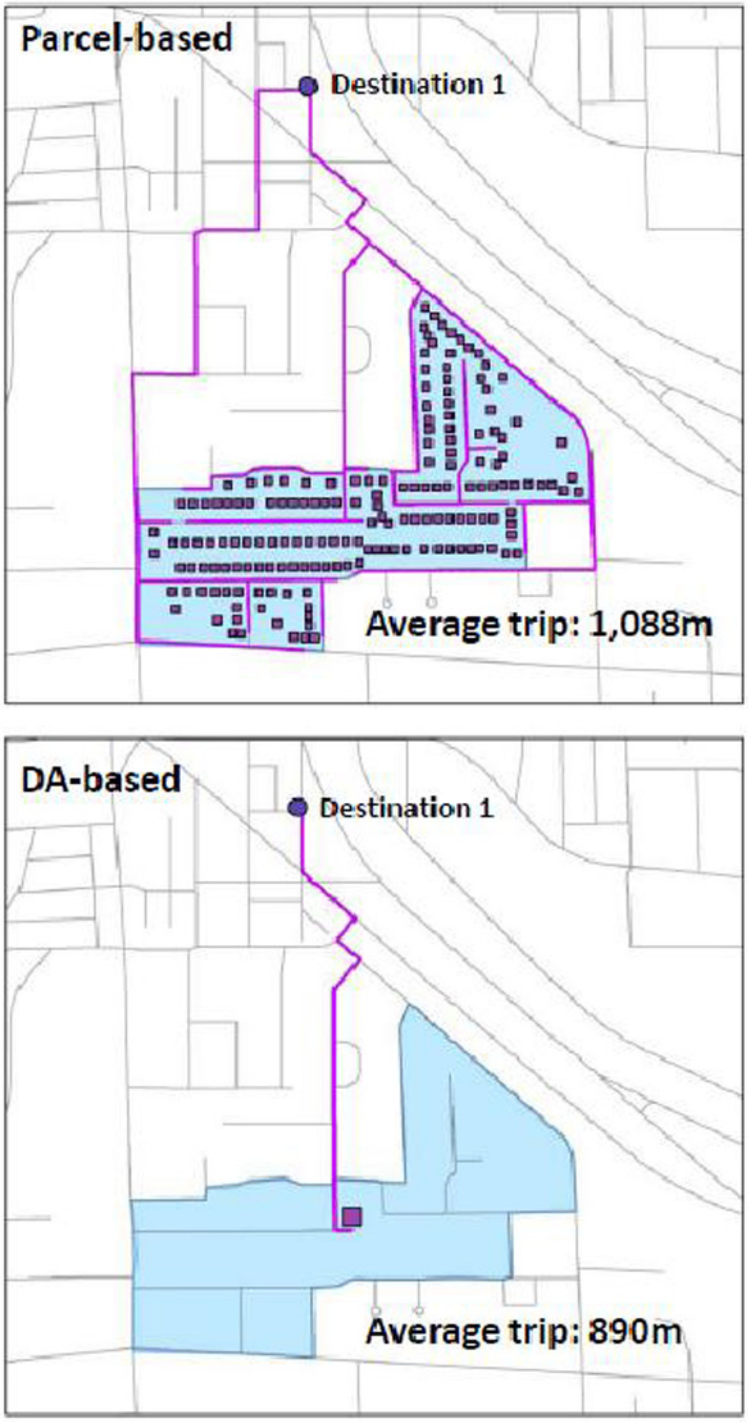


Figure 4: Comparison of trip length calculation for Parcel-based and DA-based methods.

In calculating average trip length, parcel-based dwelling data (top) provide a more accurate measure than DA-based (bottom) due to its greater geographic accuracy. However, when calculated across an entire community the difference may not be so great.

2. Destinations layer
A shapefile showing primary destinations within the community is necessary to calculate the differences in trip length (VKT) between scenarios. In the pilot program for the City of Abbotsford, this was created by identifying primary locations of employment, recreation, commerce and transportation using land use and zoning data (shown in Fig 5 below at left). Once these polygons were compiled in GIS, a point shapefile was created summarizing the major trip destinations. It is important to note that these destinations do not include schools (VKT for school trips is calculated separately) and only include major destinations such as the CBD or airport (i.e. not local neighbourhood businesses.) Network Analyst calculates the average trip distance from each dwelling to each destination to provide an average trip distance based on the current or forecast land use patterns in the community. This distance is then converted to a multiplier, and applied to estimate the trip length for each scenario.

Without Network Analyst, this average trip length for each scenario needs to be estimated from another source. Initial indications from the piloting process indicate about a 515% change in trip length for the City of Abbotsford due to land use change alone; other literature may provide more insight if estimates of trip length are necessary in the absence of GIS.

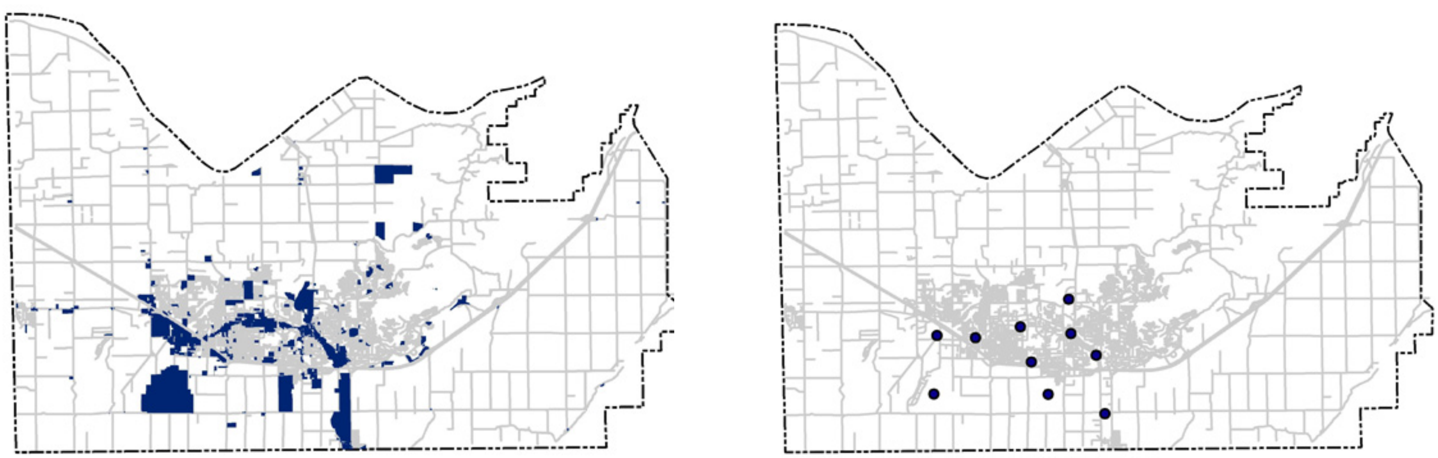


Figure 5: Destinations layer (on right) was generated from GIS land use data (left)

3. Elementary and Secondary School layer
These layers are used in the same way as the destination layer to estimate average trip length in the community. Geographically correct point files are needed for each school type. Unlike the destinations layer, trips to schools only include one school (the closest) for each dwelling, and in addition the model includes a weighting for school districts that allow students to attend schools outside their catchment areas. See Appendix C for the suggested workflow.

4. Central Business District layer
A CBD layer can easily be created using the methodology described in the destinations section, with the slight difference of creating a single polygon rather than points from the initial land use and zoning data. If your community already has its CBD defined, this can be transferred to GIS "as is" if it hasn't already been done. See Appendix C for a discussion of methodology.

5. Bus Stop layer
To run a full analysis using the Network Analyst extension for ArcMap, a point shapefile of bus stop locations is

required. In British Columbia, this may be available from BC Transit, or locally depending on the community's resources. In the piloting process for the District of Kent, there were few enough stops that staff drew them on a paper map, and then transferred those locations to a GIS shapefile. Bus stops could also be geo-coded if streets and addresses are available.

Lacking specific bus stop information, an analysis can also be performed in GIS using route (line) data. While not as rigorous, these results may provide an adequate level of detail. See Appendix C for a discussion of methodology.

6. Roads layer

As the road network provides the basis for using the Network Analyst extension, it is essential that the network data is "clean" in that the source dataset must be corrected for topological errors and verified for connectivity. See Appendix C for a discussion of requirements for the road network. Without the Network Analyst extension, this layer is only needed to calculate the total length of roads in the community. If road length is known through another source, this layer is not necessary without the Network Analyst extension.

7. Sewage System Boundary layer

The intent of this layer is to calculate the number of dwellings in a community that are serviced by the municipal sewage system. Ideally this layer is a polygon covering the entire serviced area, but if only a shapefile of sewage lines is available, then performing a 50 metre straight buffer on the line shapefile and using that to run the analysis outlined in Appendix C is also acceptable. While number of serviced dwellings can be estimated for the baseline year from tax roll data, estimating serviced dwellings for future scenarios requires a "future" GIS polygon of the sewer system to estimate the number of future serviced dwellings.

B. Tabular (Non GIS) Data

1. Total Households

Data are available from Statistics Canada or other statistics agencies (i.e. BC Stats in British Columbia) for the baseline. For the scenarios, this variable can be estimated from projected population and household size (people per household) estimates.

2. Total Population

Data are available from Statistics Canada or other statistics agencies (i.e. BC Stats in British Columbia) for the baseline. It is important to note that the Canada Census under counts the total population, and this should be incorporated into the model if possible. For the scenarios, projected population estimates are compiled by BC Stats in British Columbia, and can also be estimated by a range of methodologies. It is important to note that in order to maintain comparability, the future population estimate should not change across scenarios.

3. People per Household

This is calculated simply by dividing the total households into the total population. It is important to have accurate household and population counts in order to have an accurate people per household estimate. This may change slightly across each scenario depending on the number of each dwelling type in each scenario.

4. Year

Enter the baseline year and future scenario years.

5. Buildings (Factors 10-13)

Building types in the model are grouped into four categories, based on Natural Resources Canada (NRCAN) efficiency designations. These categories are roughly analogous to the Canada Census categories for buildings, with the conversion as:

Natural Resources Canada (used in the model)	Canada Census
Detached	Single-detached house + movable dwelling
Attached	Semi-detached house + row house + apartment or flat in a duplex + other single attached house
Apartments up to 5 storeys	Apartments in a building that has fewer than 5 storeys
Apartments over 5 storeys	Apartments in a building that has 5 or more storeys

Figure 6: Converting census dwelling types to categories used in the model

As building type data are so easily available through the census, and are based on total household data, the census is the most reliable source in the absence of locally generated data. While the building categories used by NRCAN and the census are not exactly analogous, generally they are close enough when estimated on an aggregate scale.

6. Community Energy

A coarse analysis is used to identify the potential for district energy using a default density of 55 units per hectare.

7. Forest Cover

Forest cover includes total areas of forested park land and other forested areas within the municipal control. The total area is identified by the municipality.

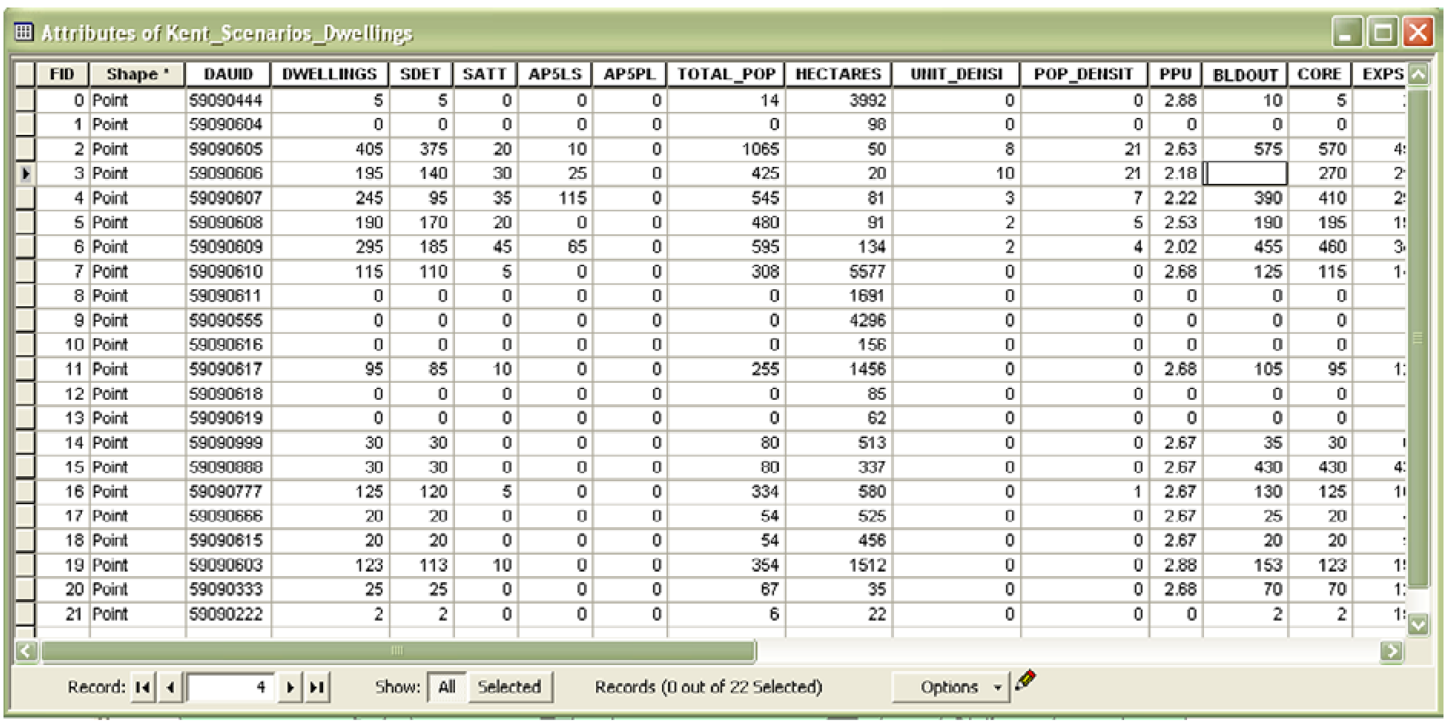
Appendix B: Building Scenarios in GIS for the Model

Note: The following assumes some experience using GIS software.

1. Dwellings layer

Building scenarios for the model first requires estimating the total future number of dwelling units in the community for the scenario target year, as well as breaking these units down by built form (e.g. detached, attached, etc…). These numbers are entered directly into the spreadsheet. If GIS analysis will not be used in the model, the secondary data inputs need to be derived manually from the projections above, and entered directly on the Inputs tab in the model. In this case, the instructions below are not applicable. If GIS analysis will be used in the model, the step after estimating the total number and type of units for the Inputs tab is to distribute these future dwelling units geographically across the community depending on land use scenarios. The following example will use census dissemination areas (DA) as the basic unit for scenario building. The same process applies for GIS layers of other geography types.

Note that although dwelling units are broken down by type on the Inputs tab in the model, the dwellings layer in GIS only deals with total units per DA. The reason for this is that GIS analyzes each dwelling unit (household) based on its location, not on the type of dwelling (built form). Built form efficiency calculations based on dwelling type are performed within the model, not in the GIS analysis. For example, in Figure 3, if the dwelling units for each scenario have already been estimated by total number and type in the spreadsheet, then only the total (323 units) would need to be entered into the attribute table in GIS.


Attributes of Kent_Scenarios_Dwellings

FID	Shape *	DAUID	DWELLINGS	SDET	SATT	AP5LS	AP5PL	TOTAL_POP	HECTARES	UNIT_DENSI	POP_DENSIT	PPU	BLDOUT	CORE	EXPS
0	Point	59090444	5	5	0	0	0	14	3992	0	0	2.88	10	5	
1	Point	59090604	0	0	0	0	0	0	98	0	0	0	0	0	
2	Point	59090605	405	375	20	10	0	1065	50	8	21	2.63	575	570	
3	Point	59090606	195	140	30	25	0	425	20	10	21	2.18		270	
4	Point	59090607	245	95	35	115	0	545	81	3	7	2.22	390	410	
5	Point	59090608	190	170	20	0	0	480	91	2	5	2.53	190	195	
6	Point	59090609	295	185	45	65	0	595	134	2	4	2.02	455	460	
7	Point	59090610	115	110	5	0	0	308	5577	0	0	2.68	125	115	
8	Point	59090611	0	0	0	0	0	0	1691	0	0	0	0	0	
9	Point	59090555	0	0	0	0	0	0	4296	0	0	0	0	0	
10	Point	59090616	0	0	0	0	0	0	156	0	0	0	0	0	
11	Point	59090617	95	85	10	0	0	255	1456	0	0	2.68	105	95	
12	Point	59090618	0	0	0	0	0	0	85	0	0	0	0	0	
13	Point	59090619	0	0	0	0	0	0	62	0	0	0	0	0	
14	Point	59090999	30	30	0	0	0	80	513	0	0	2.67	35	30	
15	Point	59090888	30	30	0	0	0	80	337	0	0	2.67	430	430	
16	Point	59090777	125	120	5	0	0	334	580	0	1	2.67	130	125	
17	Point	59090666	20	20	0	0	0	54	525	0	0	2.67	25	20	
18	Point	59090615	20	20	0	0	0	54	456	0	0	2.67	20	20	
19	Point	59090603	123	113	10	0	0	354	1512	0	0	2.88	153	123	
20	Point	59090333	25	25	0	0	0	67	35	0	0	2.68	70	70	
21	Point	59090222	2	2	0	0	0	6	22	0	0	0	2	2	

Record: 4 Show: All Selected Records (0 out of 22 Selected) Options

Figure 1: Editing the attribute table.

Once the number of units in each DA has been determined for each scenario, they must be entered into the GIS layer. In this table, both the baseline census data and the scenario data are contained in one shapefile. The total baseline units are on the left (DWELLINGS), and also broken down by type in the adjacent four columns. The red arrow shows where the "BLDOUT" scenario is being edited. Notice that future units are not broken down by type in the attribute table. To the right of the "BLDOUT" scenario are scenarios labeled "CORE" and "EXPSN".

Once the baseline dwellings layer for the model has been completed (see Appendix A) and the dwelling counts for each scenario have been determined, the future scenario data can be added to its attribute table. This is easily accomplished by adding and editing fields to the baseline dwellings attribute table in ArcMap (see Fig. 1) to reflect the additional dwelling units expected in each area. Once the data for each scenario has been entered into the table, the DA file is finally converted into a point file for use in the GIS analysis in Appendix C. (Users of PCensus for ArcMap software may already be using a point file.)

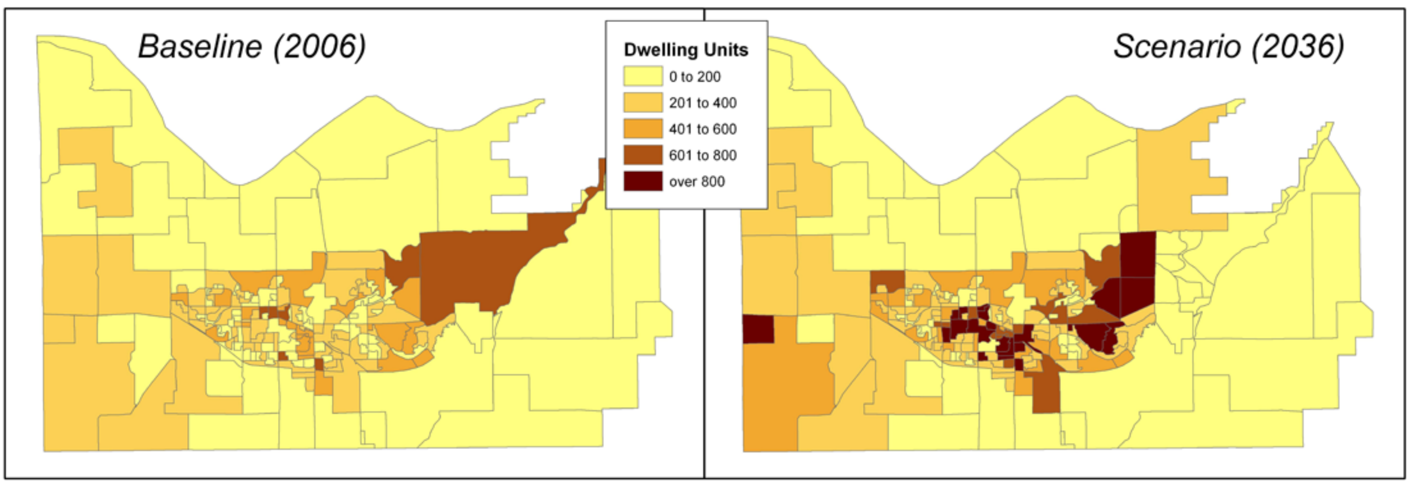


Figure 2: Comparison of dwelling unit layers used in the GIS analysis.

In the hypothetical scenario that was explored (on right), the number of units has increased by about 30,000 over 30 years, and most of the growth has been concentrated in the central and eastern areas of the city. Notice the DA in the eastern area of the city (in the red circle) that has been divided into smaller areas for the scenario to provide a more accurate geographic representation of dwelling unit locations.

Entering the data into the attribute table in GIS is actually the simple part; determining the dwelling units in the community for the scenario target year is more difficult. For the Business as Usual (BAU) scenario, these projections of growth can be based on established land use plans for the community, which often provide detail on densities, built form and infill development, all of which can help inform the scenario building process. Other scenarios can also be developed that explore other hypothetical alternative futures to help inform the community planning process.

In Figure 3, dwellings have also been broken down by type for each DA. As mentioned above, this is not necessary if it has already been done on a community wide basis, however depending on the method of estimating future dwelling units for the scenarios, it may make more sense to approach it from a "DA by DA" basis. In this case, create four extra fields for each dwelling type in the attribute table so they can be aggregated once the scenario is complete, and the totals can be entered into the Inputs tab. In the attribute table in Figure 1, census dwelling type designations have been used for each dwelling type:

- detached = SDET
- attached = SATT
- apartment ≤ 5 = AP5LS
- apartment > 5 = AP5PL

Again, for the GIS analysis it is not necessary to have these categories in the dwellings layer, but it may be a useful way to organize the data while building the scenarios.

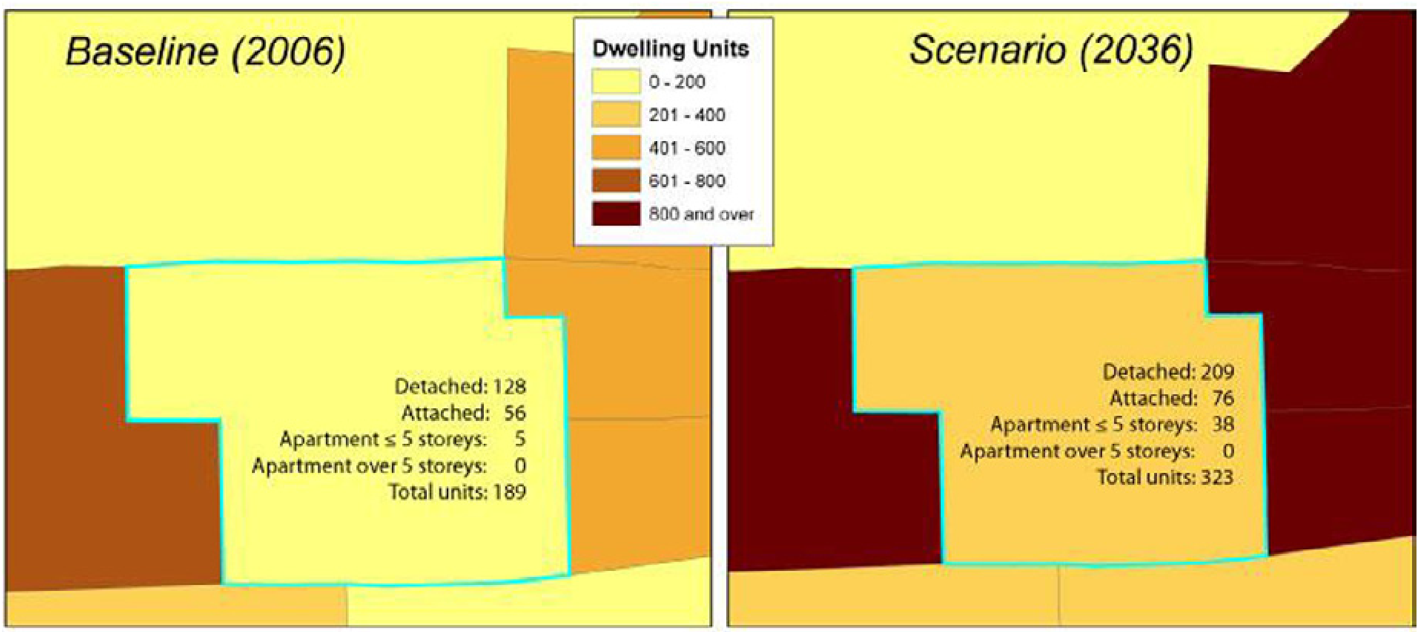


Figure 3: Detail of a single DA showing current and "future" dwelling units.

Although completely hypothetical, the increase in dwelling units in this DA is consistent with land use designations laid out in the official community plan. As mentioned above, unit counts broken out by type are only necessary if they haven't already been estimated in the spreadsheet.

2. Editing the DA layer to Create Custom Geographies for the Model

When using the census DA files for the model, there is often a need to modify the geography of the DA boundaries to account for new areas of growth in future scenarios or provide more accurate representation of existing dwellings within a community. Again, this is easily done in ArcMap using basic editing tools, and can provide a much more accurate analysis, especially within smaller communities or rural areas where the census DA geographies may be quite large. (Note: when using data at the parcel level this type of editing is not necessary.) Essentially, a DA is split up into smaller areas that represent a cluster of units or other neighbourhood or geographically cohesive area (see Figure 4). By adding a new "dissemination area," the representation of the layout of dwelling units (households) within a community is more accurate, and the secondary data that are derived from these data are more robust.

This process of creating smaller, more discrete areas may also be necessary in larger communities when developing future scenarios that assume development of an area that is currently covered by a large DA. As Figure 2 shows, the large DA in the eastern part of the city (highlighted in the red rectangle) was divided up in future scenarios to provide a more accurate geographic representation of possible future development in that area.

It is important to keep in mind that when modifying the DA boundary file, the existing dwelling units will need to be redistributed accurately into the new areas. In the piloting process this was accomplished using parcel data to estimate the current number of dwelling units in each new area. Other sources that provide local estimates of dwelling unit counts may include orthophotos, geo-coded address information, or building permit data.

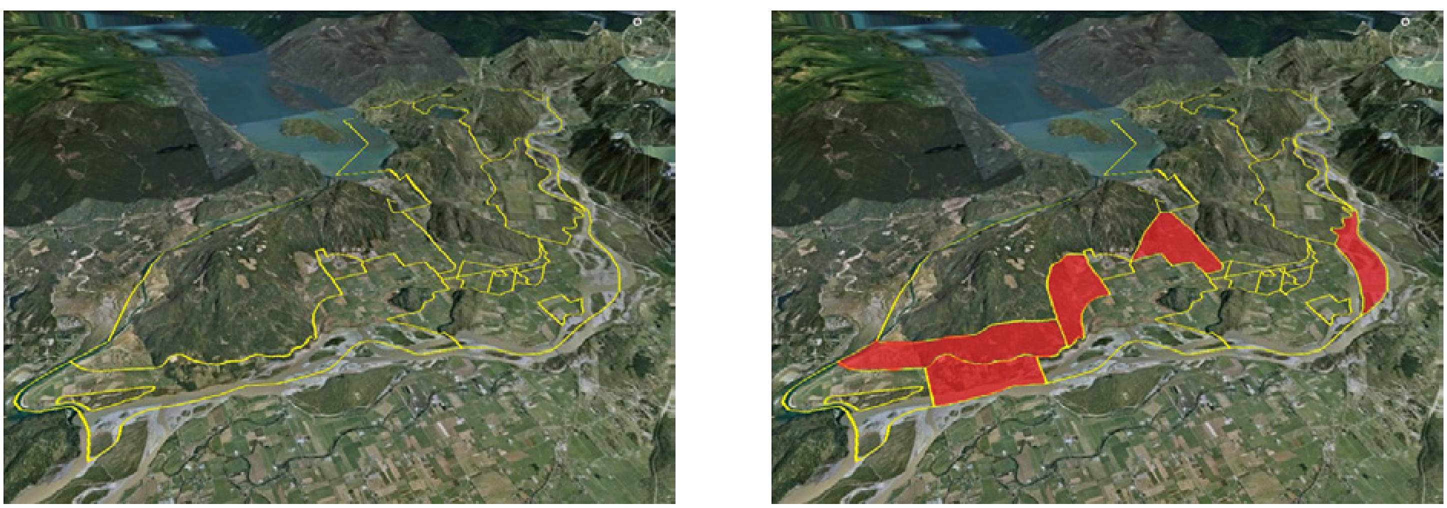


Figure 4: Modifying the DA layers

The yellow lines represent spatial geographies of the census DA boundary file for the District of Kent. The unedited DA boundaries are on the left, and the modified version is on the right. The red shapes show where new areas have been added to provide more accurate spatial representation of dwelling units. Existing dwellings in each area were redistributed into the new areas.

3. Modifying other GIS layers

Over the time periods that the model explores, infrastructure and services in a community are likely to see change as the community develops. Likewise, to increase the accuracy of the model's results, GIS layers that represent future conditions in the scenarios should also be changed. Where new developments are planned, the road network should be modified to reflect the new roads that will service the area. New bus stops may also be added based on planned future routes or land use plans. Other layers that may require editing are:

- Schools (where will new schools be located?)
- Sewage systems
- Destinations (new airport, shopping centre, or industrial park?)
- Forest cover

Land use, transportation or economic development plans for the community may be able to provide information for each of these areas. Once all the layers are edited to reflect the conditions of each scenario, the entire GIS analysis is run using the same methodology as in the baseline (see Appendix C).

Appendix C: Suggested GIS Workflows

Please note that a basic knowledge of GIS processes and the appropriate GIS software are required to run the following processes.

1. Trip Length Calculation Inputs

A. Building the network

* Note: the Network Analyst extension for ArcMap is required to run the following processes.

**Note: prior to creating a road network, the source dataset must be corrected for topological errors and verified for connectivity. Topology rules can be used to ensure that the roads are topologically correct. However, exceptions to these rules, such as dangles for cul-de-sacs and dead end roads, should be expected. Connectivity of the roads can be addressed by using the ArcCatalog tool Integrate to insert and snap vertices where road segments connect and intersect. Integrate uses a user-specified tolerance to modify the original data source. The tolerance used will depend on the accuracy of the data but it is suggested to start small (<1m) to avoid unnecessary generalization of the data.

1. In ArcCatalog, right click a folder where you want to store your network and select:

    New > File Geodatabase

2. Name the File Geodatabase.

3. Right click the File Geodatabase and select:

    New > Feature Dataset

4. Name the Feature Dataset.

5. Right click the Feature Dataset and select:

    Import > Feature Class (single)

6. Navigate to and select the appropriate road network, see above note.

7. Import the network as a Feature Class.

8. Right click the Feature Dataset and select:

    New > Network Dataset

9. Name the network and click next.

10. Click the box next to your roads Feature Class and click next.

11. Click next until you come to the window to specify attributes for the network, and click the "Add" button to add a new attribute.
12. Name it "Length" and change the units to meters (keep the defaults of cost and double) and click ok.
13. Confirm that the Evaluator for the Length attribute points to the length field of the dataset (i.e. shape, length). If it does not, assign an attribute evaluator.
14. Click no when asked to add driving directions, then click Finish.
15. When prompted, click Yes to build the network.
16. Once built, ensure that the Edges (route segments) have a positive length attribute (can use the Identify Tool in ArcCatalog).

B. Calculating Weighted Trip Distances to Destinations

1. Open ArcMap.
2. Under Tools > Extensions, check the box next to Network Analyst and click Close.
3. Add the Network Analyst toolbar to the task bar (right click a blank spot in the top task bar to bring up the toolbar menu, then click Network Analyst. Dock it in the task bar if desired).
4. Click the "Add Data" button, and navigate to and select the network you created above. Click Yes when asked if you want to add all the Feature Classes that participate in the network.
5. Click the "Add Data" button again, and navigate to the dwelling point shapefile and destinations and schools point shapefiles and add them to the table of contents.
6. On the Network Analyst toolbar, click the "Show/Hide Network Analyst Window".
7. If multiple road networks are loaded in the same map document, verify that the network of current interest is highlighted / selected in the Network Analyst toolbar.
8. On the Network Analyst toolbar, click the "Network Analyst" dropdown menu and select "New Closest Facility". Closest Facility will appear in the table of contents at the left of the screen, and the Network Analyst Window will be populated with "Facilities, Incidents, Routes, Barriers" with "(0)" beside each.
9. Right click on "Facilities" in the Network and select "Load Locations..."
10. In the "Load From" dropdown menu, select the destinations file and click ok. The destinations will be uploaded into Network Analyst and the number of destinations will appear in the brackets to the right of "Facilities" in the Network Analyst Window.
11. Right click "Incidents" and repeat the process in step 9, this time loading the dwelling point shapefile into Network Analyst.
12. Click on the "Closest Facility Properties" button in the Network Analyst Window. Under the Network Locations tab, adjust the Search and Snap tolerances appropriately (use default settings). Under the Analysis Settings tab, change the number in the "Facilities to Find" box to match the number of destinations (or schools etc) in the destination shapefile (i.e. "18" for 18 facilities). Ensure that the Impedance is in meters and the default cutoff value is <None>. Click ok.
13. In the Network Analyst toolbar, click the "Solve" button to calculate trip lengths.
14. Once the procedure has finished, open the attribute table for Routes in the table of contents. The distance from each dwelling point to each destination is recorded.

As the number of dwellings contained in each point is different (and points with more dwellings will have more trips), a weighted average of trip distance needs to be calculated for each destination.

The basic formula for calculating this is:

$$\frac{\Sigma\,(\text{Dwellings x trip distance})}{\Sigma\,\text{Dwellings}}$$

15. With the attribute table for Routes still open, click on Options > Select by Attributes at the bottom of the table. Create a SQL query to select all trip from each dwelling point to a single destination. The FacilityID field records the trip for every dwelling point to each destination with a distinct ID number, so create a SQL query of "FacilityID" = 1 where "1" is a destination. Click ok, and notice that only the trips ending at the destination chosen have been selected, and the total records selected equals the total number of dwelling points.
16. At the bottom of the table, click "Selected" then Options > Export and save the selected records to a table outside ArcMap. Don't add the table to ArcMap's table of contents. Notice the IncidentID field remains a linear progression from 1 to the total number of dwelling points when showing only selected records.
17. Repeat Steps B14 and B15, but each time changing the Select by Attributes criteria to select another destination (i.e. "FacilityID" = 2, 3, 4, etc…) Once you have exported tables for each destination, close the Routes attribute table.
18. Open the attribute table for the dwelling points. Click Options > Add Field and name it "IID" of type Short Integer with a precision of 5. Once created, right click the IID header at the top of the new field, and select Field Calculator. Calculate the IID to equal the [FID] or [OBJECTID], depending on the data type of the dwelling points. The IID field should now match the IncidentID field in the Routes attribute table. As in Step 15, export the table to the same location as the Routes table.
19. Open the exported table for the dwelling points in Excel, and delete all columns except the dwelling unit counts and the IID field.
20. Open the table for the first destination, and copy the IncidentID and Length columns into the dwelling points table. The numbers in the IID and IncidentID columns should match exactly (if they do not, do not proceed and check your work).
21. Now multiply the dwelling count cells by their counterparts in the Length column, and name it "Destination 1" or something more specific.
22. Now sum both the Destination 1 and Dwelling columns (see the formula above) and divide the dwelling total into the Destination 1 total. This is the average weighted trip distance for that particular destination.

DWELLINGS	IID	IncidentID	Total_LENG	Destination 1
406	1	1	4,960	2,013,596
228	2	2	5,894	1,343,766
177	3	3	5,461	966,520
206	184	184	5,569	1,147,246
179	185	185	6,757	1,209,511
644	186	186	9,229	5,943,635
46,856			➡ **4,536**	212,540,792

$$\frac{\Sigma\,(\text{Dwellings x trip distance})}{\Sigma\,\text{Dwellings}} = \frac{\Sigma\,(\text{Dwellings x Total\_LENG})}{\Sigma\,\text{Dwellings}} = \frac{212{,}540{,}972}{46{,}856} = 5{,}436$$

23. Delete the IncidentID fields and Length fields
24. Repeat Steps B19 through B22, renaming each destination column appropriately, until you have calculated all the weighted averages for each destination.

C. Calculating Weighted Trip Distances to Schools

1. In the Network Analyst Window, right click “Facilities” and “Routes” and select Delete All. Now right click Facilities, select “Load Locations…” and select the elementary or secondary schools point shapefile from the dropdown menu and click ok.
2. Click the “Closest Facility Properties” button in the Network Analyst Window and under the “Facilities to Find” tab, change the number to 1 (you only want to find the closest school of each type). Click ok.
3. Click the “Solve” button in the Network Analyst toolbar.
4. Open the “Routes” attribute table and repeat Step 15 only.
5. Repeat steps B19 through B22.
6. Repeat steps C1 through C5 above to calculate secondary school trip distances.

Note: Keep the Network loaded in ArcMap for use in Step 3.

2. Central Business District (CBD) Input

Using an existing shapefile (or creating one using the Editor toolbar to create a polygon of the CBD) use the Buffer tool in ArcMap and create a simple 400 metre buffer polygon of the CBD. Overlay this over the dwellings point shapefile and perform a Search By Location to calculate the number of dwelling units that fall within the buffered area. Enter this number as Factor 6 CBD, 400m on the Inputs tab in the spreadsheet.

3. Public Transit Input

Without the Network Analyst extension for ArcMap

Run a simple buffer at a desired distance (walking distance to bus stops) on either the bus route or bus stop shapefile. Similar to the CBD input, Overlay this over the dwellings point shapefile and perform Search By Location to calculate the number of dwelling units that fall within the buffered area. Enter this number as Factor 6 CBD, 400m on the Inputs tab in the spreadsheet.

With the Network Analyst extension for ArcMap

Perform the following steps:

1. Ensure that the Network that you used in Step 1 is loaded into ArcMap, and the Network Analyst toolbar is enabled.
2. Add the bus stops layer in point format (bus routes in line format cannot be used for the Network Analyst analysis) to ArcMap.
3. Click the dropdown menu in the Network Analyst toolbar and select “New Service Area”.
4. If not already showing, click the button to show the Network Analyst Window.
5. Right click on “Facilities” under Service Area and select “Load Locations…”
6. In the “Load From” dropdown menu, select the bus stops file and click ok. The destinations will be uploaded

into Network Analyst and the number of stops will appear in the brackets to the right of "Facilities" in the Network Analyst Window.

7. In the Network Analyst Window next to "Service Area" click the Service Area Properties button.
8. Under the Polygon Generation tab, ensure that the "Generate Polygons" and "Trim Polygons" boxes are checked, and set the tolerance for the latter to 50 metres. Under Multiple Facilities Options, select "Merge by break value." Leave the other defaults as they are.
9. Under the Analysis Settings tab, set the "Default breaks" value to 350 metres. Note: this number can adjusted as needed, however here it represents a 400 metre walking distance to the closest bus stop – 350 metres along the road network, plus 50 metres off either side of the road.
10. Leave the rest of the defaults in the Service Area Properties as they are and click ok.
11. Click the "Solve" button in the Network Analyst toolbar. A polygon will be generated that represents the 400 metre area where residents are willing to walk to a transit stop.
12. Ensure that the dwellings point shapefile is loaded into ArcMap, and perform a Search By Location to calculate the number of dwelling units that fall within the Service Area for transit. Enter this number as Factor 7 Public Transit, 400m on the Inputs tab in the spreadsheet.
13. Save your project.

4. Road Length

Open the Attribute table of your road shapefile in ArcMap. If there is no road surface type attribute, right click the Length field and select Statistics to get a total length of roads in your community. As most roads are probably paved, enter this in Factor 8 Road Length, Asphalt on the Inputs tab. If the roads have surface type attribute, Search by Attribute to select all the roads of each type, then enter the total length in Factors 8 and 9.

5. Liquid Waste Inputs

Load the Sewer System Boundary shapefile into ArcMap. Similar to Steps 2 and 3, overlay this over the dwellings point shapefile and perform a Search By Location to calculate the number of dwelling units that fall within the Sewage System area. Enter this number as Factor 20 Liquid Waste, tertiary treatment. Subtract this number from the total number of dwellings, and enter the remaining unserviced dwelling units as Factor 21, Liquid Waste, septic on the Inputs tab in the spreadsheet. These inputs can also be derived from tax roll data in municipalities for the baseline year, however GIS analysis may be needed to estimate numbers for future years.

6. Forest Cover

Open the attribute table of your "forest cover" shapefile in ArcMap. Right click the Area field and select Statistics to get a total forested area in your community. Enter the total area in Factor 29 on the inputs tab. Note: See Appendix A for a discussion on forest cover as an input.